Abstract:
The aggregate, agricultural supply relationship is analyzed and empirically estimated through the use of a nonlinear least squares algorithm. A model is developed for estimating the adjustment process in agricultural supply by treating planned output rather than observed output as the proper response variable. Estimation techniques focus up on the dynamics of agricultural supply adjustment via distributed lag models, with results providing a probable range for the price elasticity of aggregate agricultural supply. Estimates indicate a highly inelastic short-run supply curve with response somewhat greater in the long-run, although the long-run supply curve is also very price inelastic.
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6/18/79
ESTIMATING THE AGGREGATE U.S. AGRICULTURAL SUPPLY FUNCTION

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

The aggregate agricultural supply relationship is analyzed and empirically estimated through the use of a nonlinear least squares algorithm. A model is developed for estimating the adjustment process in agricultural supply by treating planned output rather than observed output as the proper response variable. Estimation techniques focus upon the dynamics of agricultural supply adjustment via distributed lag models, with results providing a probable range for the price elasticity of aggregate agricultural supply. Estimates indicate a highly inelastic short-run supply curve with response somewhat greater in the long-run, although the long-run supply curve is also very price inelastic.
Chapter 1

INTRODUCTION

Introduction

This study is primarily an analysis of the aggregate supply of agricultural products in the United States. The study's focus falls upon the complex dynamic nature of agricultural supply response to changing prices.

Previous studies have attempted to estimate agricultural supply functions through the use of distributed lag models. In the two decades since Nerlove's pioneering research on distributed lags and the dynamics of agricultural supply, such models have become increasingly more important to the empirical estimation of the output response of agricultural products.

This study expands the general distributed lag approach. It departs from conventional theoretical treatment of lags in agricultural supply response by treating beginning of the period "expected", or planned, output as the proper response variable, rather than actually observed output for the entire period.

Statement of the Problem

There continues to exist a need for a fuller understanding of the nature of the agricultural sector of the American economy. Describing the entire aggregate of agricultural products as a single
industry has serious limitations, but there is some value in studying the responsiveness of farmers to changes in the average price level for all agricultural commodities. Such response can be interpreted as a measure of the nation's capacity to produce food and the accompanying by-products. In this sense, estimates of the long-run elasticities of supply for agricultural products in the aggregate will provide valuable information about the agricultural sector of the economy.

There have been numerous studies of specific agricultural commodities and their responsiveness to price, but there are very few estimates of the aggregate farm supply function. Estimates of the elasticities of supply for individual farm products do not serve well for the purpose of analyzing the aggregate agricultural sector of the economy. Several individual farm products apparently have relatively elastic supply functions, but there is considerable opportunity for substitution between crops and types of livestock at the farm level, and hence in the market, when relative prices vary. This substitution process, however, will not greatly change total production of all farm products. As soybean acreage is increased or decreased relative to corn acreage, for example, total farm production remains about the same. Therefore, the aggregate agricultural supply function should be much less elastic than the supply of individual farm products.

The total output response of a farm firm describes how the total production of all commodities that firm produces varies as the average
price (farm product price level) varies. The aggregate supply function for agriculture is the summation of all farm firm supply functions. Measurement of this relationship requires the use of indices for total farm output and average farm product price levels. Although such a relationship does not contain the usual direct conceptual supply connection between quantity and price, the fundamental economic principles of supply functions hold.

There are considerable implications for policy makers from an analysis of the aggregate U.S. farm supply response. Much of the past and present farm policy debate centers around the question of how responsive farm output is to price changes. Arguments that the short-run supply function is perfectly inelastic are not uncommon. Adequate empirical testing of this hypothesis has not been accomplished. Yet, the elasticity of farm supply is fundamental to estimating and forecasting the impacts of farm price supports or other subsidy programs.

For example, suppose that government planners are interested in the effects of a particular price support program on the total effective supply in the economy. Strictly speaking, the analysis must deal with individual producers and consumers, and trace through all interactions among the economic agents in the economy. This being an obviously impossible task, the alternative is to employ aggregated variables to estimate the program's impact. Even the best model that
might be employed would be no more than an approximate description of reality. Although the utilization of an aggregate agricultural supply model may be a somewhat crude process, results ought to be useful, given the prevailing limitations on knowledge and data availability.

The underlying assumptions for the process of developing and employing an aggregate model may be summarized as follows: (1) all the variables in the farming sector of the economy can be classified into a small number of groups, say, total farm output, prices received for farm products, prices paid in the production process, weather and other "random" effects, technological advances, and government programs and policies; and (2) indices representing these groups can be defined and the interaction among these indices can be studied without regard to the interactions within each group of variables.

Although these assumptions appear rather bold, they are used almost daily in analyses of the economy. The alternatives are few and frequently less attractive; ranging from abandonment of analysis and estimation to attempting to specify and estimate each contributing factor, an inherently enormous and costly task. Use of an aggregate estimation procedure is often more feasible than either of these alternatives.

The nature of American agriculture has been undergoing constant and rapid change during this century. Technological advances have increased yields and output and have created incentives for farmers
to shift away from the relatively more costly inputs of labor and land and toward capital inputs in the form of fertilizer, machinery, and other man-made factors of production. The steady disappearance of small, relatively inefficient farms should have the effect of making the aggregate supply function more elastic in recent years because these farms theoretically have the most inelastic supply functions. On the other hand, capital investments have become continuously larger, increasing the ratio of fixed to variable inputs and tending to make the aggregate supply function more inelastic. Therefore, we might expect a more elastic supply response in the long-run, but probably less elastic in the short-run.

The pervasive and persistent intervention of the government in the crop producing sector of agriculture since World War II is another source of structural change in the farming sector of the economy. Price supports and subsidy programs have served in part to reduce the risk farmers face during the production process and to lower the costs of farming relative to other types of business further than otherwise would have occurred. The overall impacts of this intervention have not been estimated for an aggregate relationship, and may, in fact, be impossible to measure, although some success has been experienced in dealing with individual crops (see Just [46]).

In the short-run the supply function for agriculture should be quite, though not perfectly, inelastic. However, the factors mentioned
above, particularly the effects of government price supports and subsidies on crop production since World War II, tremendously complicate the problem of estimating the elasticity of farm supply. In the long run — that is, in a length of run in which all possible resource adjustments in response to a given price change can be made — the aggregate supply function has probably become more price elastic since World War II.

There are two main theoretical sources of dynamic behavior in the supply of agricultural commodities: the existence of adjustment costs, or fixities, in the production function for farmers, and the formation of price expectations. A difference equation in the dependent variable is a direct result of the partial adjustment models that have been associated with agricultural markets. Existing assets of the farm owner, currently employed labor, and other short-run conditions limit the farmer's ability to adjust output fully in response to price changes in any given period.

The other major source of dynamic behavior in supply stems from the formation of price expectations. A common assumption is that experienced prices are weighted in a geometrically declining manner backwards in time as they reflect expectations for future prices. This assumption allows for an estimate of the impact of all past prices to be made while only one additional parameter must be estimated, the coefficient of the geometric weight. There have been criticisms of
this assumption because it does not allow for optimizing behavior on the part of the decision makers in the manner in which expectations are formed (see Nerlove [62] and Sims [70]), and several other distributions have been proposed to allow for more generality, such as the Pascal distribution (Solow [73]). Models designed to specify and test the relevance of more general structures in the formation of price expectations are frequently plagued with problems in identifying and estimating the critical causal factors, and hence, the relevant parameters.

Academic discussion of the dynamics of agricultural supply dates as far back as Bradford Smith's study of cotton in 1925. John Cassels was also among the first economists to recognize the dynamic nature of agricultural supply. His discussion in 1933 recognized both that supply adjustments are not achieved instantaneously and that expansion and contraction of agricultural output are not identically opposite processes.

Much theoretical discussion of the dynamics of agriculture has been developed in the half century since Smith's work on cotton. Factors contributing to this dynamic nature that have been identified at least theoretically include fixed assets, a long production period, inelastic supply functions for agricultural labor, technological advance, and price and weather uncertainties. Although there has been a great deal of rhetoric over the years about the dynamics of agricultural supply response, there have been very few empirical
studies of the dynamic relationship for aggregate agricultural supply. The purpose of this study is to hopefully fill at least a small part of this gap in econometric research and to provide meaningful results that will improve the understanding of the agricultural sector of the economy.

The next chapter of this thesis presents a review of the literature on agricultural supply response and the estimation of dynamic relationships. The chapter is divided into four sections: early works; a priori arguments about supply elasticity; distributed lags; and irreversibilities of supply. The third chapter contains the theoretical development for the economic models employed in this study. The first section discusses the dynamics of agricultural supply and problems of estimation. The second section discusses problems associated with irreversibilities in the supply response relation and develops estimating techniques in a dynamic framework. The final section of the third chapter describes the data employed in this research, its construction, and some potential limitations on interpretation of the results. The fourth chapter includes a summary of the results obtained from empirical estimation of the aggregate agricultural supply relationship and a discussion of the conclusions reached as a result of this research.
Chapter 2

REVIEW OF THE LITERATURE

This chapter contains a survey of previous works relating to agricultural supply response and to distributed lag models. The list of references cited in this survey is not complete. However, it does contain those studies considered by the author to be important to the development of this research. The literature review is divided into four sections which overlap to some extent. The first section summarizes some important early works in the general area of agricultural supply analysis. The second section then presents several arguments from the academic theorists concerning the nature of the agricultural supply function and its price elasticity. The third section reviews the work that has been completed to the present in the area of distributed lags and dynamic supply analysis. The final section of the chapter discusses the relatively recent developments for specifying and testing for irreversibilities in the supply relationship.

Early Works

H. L. Moore [54] presented the first study of actual supply response in 1919 in his book on forecasting yields and prices for cotton. He introduced the method of relating quantities supplied to prices prevailing at an earlier period. He argued, "there should . . . in normal times, be some relation between the percentage change in the price of cotton last year over the preceding year and the percentage change in the acreage of cotton this year over last year." (p, 87). Moore's use of
price lagged one year to represent the price to which farmers react has been carried through in a substantial amount of subsequent supply analysis.

John D. Black [5] summarized the results of a study group at the University of Minnesota in an article published in 1924 in which several simple correlations between first differences of acreages and first differences of price lagged one year were estimated for ten commodities. Though the technique employed was relatively crude, results for five of the ten commodities considered were quite good.

In 1925, Bradford B. Smith [71] published an article reporting an attempt to relate cotton acreage to economic factors. He related absolute changes in cotton acreages to prices during the months of November, December, January, February, and March preceding planting, each month's price being deflated by a wholesale price index of agricultural commodities for the same month. Smith initiated techniques of estimating a dynamic relationship through introducing (1) the absolute change in production lagged one year, (2) the absolute change in yields per harvested acre lagged one year and deflated by an index of farm production of all commodities, and (3) a trend variable into his supply analysis.

In a well-known article published in 1929, Louis H. Bean [4] reported his analysis of changes in the acreage of potatoes, sweet potatoes, cabbage, strawberries, watermelon, flax, rye, and cotton. All of Bean's regressions used prices received by producers during the preceding
two seasons as the independent variables and the absolute change in acreage harvested as the dependent variable. He deflated the prices received by farmers with the general level of farm prices in all but four cases. He argued that acreage changes for sweet potatoes and flax are definitely related to the price of competing crops, cotton competing with sweet potatoes and wheat competing with flax. (p. 371). He appears to have been the first researcher to have specifically introduced the price of a competing crop into supply analysis by deflating the price of sweet potatoes with the price of cotton and the price of flax with the price of wheat.

Bean found the price received for the production of the preceding year to be the dominant factor in the change in production in any given year, with the price received during the season two years preceding also often an important factor, particularly if the price had been low. He also found that there are limits to the farmer's ability to respond to price changes in any single year. (pp. 375-376).

John M. Cassels [12] criticized earlier agricultural supply studies in an article published in 1933. He distinguished between "market," "short-run normal," and "long-run normal" supply curves, concluding that statistical investigation of "market" supply curves is impossible, and that the same is likely to hold true for the derivation of "long-run normal" supply curves because of continually changing technology. He also recognized that there is likely to be more than one short-run supply
"The more sudden and violent the increase in demand the more difficult it will be for supply to keep pace with it. Time is required for the organization of extra shifts, for the renovation of old machinery, for the augmentation of the labor force and for the assembling of additional supplies of the input elements. More time is required for new producers to come into the field and still more for efficiency to be introduced into all the new arrangements. The longer the period allowed for adjustments to be made the more successfully can the tendency to transitional decreasing returns be overcome and the more advantage can be taken of the economics of large-scale production . . . Hence there is no curve which can be regarded as the one-and-only supply curve for any particular commodity."

(p. 382).

Cassels also pointed out the possibility that the short-run supply curve is likely to be characterized by irreversibilities with respect to price increases vs. decreases. He suggested that each supply curve be regarded as relating to an established level of output and consisting of two parts, one representing expansion beyond that output and the other representing contraction below it.

A Priori Arguments About Agricultural Supply Elasticities

During the period from the late 1930's to the mid 1950's there was much serious debate in the field of agricultural economics concerning the nature of the agricultural supply function in the United States. Much of this debate centered around the question of how responsive farmers are to price changes and the adjustment process that farmers underwent while trying to expand or contract levels of output. This section presents a summary of the main arguments presented during this time in
the area of aggregate agricultural supply.

John K. Galbraith and John D. Black [27] discussed the maintenance of agricultural output during the depression years in 1938. They argued, in accordance with classical economic theory, that fixed assets but not fixed costs contributed to continued high-level production during depression. They also asserted that agriculture is characterized by a long production period, limiting the ability of farmers to adjust output promptly or certainly to changing prices.

As did Galbraith and Black, D. Gale Johnson [43] rejected the belief that high fixed costs are responsible for maintained farm output during a depression in his article contrasting the agricultural supply function under depression and prosperity conditions in 1950. Johnson also rejected the arguments that subsistence production and technological conditions creating a long production period are responsible for the difference between agriculture and non-agriculture output levels during depressions. He argued that farm wages dropped by more than 50 per cent during 1929-1933, while the hourly earnings of production workers in manufacturing fell less than 22 per cent during the same period, giving evidence that the factor markets for agriculture might be significantly more competitive than the factor markets for non-agriculture. The assumption that farmers are profit maximizing entrepreneurs then implies that output behavior will be determined by the relationship between output and factor prices.
In 1946, John M. Brewster and Howard L. Parsons [7] argued that farmers are not responsive to price changes because the dominant drive of most farmers is to maximize output in the hope of maximizing profits rather than operating at the profit maximizing level of output through bargaining over the price of inputs and outputs.

Willard W. Cochrane [13] argued in 1947 that the tendency for total agricultural output to remain relatively fixed in the short-run is a manifestation of unresponsiveness to price changes and creates, along with shifting aggregate demand for farm products, a chronic oscillation from surplus to shortage. He asserted that "the peculiar unity of occupational functions (labor, technological and business management), the fixity of the labor supply, and the importance of overhead costs as compared with operating costs on family farms, argue for the plausibility of an inelastic aggregate output curve." (pp. 384-385).

Cochrane developed a rationale for treating agricultural supply in the aggregate because of the fact that there is a "high degree of substitution between individual farm enterprises in most areas and at the extensive margin of all areas in response to commodity price changes, but not between farm and nonfarm enterprises." (p. 384). On the demand side as well, particularly in the case of foods, consumers substitute less expensive items for more expensive items, but do not substitute nonfood items for food, thus providing an economic justification for an aggregative analysis which has total agricultural output as the
unit of analysis.

Cochrane and William T. Butz [14] in 1951, and Cochrane [15] alone in 1955, argued that technology is responsible for virtually all change or lack of change in aggregate farm output and that the aggregate agricultural supply function is perfectly inelastic in the short-run, because the family labor force, the total number of acres per farm, the total amount and form of heavy machinery and equipment, and the capacity and form of farm buildings remain fixed in the short-run and impose constraints over the substitution of resources among farm enterprises. Because the aggregate agricultural supply relation for the nation is simply the summation of individual firm supply relations, then, "since the typical supply relation for firms is severely inelastic, it must follow that the aggregate supply relation for the nation is severely inelastic." (Cochrane, [15]: p. 1167). Cochrane also asserted that the agricultural supply curve has shifted to the right due to technological advances in an uneven, skipping fashion, surging forward when aggregate demand is expanding and technological advances are being made, but remaining fixed in response to price changes. Because a technological advance by definition reduces unit costs, once adopted it is rarely given up, creating an irreversible output response relation with respect to technology and hence with respect to rising vs. falling prices.

In 1958, Thomas T. Stout and Vernon V. Ruttan [75] reported their
study of technological change in American agriculture for the period 1925-1955. They employed output per unit of input, both measured "net" of current operating expenses, as the measure of technological change used to analyze Cochrane's thesis that the aggregate agricultural supply relation has expanded in a hopping or skipping fashion. Although they found this hypothesis to be somewhat verified in the aggregate, in both the Northeast and Southern agricultural regions output per unit of input expanded at a steady rate throughout the period of study.

Theodore W. Schultz [67] discussed the instability of prices in the agricultural sector, while agricultural production as a whole is quite stable. He analyzed aggregate agricultural input and found it to be even more stable than aggregate output. In 1953, Schultz [68] again discussed the instability of agriculture, positing a simple explanation, namely, "that the price elasticities of the demand and of the supply of farm products are so low and that the shift in one or the other of the schedules is large and abrupt." (Schultz, [68]: pp. 175-176). He also asserted that yield instability is an important factor, but that any instability in the production of farm products as a whole is not the consequence of planned changes by farmers of the quantity of inputs committed to the production of farm products from year to year. He noted, however, that sight should not be lost of the fact that some adjustment in the quantity of inputs occurs in response to favorable and unfavorable turns in farm prices.
Earl O. Heady [39] presented a paper in 1955 on the supply of farm products during periods of full employment. Like Galbraith and Black, and D. Gale Johnson, Heady stuck close to neo-classical marginal analysis. In disagreement with Cochrane and in some disagreement with Schultz, he argued that there were much greater possibilities for aggregate output to respond positively and negatively to changes in "factor/product price ratios." Heady used aggregate resource flows into and out of the agricultural sector to support the hypothesis that a properly identified aggregate supply function would have a positive slope. He explained the low elasticity of aggregate supply in terms of: (1) low reservation prices for family labor in farming, (2) capital limitations, including capital rationing, resulting from risk discounting, (3) asset fixities, low reservation prices on particular resources and a greater degree of short-run fixed costs. He argued that flexibility in factor prices, technical change and capital accumulation and redistribution of assets combine to create an illusionary vertical short-run supply curve.

In 1958, Glenn L. Johnson [44] reviewed the historical works on agricultural supply response and was critical of the lack of conceptual explanation for asset fixities and their influences on the aggregate supply function. He pointed out that the analytical framework employed in supply problems must be capable of determining which assets are fixed and to what extent they are fixed. He defined a fixed asset as one whose marginal value productivity in its present use neither
justifies additional acquisition nor its disposition. Thus, if the acquisition cost and salvage value of an asset differ substantially, the asset can remain fixed for wide ranges of product price variation. If, however, the acquisition cost and salvage value are equal, then any variation in product price relative to the price of the asset will cause either acquisition or disposal of the asset.

Johnson classified farm inputs into nine groups and analyzed resource use for the period 1911-1954, concluding that the aggregate supply curve for agriculture: (1) has a positive elasticity during periods of inflation, deflation, prosperity, and depression; (2) is more elastic upward than downward; (3) is more elastic upward at full prosperity and during recovery than during recession and depression; and (4) is less elastic downward during prosperity and recovery than in recession and depression.

During the same period of time that the debate outlined here concerning the nature of the agricultural supply relation was developing, there was considerable discussion in the political arena concerning policy options and programs to stabilize farm output and prices. The truth as to whether or not agricultural output is virtually unresponsive to price changes has important implications for the impacts of the policies and programs proposed during this time. If in fact agriculture is characterized by a vertical supply curve, then price supports should only affect farm incomes and not output levels, at least in the
short-run. Impacts of such price support programs on risk factors, however, would tend to shift the supply curve outward which, coupled with an inelastic aggregate demand, would depress market prices outside of the price supports. This process is essentially a dynamic one, yet the dynamics of the agricultural sector had not been tested empirically at the time of the policy debates. The next section reviews the major developments since the mid 1950's in the area of estimating the dynamics of agricultural supply through the employment of distributed lag models.

**Distributed Lags and the Dynamics of Agricultural Supply**

In a pioneering effort to develop a theory for the dynamics of agricultural supply, Marc Nerlove (see Nerlove [57], [58], [59], and [60]) developed the partial adjustment model which resulted in a distributed lag specification. He employed this distributed lag model to estimate farmers' response to changes in price in the production of corn, cotton, and wheat. Nerlove argued that when "static models" are used to estimate elasticities of demand or supply under conditions in which it takes the decision maker longer than one period to adjust to changed conditions, "then statistical relationships among observations on the relevant variables, each of which is taken at the same time, tell us little about the long-run elasticity or any of the short-run elasticities." (Nerlove, [59]: p. 306). He asserted that the distributed lag model provides a solution to this problem:
"Distributed lags arise in theory when any economic cause . . . produces its effect . . . only after some time, so that this effect is not felt all at once, at a single point in time, but is distributed over a period of time. . . . Thus the formulation of economic relationships containing distributed lags is related to the problem of formulating meaningful relationships among variables we can observe, and the problem of estimating distributions of lag is really the problem of estimating long-run elasticities."

(Nerlove, [59]: pp.306).

Although Nerlove's utilization of a distributed lag model in estimation problems for agricultural supply was new to the field of agricultural economics in 1956, the concept of distributed lags was not new. The most general form of a distributed lag implies that the current level of the dependent variable is a function of an infinite series of past values of the independent variables. This infinite lag structure, without further restrictions, is not a workable hypothesis for common estimation techniques since an infinite number of parameters is involved.

There have been several approaches taken or suggested for the problem of estimating a distribution of lag, most utilizing the result that under an assumption of a finite sum for the lag coefficients the distributed lag can be approximated by a probability distribution to estimate the relative values of the lag coefficients.

Fisher [23] was the first to use and discuss the concept of a distributed lag in 1925. His approach was to assume a general form for the distribution of lag and estimate the parameters defining the exact distribution. This approach has been followed by several others, including
Koyck [49], Cagan [11], and Friedman [25].

Koyck [49] showed in 1954 that a geometric lag distribution of the form

\[ Y_t = \alpha \sum_{i=0}^{\infty} \lambda^i X_{t-i} + u_t, \quad 0 < \lambda \leq 1 \]

can be reduced to

\[ Y_t = \alpha X_t + \lambda Y_{t-1} + u_t - \lambda u_{t-1}. \]

This provides a much simpler estimation problem than (1), although ordinary least squares estimators will be biased and inconsistent due to the introduced correlation of the composite error term with \( Y_{t-1} \).

Fuller and Martin [26] and Zvi Griliches [34] independently showed in 1961 that serial correlation bias in distributed lag models will be positive (i.e. overestimate \( \lambda \)) if the serial correlation is positive, and negative (i.e. underestimate \( \lambda \)) if the serial correlation is negative. Fuller and Martin also showed that the Durbin-Watson test statistic for serial correlation is of very low power (often fails to reject the null hypothesis of nonautocorrelated errors) when applied to distributed lag models.

Cagan [11] developed the adaptive expectations model in 1956 in which price expectations (\( P^* \)) are revised each period in proportion to the error associated with the previous level of expectations

\[ P_t^* - P_{t-1}^* = \beta (P_{t-1} - P_{t-1}^*), \quad 0 < \beta \leq 1. \]

This model reduces to a geometrically declining distributed lag form for expected price as a function of all past prices, as given by the relation
When applied to a model of the form
\[ Y_t = \alpha + \lambda P_t^* + u_t, \]
the Koyck transform can be applied giving
\[ Y_t = \alpha + \lambda P_{t-1}^* + (1 - \lambda)Y_{t-1} + v_t, \]
where \( v_t = u_t - (1 - \lambda)u_{t-1}. \)
If this model is operationally correct, then a search procedure over all possible \( \lambda \)'s on the interval (0,1] will yield maximum likelihood estimators for the parameters corresponding to that value of \( \lambda \) which maximizes the \( R^2 \) of a linear least squares relation, given \( \lambda. \)

Nerlove's partial adjustment model assumes that current values of the independent variables determine the "desired" value of the dependent variable
\[ Y_t^* = \alpha + bX_{t-1} + u_t. \]
But, due to adjustment costs, or fixities, such as existing assets of the firm, currently employed labor, and other short-run conditions, only some fraction of a desired adjustment is accomplished in any particular time period
\[ Y_t - \hat{Y}_{t-1} = \gamma(Y_t^* - Y_{t-1}), \quad 0 < \gamma \leq 1. \]
This model reduces to
\[ Y_t = \gamma \alpha + \gamma bX_{t-1} + (1 - \gamma)\hat{Y}_{t-1} + \gamma u_t, \]
which is the same reduced form as the adaptive expectations model, except it introduces no additional serial correlation in the error terms if there was none to begin with.
Nerlove combined the conceptual aspects of both models so that the desired value of the dependent variable is determined by the unobserved expected value of the independent variable

\[(10) \quad Y_t^* = a + bP_t^* + u_t \]

which reduces to

\[(11) \quad Y_t = \gamma \beta a + \gamma \beta bP_{t-1} + (2 - \gamma - \beta)Y_{t-1} - (1 - \gamma)(1 - \beta)Y_{t-2} + \nu_t,\]

where \( \nu_t = \gamma u_t - \gamma(1 - \beta)u_{t-1} \), a composite disturbance term. Because \( \gamma \) and \( \beta \) enter (11) symmetrically, it is not possible to distinguish between the two cases if either \( \gamma = 1 \) or \( \beta = 1 \), creating an identification problem with respect to these parameters (Nerlove, [59]: p. 64).

The "Nerlove model" has become a widely used and successful model for estimating agricultural supply over the past two decades. A survey by Hossein Askari and John Thomas Cummings [3] in 1977 cites 190 studies that have employed this model and several adaptations of it in agricultural supply studies. One reason for this attractiveness centers around the approach itself; to develop an explicit dynamic theory of consumer or producer behavior which implies a distributed lag only incidentally, as opposed to grafting a distributed lag onto fundamentally static models.

In 1958, Griliches [31] employed the partial adjustment model to analyze the demand for fertilizer in the United States over the period 1911-1956. He argued that the tremendous increase in fertilizer use was mainly the result of a lower real price for fertilizer. Technological
change occurred not in the agricultural industry, but in the fertilizer
industry in the form of new fertilizer production processes resulting
in a substantial secular fall in the real price of fertilizer. The
lower real price of fertilizer stimulated increased fertilizer use,
with the partial adjustment model allowing for the adjustment to a
change in price to spread over more than one year.

In a further study of the demand for agricultural inputs, Griliches
[32] analyzed the derived demands for fertilizer, hired labor, and
tractors in 1959. He again employed the partial adjustment model in
the specification for input demand. From the estimated elasticities of
demand for inputs, he imputed a short-run aggregate farm supply elasti­
city of 0.3 and a long-run elasticity between 1.2 and 1.3. He asserted
that the time had come to give up the argument for a perfectly inelastic
short-run aggregate agricultural supply function.

Although the distributed lag model performed extremely well though­
out the entire set of demand studies, Griliches made these cautionary
comments:

"I do not believe that the theory is as good as the model
makes it out to be. The reason why this model performs so
well may be due to the fact that it takes care of almost
all the mistakes that one can make by introducing the
lagged value of the dependent variable as an additional
explanatory variable. Therefore, one should take great
care in interpreting its estimated coefficients. They
may measure more than just the 'adjustment' or expecta­
tion process. They may actually take into account most
of the variables that one should have included explicit­
ly in the model but did not do so." (Griliches, [32]: p. 317).
In the first direct attempt to estimate the aggregate U.S. farm supply function empirically, Griliches [33] assumed a Cobb-Douglas type of farm production function which included lagged output as an explanatory variable

\[ Y_t = \alpha P_t^{\beta} W_t^{\gamma} Y_{t-1}^{\lambda} \theta_t, \]

where

- \( Y_t \) is the Agricultural Research Service (ARS) index of farm output for year \( t \),
- \( P_t \) is the USDA index of prices received deflated by the index of prices paid for production items, farm wage rates, interest, and taxes,
- \( W_t \) is Stallings' [74] index for the effects of weather on farm output in year \( t \), and \( \alpha, \beta, \gamma, \lambda, \) and \( \theta \) are constants.

Griliches studied aggregate farm output and two sub-aggregates; all crops, and livestock and livestock products. For the aggregate farm output and all crops studies, the price series were as of March 15 of the current year. He argued for the use of this price over lagged average annual price in his earlier study on fertilizer demand:

"The assumption that farmers are able to predict fall prices in the spring, in the author's opinion, results in less error than the assumption that they base their expectations throughout the year on last year's prices, without taking into account the current price developments."

(Griliches, [31]: p. 601).

For the livestock and livestock products study Griliches employed the annual average price lagged one year.

The estimation procedure Griliches employed was to use the logarithms of the original values of all variables except for trend
in a linear regression (trend was left in its original form). The model estimated is given by

\[(13) \ln Y_t = \alpha' + \beta \ln P_t + \gamma \ln W_t + \lambda \ln Y_{t-1} + \theta t + u_t,\]

where \(\alpha' = \ln a\) and \(u_t\) is a random disturbance. This model can be interpreted as a modified partial adjustment model in which the adjustment equation is linear in logarithms

\[(14) \ln Y_t - \ln Y_{t-1} = \lambda (\ln Y^*_t - \ln Y_{t-1}), 0 < \lambda \leq 1.\]

By converting back to the original units, the actual percentage change in output is a power function of the percentage difference between "desired" output this year and actual output last year

\[(15) Y_t / Y_{t-1} = (Y^*_t / Y_{t-1})^\lambda.\]

The use of a linear trend in a logarithmic relationship as a specification for technological change assumes that the supply function has been shifting to the right at a constant (compounded annually) percentage rate. Griliches was able to employ a weather variable in his study due to the pioneering research effort by James L. Stallings [74] in 1958 to construct an aggregate index for the impacts of weather on farm output.

A summary of Griliches' main results from this study are shown in Table 1. Griliches estimated long-run elasticities of supply by dividing the estimated price coefficients by one minus the coefficient of lagged output. One minus the coefficient of lagged output gives an estimate of the "adjustment coefficient" -- the fraction
Table 1. Summary of Griliches' 1960 Results

<table>
<thead>
<tr>
<th>Coefficients Of</th>
<th>&quot;Real&quot;</th>
<th>Weather</th>
<th>Trend</th>
<th>Lagged</th>
<th>R</th>
</tr>
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<tbody>
<tr>
<td>Farm Output</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1921-1957</td>
<td>.095</td>
<td>.383</td>
<td>.0047</td>
<td>.298</td>
<td>.979</td>
</tr>
<tr>
<td></td>
<td>(.045)</td>
<td>(.065)</td>
<td>(.0007)</td>
<td>(.096)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[.319]</td>
<td>[.723]</td>
<td>[.758]</td>
<td>[.481]</td>
<td></td>
</tr>
<tr>
<td>1920-1957</td>
<td>.101</td>
<td>.385</td>
<td>.0046</td>
<td>.303</td>
<td>.980</td>
</tr>
<tr>
<td></td>
<td>(.043)</td>
<td>(.064)</td>
<td>(.0007)</td>
<td>(.095)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>[.377]</td>
<td>[.725]</td>
<td>[.761]</td>
<td>[.486]</td>
<td></td>
</tr>
<tr>
<td>All Crops</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1911-1958</td>
<td>.164</td>
<td>.392</td>
<td>.0028</td>
<td>.299</td>
<td>.939</td>
</tr>
<tr>
<td></td>
<td>(.042)</td>
<td>(.064)</td>
<td>(.0004)</td>
<td>(.095)</td>
<td></td>
</tr>
<tr>
<td>Livestock and Livestock Products</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1911-1958</td>
<td>.194</td>
<td>-.191</td>
<td>.0014</td>
<td>.727</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.050)</td>
<td>(.057)</td>
<td>(.0006)</td>
<td>(.082)</td>
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</tr>
<tr>
<td>1911-1934</td>
<td>.196</td>
<td>-.232</td>
<td>.0021</td>
<td>.414</td>
<td>.971</td>
</tr>
<tr>
<td></td>
<td>(.064)</td>
<td>(.062)</td>
<td>(.0012)</td>
<td>(.205)</td>
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<tr>
<td>1935-1958</td>
<td>.190</td>
<td>-.346</td>
<td>.0015</td>
<td>.723</td>
<td>.981</td>
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<tr>
<td></td>
<td>(.071)</td>
<td>(.114)</td>
<td>(.0013)</td>
<td>(.126)</td>
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<tr>
<td></td>
<td>[.526]</td>
<td>[-.569]</td>
<td>[.257]</td>
<td>[.797]</td>
<td></td>
</tr>
<tr>
<td>Ratio of Livstk to Feed Prices</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1911-1958</td>
<td>.193</td>
<td>.0014</td>
<td>.727</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.049)</td>
<td>(.0005)</td>
<td>(.080)</td>
<td></td>
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<tr>
<td></td>
<td>[.511]</td>
<td>[.378]</td>
<td>[.807]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1911-1934</td>
<td>.216</td>
<td>.0023</td>
<td>.431</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.058)</td>
<td>(.0012)</td>
<td>(.201)</td>
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</tr>
<tr>
<td></td>
<td>[.641]</td>
<td>[.394]</td>
<td>[.431]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1935-1958</td>
<td>.185</td>
<td>.0023</td>
<td>.676</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.074)</td>
<td>(.0013)</td>
<td>(.130)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>[.485]</td>
<td>[.373]</td>
<td>[.759]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Numbers in parentheses are standard errors; numbers in brackets are respective partial correlation coefficients; R is the multiple correlation coefficient.
of a desired adjustment that is eliminated in one period. The estimated long-run price elasticities of supply are:

<table>
<thead>
<tr>
<th>Category</th>
<th>Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm Output</td>
<td>0.15</td>
</tr>
<tr>
<td>All Crops</td>
<td>0.23</td>
</tr>
<tr>
<td>Livestock &amp; Livestock Products</td>
<td>0.70</td>
</tr>
</tbody>
</table>

One feature of the results achieved by Griliches that was perplexing to him was the relative instability of the distributed lag model for aggregate farm output and all crops when shorter sample periods were specified. He suggested this explanation:

"This may be due to several causes (besides the inappropriateness of the basic model): (a) the very high multicollinearity with trend; (b) the existence of price supports for crops after 1934, making the expected price equal to the support price or higher; and (c) the fact that measured output is not necessarily equal to planned output, due to 'weather' and other random effects. This last factor would lead to a downward bias in the estimate of the coefficient of lagged output since the adjustment assumed by the model proceeds from the previously 'planned' output, of which actual output is not an error-free measure."

(Griliches, [33]: p. 291).

In a footnote at an earlier stage of development in his article (p. 284), Griliches pointed out the importance of distinguishing between planned and realized output, as well as between desired and actual output. He also discussed the fact that the weather variable ought to be included in the adjustment portion of the response relationship rather than entering in the same manner as price.

Subsequent to the research by Griliches in 1960, the literature is relatively void of theoretical and empirical discussion of the aggregate
agricultural supply relation until 1969, when Luther G. Tweeten and C. Leroy Quance [79] reported a study in which three separate approaches were used to estimate the aggregate agricultural supply elasticity. One approach was a direct least squares estimate of the aggregate supply function. Two disaggregate approaches were also used: (1) direct least squares estimates of the separate yield and basic production unit components of (a) crops and (b) livestock which were aggregated to form an estimate of the elasticity of total supply, and (2) estimation of production elasticities and demand elasticities for eight farm inputs to estimate the supply elasticity.

Tweeten and Quance employed the following model in their estimation procedure:

\[ O_t = \alpha + \beta P_{t-1} + \gamma S_t + \phi T_t + u_t \]

where \( O_t \) is the index of aggregate farm output for year \( t \), \( P_{t-1} \) is the lagged ratio of the index of prices received for all farm products to the index of prices paid for items used in production, \( S_t \) is the stock of productive farm assets as of January 1st of year \( t \), and \( T \) is a "productivity index", the ratio of the index of farm output to the index of all farm production inputs in the year \( t \).

Tweeten and Quance attempted to test for differing responses of farm output to falling and rising prices by breaking the price variable into two components; one for decreasing prices and one for increasing prices. They also employed their only dynamic specification in the study
while testing for irreversibilities with respect to price by lagging output one year. Results from this test for irreversibilities showed the coefficients for the segmented price variables to be nearly identical. Nevertheless, the two researchers concluded:

"The supply elasticity is 0.10 in the short run and 0.80 in the long run for decreasing prices. But the supply elasticity is 0.15 in the short run and 1.5 in the long run for increasing prices." (p. 351).

In a comment published in 1971, O. R. Burt [8] criticized the use of a productivity index which contained the index of farm output, i.e. the dependent variable in Tweeten and Quance's regression, as its numerator. This results in the contemporaneous inclusion of the dependent variable on both sides of the regression equation and forces correlation of the random disturbance term, $u_t$, with the "independent" variable $\theta_t/X_t$, where $X_t$ is the index of total farm inputs in year $t$, since $u_t$ is an additive component of $\theta_t$ in the same period. This results in estimation bias and inconsistency. Also, standard errors and t-statistics lose their validity due to the severe violation of the distribution theory applied to obtain the estimated coefficients. Burt argued that these considerations should make any inferences drawn from an analysis performed in this fashion quite suspect.

Although there was little work done in the area of estimating the aggregate agricultural supply function during the decade of the sixties and the nine years since Tweeten and Quance reported their effort,
a lot of work has been done in the area of distributed lag analysis.

L. R. Klein [48] discussed the problem of serial correlation and
inconsistent estimates associated with the Koyck transformation for dis­
tributed lags in 1958. He proposed an errors in variables model for
least squares estimation techniques, and showed that the resulting esti­
mators are equivalent to a form of "limited information maximum likeli­
hood" estimates. In 1960, R. M. Solow [73] suggested the use of the
Pascal distribution family as a generalization of Koyck's geometric mod­
el which would allow J-shaped or unimodal lag distributions.

N. Liviatan [50] approached the problem of distributed lag estima­
tion when the error terms are subject to an autoregressive structure in
1963. He suggested the use of lagged values of the exogenous variables
as instrumental variables for the estimation procedure. E. J. Hannen [36]
showed in 1965 that Liviatan's estimator is inefficient, however. He
proposed the use of spectral analysis techniques to derive an asymptotically efficient estimator.

D. W. Jorgenson [45] showed in 1966 that any arbitrary distributed
lag function can be approximated to any desired degree of accuracy by a
member of the class of rational distributed lag functions. A distributed
lag function is a member of the class of rational distributed lag func­
tions if and only if it may be written with a finite number of lags in
both dependent and independent variables.

Yair Mundlak [55] considered the microeconomic theory of
distributed lag models in an article published in 1966. He observed
that specification of an adjustment equation such as that used impli-
citly by Koyck and explicitly by Nerlove creates a link between theory
and empirical analysis, but that such a formulation assumes intrinsic
relationships between economically endogenous variables that cannot be
justified by economic theory. He argued that the existence of such re-
lationships may imply very strong restrictions on comparative statics
theory, and that the path of convergence in a dynamic system is a var-
iable in the analysis that cannot be preassumed.

Griliches [35] published a survey article in 1967 discussing the
history and theoretical development of distributed lag models. He com-
mented that even though distributed lag models are widely and variously
used, most of them have "almost no or only a very weak theoretical under-
pinning. Usually the form of the lag is assumed a priori rather than
derived as an implication of a particular behavioral hypothesis." (p.42).
He argued, however, that the adaptive expectations and partial adjust-
ment models are exceptions to this.

In 1968, Roger N. Waud [83] argued that use of the partial adjust-
ment model is probably quite often a misspecification of adaptive expec-
tations formation. Similarly, use of an adaptive expectations model may
be a misspecification of habit persistence. He argued that either is
suspected, then both must be tested, since failure to specify both re-
results in misspecification bias. He showed that this bias is downward in
the estimated coefficient for the lagged dependent variable, upward in
the estimated mean lag, and creates noticeable increases in the size of
the standard errors relative to the estimated coefficients.

Phoebus J. Dhrymes [18] developed in 1969 a direct search proce-
dure for obtaining estimators of the parameters of an infinite geometric
lag structure which produces global maximum likelihood estimators when
the disturbances are assumed to follow a first-order Markov process and
are normally distributed with zero mean and constant (finite) variance.
The search is over all possible values of $\lambda$ and $\rho$ on the interval (-1,1)
for each, where $\lambda$ is the coefficient of geometric decline and $\rho$ is the
serial correlation coefficient. The maximum likelihood estimators are
those that correspond to the ordered pair for $\lambda$ and $\rho$ yielding the smal-
lest residual variance. The estimators derived are essentially Aitken
estimators (generalized least squares with nonstandard covariance matrix)
and Dhrymes showed that the estimators are consistent, asymptotically
unbiased, and efficient.

In 1971 G. S. Maddala and A. S. Rao [52] developed maximum likeli-
hood estimation procedures for Solow's (Pascal distribution) and for
Jorgenson's (rational distributed lag function) distributed lag models.
The procedure involves the use of synthetic variables and a search pro-
cedure extending that developed by Dhrymes in a linear regression frame-
work.

The procedures for estimating low order rational distributed lags
in an essentially linear regression framework that have been developed by Maddala and Rao can be generalized to a nonlinear least squares estimation procedure with maximum likelihood estimators identical to the results obtained from the linear search procedure. O. R. Burt [10] outlined the nonlinear least squares estimation technique for distributed lag models in 1978. The nonlinear algorithm approach appears to have certain advantages over the direct search procedure due to the fact that more general assumptions can be specified for the disturbance terms and the order and form for the rational distributed lag model. This nonlinear least squares procedure and algorithm are employed in this study to obtain maximum likelihood estimates under the normality assumptions for the aggregate agricultural supply function.

Specifying and Testing for Irreversibilities in Supply

The notion of irreversibilities in the agricultural supply function have been prevalent since the works of Câssels in 1933. However, the effort by Tweeten and Quance to test for irreversibility with respect to price in the aggregate supply relation has instigated much recent development in the area of specifying and testing for irreversibilities in supply. This section summarizes these developments.

In a comment published in 1971, Rudolf Wolfram [84] criticized the methodology used by Tweeten and Quance to estimate irreversibilities in the supply response relation. He showed that the quantification of irreversible relations cannot be done by separating an independent
variable into two components, one for increases in the variable and the other for decreases. Wolffram showed that the method employed by Tweeten and Quance is absolutely correct in the case of reversibility, though unnecessary since it provides no additional information. In the case of irreversibility, however, the method leads to biased estimates for all coefficients when least squares techniques are employed. (p. 357). Wolffram proposed a procedure for estimating irreversibilities through splitting the first differences of the independent variable into positive and negative changes.

James P. Houck [41] published an article in 1977 that developed an approach to testing for irreversibilities that is consistent with the Wolffram technique but is operationally clearer. The approach is summarized by the model

\[
(17) \ Y_t - Y_o = a_0 t + a_1 (\epsilon_t^x X'_1) + a_2 (\epsilon_t^x X''_1),
\]

where \(Y_o\) is the initial value of \(Y\), \(X'_1 = X_1 - X_{1-1}\) if \(X_1 > X_{1-1}\), and = 0 otherwise, and \(X''_1 = X_1 - X_{1-1}\) if \(X_1 < X_{1-1}\), and = 0 otherwise.

Houck cautioned researchers utilizing the technique developed in his article to be aware of the following potential problems:

"First, the segmentation and data transformation consume two degrees of freedom: one for the added price variable and one for the loss of explanatory power in the initial observation. Second, intercorrelations among explanatory variables may be intensified. When a variable is segmented into increasing and decreasing components, it is possible that the two segments will be highly correlated with each other or with other trendlike variables in the analysis."

(p. 571).
Bruce Traill, David Colman, and Trevor Young [76] criticized the Wolffram technique for estimating irreversible supply functions in 1978 on the basis that if the coefficient for positive price changes is assumed to be greater than the coefficient for negative price changes, then for given starting and finishing prices, the Wolffram model implies that the greater the price changes in the intermediate period, the larger is output at the end of the period. They argued that given a high correlation between price variability and uncertainty (uncertainty being defined as unexpected variability), highly variable prices would lead to a reduction in output due to risk considerations.

The model they proposed is a modification of the Wolffram model in which price increases below the previous maximum price are added to the falling price series rather than to the rising price series. The coefficient of this modified rising price series thus no longer represents the output response for every price rise, but the response to a price rise beyond the previous maximum. The modified falling price series shows the response of output to price movements in either direction below the historical high. They also showed that estimating this modified Wolffram model is equivalent to estimating the relationship

\[ Y_t = \alpha + b_1 P_t^* + b_2 P_{\text{max}}^* + \epsilon_t, \]

where \( P_{\text{max}}^* \) is the previous maximum expected price and \( P_t^* \) is the current expected price level.

O. R. Burt [10] discussed the estimation of the dynamics of farm
supply in 1978. In regard to irreversibilities, he argued:

"It would appear that finding irreversibility in a linear supply function with respect to price changes is a symptom of specification error associated with the dynamic structure of the model. In fact, an irreversibility with respect to one variable in the supply response function would seem to suggest irreversibility in most other variables of the equation.

"A sufficiently high order difference equation in the supply response variable jointly with a relatively short distributed lag on price, and possibly other exogenous variables, should remove the irreversibility problem."

(Burt, [10]: p. 6).

The review of the literature presented in this chapter identifies several important aspects of the aggregate agricultural supply function that are in need of further study. The question of the magnitude of the elasticity of supply has not been adequately answered, even though the price elasticity has serious implications for the agricultural sector and policy makers. There has not been adequate estimation of the dynamics of the aggregate supply relation. The focus of Heady and Griliches on the ratio of output prices to input prices seems to indicate that there is likely to be substantial ability to adjust on the part of the farmer in response to changes in this price ratio, or "real price." Technological advance has born the burden of responsibility in terms of theoretical arguments for the ability or lack of ability to adjust to changing prices in agriculture. Yet, an adequate measure of technology has not been developed. There has not been sufficient testing of the hypothesis that the supply function is characterized by irreversi-
bilities. The argument that technology is responsible for all adjustments in agricultural supply supports the assertion by Burt that an irreversibility with respect to one variable indicates irreversibility with respect to most other variables. In a dynamic relationship, an irreversibility would most likely be manifested in the functional form of the adjustment relation. However, testing for an irreversible adjustment presents serious problems with respect to continuity in the residual sum of squares space when least squares methods are used. This problem seems to be overpowering, at least at the present. For the purposes of this study, the methods and data employed by Griliches, the estimating techniques developed by Burt, and the irreversibilities models developed by Houck and by Traill, Colman, and Young are the most relevant. The next chapter outlines the theoretical development of the empirical models employed in this research and describes the nature, construction, and limitations of the data used to estimate the aggregate agricultural supply function.
Chapter 3
THEORETICAL CONSIDERATIONS

The literature survey in the previous chapter identified several conceptual issues concerning the economic theory of aggregate agricultural supply. Several scholars have argued that, in the short-run, at least, the aggregate farm supply function is severely, perhaps perfectly, price inelastic. Those arguing that the farm supply curve has a significantly positive price elasticity have been somewhat fewer in number, although the scant empirical evidence seems to favor this position.

One unambiguous aspect of agricultural supply is that it is dynamic in nature. Academic discussion of this characteristic of agriculture has ranged from arguments placing virtually all responsibility for adjustments, or lack of adjustments, in American agriculture on technological advances to arguments asserting that what appears to be technological change in farming is actually response to varying relative prices of inputs. Yet, this aspect of agriculture has received very little empirical treatment in the aggregate. In particular, theoretical models developing dynamic hypotheses rarely match the actual empirical methods employed to these same hypotheses.

Several economists have argued that the short-run farm supply function is irreversible with respect to price changes. This notion has been prevalent for many years, although methods to statistically
test for irreversibility have been developed only rather recently. As a result, sufficient testing of the hypothesis that agricultural supply is irreversible has not been achieved, especially in the area of aggregate agricultural supply. If farming is characterized by irreversibilities, then it seems logical that this would be most obvious in the aggregate. Resources can be transferred across enterprises and to different crops due to relative price changes and significant differences between marginal value products and salvage values within farming, but the total quantity of resources available to or employed in agriculture remains much more fixed from year to year.

The next section outlines the conceptual approach taken in this study to the problem of estimating aggregate agricultural supply. The third section discusses the problem of testing for irreversibilities. The final section in this chapter then describes the data employed, the manner in which it was constructed, and a brief discussion of some potential limitations in interpreting the results from a study using this data.

The Dynamics of Supply Adjustment

The methods employed by Griliches [33] appear to be the most theoretically acceptable for the overall purposes of this study. His aggregate supply analysis and Burt's [10] work on estimation of dynamic agricultural supply relationships provide the theoretical framework for this research. The supply of farm products is posited
to be a function of relative prices, weather, technology, and other variables including government programs and policies. The basic approach is to employ the concept of distributed lags to estimate the dynamics of the supply relationship.

Fundamental arguments for specifying and estimating values of expected normal (planned) output as the correct behavioral response variable in a distributed lag framework for estimating agricultural supply are presented in Chapter 2 above. Ultimate farm output in a given year is highly dependent upon weather and other random effects. At best, farmers at planting time can plan for an expected level of output, given a normal or average season in terms of these uncontrollable factors. This fact implies that beginning of the period (season) "planned" output ought to be the proper behavioral variable for estimating agricultural supply response, and brings to light the problem of identifying such a response variable. Clearly, planned output is a conceptual, unobservable variable. The real question, then, relates to how farmers form their expectations for farm production at the planning level.

The development of a theory for the behavior of farmers in response to price changes must begin at the individual farm level. Let us consider a simple partial adjustment model for the purpose of permitting the concept of rigidities, or asset fixities, to enter the firm response relation, and to show the distinction between planned
Let $x^*_{it}$ be desired long-run equilibrium production for firm $i$ in year $t$, $i=1,2,...,N$, where $N$ is the total number of farm firms in the nation; $\bar{x}_{it}$ be planned production for firm $i$ in year $t$; $x_{it}$ be observed production; $P_t$ be the expected average price level for farm products in year $t$; and $T_t$ be the technological state for year $t$. Here it is assumed, for simplicity, that the expected average impact of weather is zero. Desired long-run supply for an individual firm is approximated by the linear equation

$$x^*_{it} = a + b P_t + c T_t + e_{it},$$

where $e_{it}$ is a random variable to account for variation among firms.

The argument for asset fixity limiting the farmer's ability to adjust applies to planned and not observed output. If this were not true, then the size of the adjustment would depend heavily on weather conditions in year $t-1$. It seems extremely unlikely that exceptionally favorable weather last year resulting in a bumper crop would cause farmers to believe that they are now on a new and higher production function and can expect yields similar to last year's from now on.

The partial adjustment relationship is therefore given by

$$x_{it} - x_{it-1} = \gamma_i (x^*_{it} - \bar{x}_{it-1}), \; 0 < \gamma_i < 1,$$

Substitution of (15) into (16) and reduction yields

$$x_{it} = \gamma_i a + \gamma_i b P_t + \gamma_i c T_t + (1 - \gamma_i) \bar{x}_{it-1} + \gamma_i e_{it}.$$
Inclusion of the subscript $i$ on the adjustment parameter $\gamma_i$ reflects the consideration that not all firms in the agricultural sector are able to adjust equally well because each firm faces unique resource constraints and is in a unique financial position in any specific period. This allows the adjustment factor to vary between firms in any given year. In the strictest sense, the $\gamma_i$'s should also contain a time subscript. This would allow the proportion of a firm's desired adjustment that is achieved in a year to vary over time and as conditions change. Such a specification could actually be an empirical representation of a nonlinear adjustment relation of the general form

$$\bar{x}_{it} - \bar{x}_{it-1} = f_i(x^*_{it} - \bar{x}_{it-1}),$$

where $f_i(\cdot)$ is any general function with a range on the interval $(0,1]$. As Mundlak pointed out, even this restriction on the range of the adjustment function might be too restrictive to accurately reflect reality. In this very general case, the adjustment coefficient would necessarily be considered as an additional variable rather than as a parameter, and inherent identification and estimation problems result if further restrictions are not imposed. Therefore, the more restrictive assumption of equation (20) is employed.

Assuming that equation (21) is the correct specification for planned output at the farm level, then total aggregate "planned" agricultural output is the summation of all individual farm firms' planned outputs. This can be represented by the relation
\[ \bar{X}_t = \sum_{i=1}^{N} (x_{it}) \]

(22) \[ \bar{X}_t = \sum_{i=1}^{N} [\gamma_i a + \gamma_i b \bar{P}_t + \gamma_i c \bar{P}_t + (1 - \gamma_i) \bar{X}_{it-1} + \gamma_i e_{it}] \]

\[ = \alpha + \beta_1 \bar{P}_t + \delta \bar{T}_t + \sum_{i=1}^{N} (1 - \gamma_i) \bar{X}_{it-1} + v_t \]

where \( \alpha = \sum_{i=1}^{N} \gamma_i a, \) \( \beta = \sum_{i=1}^{N} \gamma_i b, \) \( \delta = \sum_{i=1}^{N} \gamma_i c, \) and \( v_t = \sum_{i=1}^{N} \gamma_i e_{it} \) an aggregate disturbance term.

A conventional statistical estimation equation for this form of aggregated supply function is given by

(23) \[ X_t = \alpha + \beta_1 \bar{P}_t + \delta \bar{T}_t + \lambda X_{t-1} + u_t \]

where \( X_t \) is observed output and \( \lambda \) is a type of "weighted average" adjustment coefficient of the form

(24) \[ \lambda = \sum_{t=1}^{m} \left[ 1 - \left( \sum_{i=1}^{N} \gamma_i X_{it-1} / X_{t-1} \right) \right] / m, \]

where \( m \) is the number of years in the sample. The usual interpretation of the coefficient \( \lambda \) is that it is of the form \( \lambda = (1 - \bar{\gamma}) \), where \( \bar{\gamma} \) is defined to be an average, or representative, firm's coefficient of adjustment. This interpretation can be considered to imply either that the net effect of the variation of the \( \gamma_i \)'s around \( \bar{\gamma} \) is expected on average to be zero, or that \( \gamma \) is constant across all firms.

The common interpretation that \( \lambda = (1 - \bar{\gamma}) \) results in a geometrically declining distributed lag on the independent variables. However, it should be obvious that equation (23) cannot be argued to have come directly from the partial adjustment model of equation (22). The adjustment relation arises from the level of planned output at the beginning of the season, not from observed output for the entire period.
As Griliches pointed out, actual output is not an error-free measure of planned output. If the correct model is specified by a linear adjustment relationship between planned and desired output, then estimation by inclusion of lagged values of observed output will result in an errors in variables model, and the coefficients for the lagged output variables will usually be biased towards zero.

Even if it is reasonable to assume that a planned adjustment is roughly proportional to the desired long-run adjustment in a given year, this cannot be logically carried over to actual output for the simple reason that observed output is strongly dependent upon weather conditions. It is not difficult to conceive of a situation where farmers desire to contract output due to particularly low prices (and plan to do so) but weather conditions result in an actual increase in output or one in which farmers desire (and plan) to expand output but poor weather conditions result in an actual contraction. Yet the constraint on the adjustment coefficient in the partial adjustment model forces it to fall between zero and one, implying that the actual and desired adjustments must be in the same direction, which is inconsistent with both of the above situations.

Assume that observed, or actual, farm output differs from planned output due to two sets of random effects; weather and other factors. Actual output is then related to planned output, assuming linearity, by

\[x_{it} = \bar{x}_{it} + g_{it} W_t + u_{it},\]
where $W_t$ is an index for the impacts of weather and $u_{it}$ is the random disturbance term accounting for all other factors affecting unplanned output. The earlier assumption that the average impact of weather is zero, i.e. $E(W_t) = 0$, implies the following when mathematical expectations are taken:

$$E(x_{it}) = E(x_{it})$$

$$= \gamma_1 a + \gamma_1 b P_t + \gamma_1 c T_t + (1 - \gamma_1)E(x_{it-1}) ,$$

assuming $E(e_{it}) = E(u_{it}) = 0$. Note also that $E(x_{it-1}) = E(x_{it-1})$, so that (26) is equivalent to

$$E(x_{it}) = \gamma_1 a + \gamma_1 b P_t + \gamma_1 c T_t + (1 - \gamma_1)E(x_{it-1}) .$$

This relation provides the interpretation that the systematic, measurable components of planned output are equivalent to the "expected" production level that would occur given average weather and no unusual events or conditions. This interpretation matches the theory of adjustment costs, asset fixities, or producer inertia quite well. The theory pertains to the systematically determined, or explained, level of output with a random error attached to account for all factors left unexplained by the theory. When lagged output enters an estimation equation for output response to changing prices and represents inertia, habit persistence, asset fixity, the formation of expectations or other theoretically justifiable forces creating lags in adjustment, only the theoretically explained, or systematic components of that lagged output variable contribute to the production inertia, etc. The
occurrence of random events not directly related to the application of inputs to the production process does not seem logically to lead to the buildup or depletion of assets or to added or diminished momentum on the part of the farmer.

One possible exception to this might be the impacts of weather on quantities of stored or carryover grains or other crops. The assumption that the "average" impact of weather is zero can be removed from the analysis, however, without significantly changing the interpretation. We define $E(x_{it})$ as a conditional expectation, given the influence of the weather variable. If we were dealing with a static regression equation,

$$(28) \quad E(x_{it}) = \gamma_i a + \gamma_i bP_t + \gamma_i cT_t + g_i W_t.$$  

The dynamic version is then defined to be a difference equation in the adjusted expectation of $x_{it}$ after removing weather effects. Equation (27) then becomes

$$(27') \quad E(x_{it}) - g_i W_t = \gamma_i a + \gamma_i bP_t + \gamma_i cT_t + (1 - \gamma_i)[E(x_{it-1}) - g_i W_{t-1}]$$

Transposing the term $g_i W_t$ to the right hand side of (27') gives

$$(27'') \quad E(x_{it}) = \gamma_i a + \gamma_i bP_t + \gamma_i cT_t + g_i W_t + (1 - \gamma_i)[E(x_{it-1}) - g_i W_{t-1}]$$

The interpretation of (27') is simply that the measurable components of planned output are net of, or given, the effects of weather and no other unusual conditions or events occur (assuming correct specification of the model and full information). In regard to the original partial adjustment equation (20), $\bar{x}_{it}$ is replaced by
Several other theoretical justifications for a general, low-order difference equation specification in the supply response variable have been developed such as: the adaptive expectations hypothesis, the result of Jorgenson that any distributed lag function can be approximated to any desired degree of accuracy by a rational distributed lag, the suggestion of Solow that the distributed lag pattern be approximated by the Pascal distribution, the results of Grether [30] showing that rather general economic assumptions resulting in an unobservable variable in the regression equation will produce a rational distributed lag framework, and the very recent results of McLaren [53] which show that all specifications of economic relationships containing a wide-sense stochastic variable (for example, a random disturbance or a random weather variable) lead to rational distributed lags. Christopher A. Sims [70] asserts, "A time series regression model arising in econometric research ought in nearly every case to be regarded as a distributed lag model until proven otherwise." (Sims, [70]: p. 289). The argument that only the systematic component of the lagged dependent variable ought to appear in an estimation equation is equally applicable to each of these theoretical models.

There is, in fact, virtually no difference in the empirical interpretation of this specification and a rational distributed lag specification if the error term is constrained to follow a first-order Markov
process with moving average error such that $\theta = -(1 - \gamma)$. If we are willing to assume that the error term follows this type of path, then the model given by equation (27') can be represented by

$$x_{it} - g_{i}W_{t} - e_{it} = \gamma_{i}a + \gamma_{i}b_{P} + \gamma_{i}c_{T} + (1 - \gamma_{i})(x_{it-1} - g_{i}W_{t-1} - e_{it-1}),$$

which is equivalent to the rational distributed lag given by

$$x_{it} = \frac{\gamma_{i}a + \gamma_{i}b_{P} + \gamma_{i}c_{T}}{1 - (1 - \gamma_{i})L} + g_{i}W_{t} + e_{it}.$$

The lag operator $L$ provides a simple notational means of specifying any desired degree of lag on a variable by being defined such that

$Lx_{t} = x_{t-1}, \quad L^{2}x_{t} = x_{t-2}, \ldots, \quad L^{k}x_{t} = x_{t-k}$, for any integer $k$.

Taking mathematical expectations (conditionally on weather) in equation (30) results in

$$E(x_{it}) = \frac{\gamma_{i}a + \gamma_{i}b_{P} + \gamma_{i}c_{T}}{1 - (1 - \gamma_{i})L} + g_{i}W_{t},$$

which can be easily reduced to the relation given by (27'') above.

Up to this point, the argument has focused on the effects of weather on output creating a divergence between expected and realized output levels. Livestock production is much less dependent upon weather than crop production. However, unanticipated disease and death losses, variability in feed availability due to random weather and other factors, particularly where a large proportion of feeds are grown on the same location as the livestock are raised, and various other unsystematic impacts create a divergence between expected and realized output levels for livestock production. This implies that only the
systematic components of lagged production should appear in a dynamic estimation equation for aggregate livestock production as well as in a dynamic model for total farm output or all crops production.

If it can be assumed that equation (27'), or alternatively equation (31), is the correct specification for the microeconomic behavior of individual farmers, then an aggregate relation can be obtained by summing over all firms

\[ E(X_t) = \sum_{i=1}^{N} E(x_{it}) = E(\sum_{i=1}^{N} x_{it}) \]

\[ = E[\sum_{i=1}^{N} (\gamma_i a + \gamma_i bP_t + \gamma_i eT_t + (1 - \gamma_i)\{E(x_{it-1}) - g_i W_{t-1}\}) + g_i W_t + u_{it} + \gamma_i e_{it})] \]

\[ = \alpha + \beta P_t + \delta T + \sum_{i=1}^{N} [(1 - \gamma_i)\{E(x_{it-1}) - g_i W_{t-1}\}] + \phi W_t. \]

It appears obvious that a relation such as equation (32) represents a severe aggregation problem. The problem is increased when a more general specification permitting a nonlinear adjustment relation is employed, and there does not seem to be any simple solution to the question of specifying and estimating an aggregate supply function based on microeconomic hypotheses for producer behavior. Further restrictions seem necessary, particularly when it is realized that aggregated data are typically in the form of constant base weighted averages forming an index of relative outputs and price levels. This eliminates the possibility of estimating an aggregated sum such as in equation (32) above. If in fact it were possible to obtain such a complete set of data that individual farm responses were represented for each and every
farm firm in the country, then there would be no need to employ an aggregate model to approximate the sum of individual firm responses. The world is not that utopic, and simplifying assumptions are necessary to make the analysis manageable.

In the aggregate, total available resources for agriculture are to a large extent fixed in any single year, and a linear approximation to the aggregate supply adjustment relation might be as plausible as any other type of specification. However, when the dynamics of agricultural supply are to be estimated via lagged values of the dependent output variable, it should be clear, at least, that a linear approximation is probably not as plausible for lagged observed output as it is for the systematic components of lagged output. The aggregate specification that results, then is given by

\[
E(X_t) = \alpha + \beta P_t + \delta T_t + \lambda [E(X_{t-1}) - \phi W_{t-1}] + \phi W_t.
\]

This relationship is estimated by adding an error term to \(E(X_t)\) resulting in

\[
X_t = \alpha + \beta P_t + \delta T_t + \lambda [E(X_{t-1}) - \phi W_{t-1}] + \phi W_t + u_t.
\]

It is important to remember that the error term \(u_t\) is a composite disturbance accounting for misspecification due to potential nonlinearities or omitted explanatory variables, measurement errors due to the aggregation process, and all other potential effects of the estimation process as well as the natural types of disturbances on each firm creating divergences between expected (or planned) output levels
and realized production. The disturbances are likely to be autocorrelated, although there is no a priori reason to suspect that the autocorrelation will necessarily follow a constrained first-order Markov process with $\rho = -(1 - \lambda)$. There is also little hope of ferreting out the various distinct components contributing to each period's estimation error.

When the impacts of the disturbance term in period $t-1$ are removed from the value of lagged output in the dynamic regression equation, the lagged dependent variable is no longer a stochastic explanatory variable and the related problems of estimation are circumvented since $E(X_{t-1})$ is independent of the error terms, whereas $X_{t-1}$ is linearly dependent upon $u_{t-1}$. This partitioning of the regression equation into two wholly distinct parts, one nonstochastic and consisting of the explanatory variables including $E(X_{t-1})$, and the other a stochastic disturbance term permits maximum likelihood estimates to be obtained with a nonlinear least squares estimation procedure under normality assumptions for the error terms. The use of a nonlinear estimation procedure is additionally advantageous because the assumptions about the nature of the disturbances can be made to be much more general without affecting the maximum likelihood properties of the estimates obtained.

Of course, the first-order difference equation model specified in equation (33) is a simplified case which can be readily expanded upon through the employment of lagged values of the independent variables.
and/or higher order difference equations on expected output. Expansion of the model in this manner would serve as a test for specification errors in terms of the structure of the distributed lag function. It would not be expected a priori that lags of more than two or three years would prove to enter the relationship significantly, mainly because aggregate agricultural data are extremely crude estimates of the relevant variables. This could, in fact, be a serious limitation to efforts towards making intelligent distinctions between models. The nature of the data, its construction, and some likely limitations are discussed in more detail in the final section of this chapter.

Recall that Griliches used the logarithms of the original values for all variables except trend in a linear regression. There are certain advantages to this approach. The log-linear specification is a curvilinear model that is easily accessible to ordinary regression techniques, although there is no real evidence that the log-linear specification will produce superior statistical results than a linear approximation. A Cobb-Douglas supply relation such as the one specified by Griliches permits simultaneous estimation of the regression coefficients and elasticities (forced to be constant) for the independent variables. The employment of a linear trend in a log-linear equation permits the assumption that the supply function has shifted to the right at a constant, compounded annually, percentage rate equal to the estimated trend coefficient.
A comparable model to the log-linear specification employed by Griliches which contains lagged output net of the effects of last year's error term is given by

\[ \log X_t = \alpha + \beta \log P_t + \delta t + \lambda [E(\log X_{t-1}) - \phi \log W_{t-1}] + \phi \log W_t + u_t. \]

Because the error term in this model is additive in logarithms, but multiplicative in the original variable values, and because the logarithmic transformation is not a linear operator, there is no straightforward interpretation of the adjustment relation for this specification in terms of the original values of the output variable that is similar to the power function interpretation of the adjustment assumed by Griliches. This does not create a problem in practice as long as the fact that the adjustment is linear in logarithms is kept in mind, as well as the idea that the impacts of the disturbance term on lagged output are removed in the estimation procedure is understood to be the primary distinction between this model and the model specified by Griliches.

Cochrane argued that the aggregate supply curve has shifted to the right in a much less smooth fashion than a trend variable such as the one assumed by Griliches suggests. The technological studies of Stout and Ruttan seemed to verify the Cochrane hypothesis at least for the aggregate. However, a solution to the problem of specifying technological advance accurately that is compatible with least squares
techniques has not yet been developed. Because trend, or technological advance, is an important theoretical component of supply, it remains necessary to employ some type of trend removal technique for specifying technology.

This study analyzes the three aggregate output series studied by Griliches in 1960; total farm output, all crops production, and livestock and livestock products. In addition to straightforward dynamic modeling in an attempt to expand upon the methods and results achieved by Griliches, an attempt is also made to determine whether the aggregate agricultural market is characterized by irreversibilities. Both linear and log-linear models are employed in order to test the assumption that the log-linear model is a superior specification.

The next section discusses the problem of estimating irreversible supply functions. In as much as the model developed by Houck and the model developed by Traill, Colman, and Young represent the present level of theoretical advancement in the area of measuring irreversibilities, both of these models are discussed in relation to this research.

Specifying and Estimating Irreversible Supply Functions

The recent attention that has been paid to methods of testing for irreversibilities is largely the result of the attempt by Tweeten and Quance to test for differences between farmers' response to price increases and price decreases by simply splitting the price variable into separate rising price and falling price series. Wolffram
showed that this is an incorrect procedure unless the function is entirely reversible and suggested a method based upon first differences of the price and output variables. Houck developed a technique consistent with the Wolffram method, but operationally easier. Traill, Colman, and Young were critical of the Wolffram method on grounds of its implications for risk, and proposed an estimation procedure based upon establishing a separate series for the historical maximum observed price. Both the Houck and Traill et al. models have limitations in practice. This section discusses the nature of these limitations and theoretical adaptations of the models to fit a dynamic framework.

Houck showed that for a simple model with one independent variable

\[ \Delta y_i = a_0 + a_1 \Delta x'_i + a_2 \Delta x''_1, \quad i = 1, 2, \ldots, t, \]

where \( \Delta y_i = y_i - y_{i-1}, \Delta x'_i = x_i - x_{i-1} \) if \( x_i > x_{i-1} \) and = 0 otherwise, \( \Delta x''_i = x_i - x_{i-1} \) if \( x_i < x_{i-1} \) and = 0 otherwise.

By definition

\[ y_t = y_0 + \sum_{i=1}^{t} \Delta y_i, \]

so that

\[ y_t - y_0 = \sum_{i=1}^{t} \Delta y_i = a_0 t + a_1 (\sum_{i=1}^{t} \Delta x'_i) + a_2 (\sum_{i=1}^{t} \Delta x''_i). \]

By letting \( t = 1, 2, \ldots, m \) we have an estimable system of equations.

Assume that the model specification is given by

\[ X_t = \alpha + \delta t + \beta P_t + \phi W_t + \lambda E(X_{t-1}) + u_t. \]

By taking first differences as a discrete approximation of the total differential of \( X_t \) we have
\[(40) \quad \Delta X_t = \delta + \beta \Delta P_t + \phi \Delta W_t + \lambda \Delta E(X_{t-1}) + \Delta u_t.\]

Employing Houck's result gives

\[(41) \quad X_t - X_o = \delta t + \beta \Sigma_{1}^{t} \Delta P_i + \phi \Sigma_{1}^{t} \Delta W_i + \lambda \Sigma_{1}^{t} E(\Delta X_{i-1}) + \Sigma_{1}^{t} \Delta u_i.\]

It can easily be shown that

\[(42) \quad \Sigma_{1}^{t} E(\Delta X_{i-1}) = E(\Sigma_{1}^{t} \Delta X_{i-1}) = E(X_{t-1} - X_{-1}).\]

By defining \(X'_t = X_t - X_o\) and \(u'_t = \Sigma_{1}^{t} \Delta u_i\), equation (41) becomes

\[(43) \quad X'_t = \delta t + \beta \Sigma_{1}^{t} \Delta P_i + \phi \Sigma_{1}^{t} \Delta W_i + \lambda E(X'_{t-1}) + u'_t.\]

If an irreversible relationship is suspected with respect to price, then (43) can be represented by

\[(44) \quad X'_t = \delta t + \beta \Sigma_{1}^{t} \Delta P'_i + \beta \Sigma_{1}^{t} \Delta P''_i + \phi \Sigma_{1}^{t} \Delta W_i + \lambda E(X'_{t-1}) + u'_t,\]

where \(\Delta P'_i = P_i - P_{i-1}\) if \(P_i > P_{i-1}\) and = 0 otherwise, and \(\Delta P''_i = P_i - P_{i-1}\) if \(P_i < P_{i-1}\) and = 0 otherwise.

Houck pointed out the problems this type of model presents in terms of lost degrees of freedom and the tendency for the separated price variables to be highly correlated with each other and other trend like variables. Traill et al. established the problems associated with risk considerations. Cochrane's argument that it is technological change that creates irreversibilities in the supply relation and Burt's argument that irreversibility with respect to one variable suggests irreversibility with respect to most other variables bring to light the question of whether or not this model indeed specifies the proper irreversible relationship.

It is not clear just how an irreversibility with respect to
technological change could be specified when a monotonically increasing trend variable represents technology. It also seems very likely that an irreversibility with respect to increasing vs. decreasing output levels ought to enter a dynamic relationship. This consideration, however, presents considerable estimation problems for least squares techniques. Therefore, the simplified irreversibilities model represented by equation (44) is assumed for the purposes of this study.

Traill, Colman, and Young argued that any irreversibility ought to be with respect to the historical maximum price on the grounds that, in the short-run, the level of fixed assets existing on farms at any given time will be a function of the level employed during the period in which price, and therefore output, was greatest. The model they proposed is given in equation (18) of Chapter 2 above. This model is adaptable straightforwardly to a dynamic model such as

\[ X_t = \alpha + \beta P_{t} + \beta \frac{p_{t}^{\text{max}}}{2} + \delta t + \lambda E(X_{t-1}) + u_t. \]

Such a model, however, is strongly dependent upon the relative time of the appearance of the absolute maximum price for the sample period. Should this maximum value appear quite early in the data, then the maximum price series remains constant at this value for a large part of the sample, and the maximum price variable will be highly correlated with the constant term \( \alpha \) in the estimation process.

It seems apparent that there has been insufficient testing of the hypothesis that irreversibilities with respect to price characterize
agricultural supply. Tweeten and Quance performed the only empirical test of this hypothesis for the aggregate, although their methodology appears to be inadequate for least squares techniques. The two separate methods discussed in detail in this section are somewhat representative of the state-of-the-art in econometrics for testing for irreversibilities. Notwithstanding the fact that there are potentially severe limitations to both models, these two methods represent the most promising techniques for the purposes of this study. Therefore, the adaptations of the models represented by equations (44) and (45) above are employed in this research in an attempt to test the three aggregate farm supply functions for irreversibilities with respect to price.

The Data, How It Was Constructed, and Some Limitations

This section presents a description of the data used in this study, a brief summary of how it was constructed and a discussion of some limitations to which interpretation of the data is subject with regard to supply analysis.

Output is measured by the USDA Agricultural Research Service's Index of Farm Output for the aggregate farm output model, the Index of the Output of All Crops for the all crops model, and the Index of Output of Livestock and Livestock Products for the livestock model. Prices received by farmers and prices paid for production items, wages, taxes, and interest were obtained from the USDA series Agricultural Prices. The effects of weather on total farm output and all crops production is
measured by Stallings' respective weather indexes. Technological ad-
vance is estimated through the use of a linear trend variable (although
attempts were made during the course of this research to specify tech-
nology through several means, including an index of lagged expected out-
put per unit of input, a quadratic trend variable, a logarithmic trend,
and a quadratic in a logarithmic trend variable).

The description of the construction of the aggregate price and
output indexes which follows below is taken largely from the USDA [80]
publication Major Statistical Series of the U. S. Department of Agri-
culture: How They Are Constructed and Used. The reader is referred to
this reference for a more detailed discussion.

The indexes for crop production, livestock and livestock products
output, and total farm output are calculated by the weighted aggregate
method in which the quantity of an individual farm product each year
is multiplied by a fixed price as a weight. Four weight base periods
have been used in calculating the indexes: 1935-39 average prices for
1940 and prior years, 1947-49 average prices for the period 1941 through
1954, 1957-59 average prices for the period 1955 through 1964, and
1971-73 for the period 1965 to the present. Each series is "spliced"
together in 1940, 1955, and 1965 through the use of overlapped calcu-
lations for those years. The indexes of crop and livestock production
are combined through the "product added" method to form the index of
total farm output. This method involves a deduction for feeds consumed
during the year and a deduction for crops grown solely for the purpose of seed production, both measured in terms of constant dollar values. The aggregate for each series is extended back to 1910 in two steps. First, production of a given commodity in each of the years 1910-1918 is expressed as a percent of the 1919 production level. Second, these percentages are multiplied by the 1919 quantity-price aggregate for the commodity. The weighted sum of these products for all commodities represents the total output index for each of the respective years 1910-1918.

The indexes of prices received by farmers for all farm products, all crops, and livestock and livestock products are modified fixed quantity weighted (laspeyres) indexes. Some modifications include: (1) items that are not included in the indexes are added to items that are in the indexes through a quantity weighting scheme; (2) four weight base periods are used, 1924-29 for the period 1910 through 1934, 1937-41 for the period 1935 through 1951, 1953-57 for the period 1952 through 1964, and 1971-73 for the period 1965 to the present; and (3) the indexes using the separate weight periods are linked together in 1935, 1952, and 1965 to provide a continuous series. The index numbers are a measure of the change in average prices for important agricultural commodities at their point of first sale out of farmers' hands. Data is collected mainly from voluntary price reporters, who are generally buyers of farm products. Seasonal patterns of price movements for
individual commodities appear to largely offset each other, hence, there is no seasonal adjustment for the indexes of prices received for all crops, livestock and livestock products, and total farm output.

The index of prices paid for items used in production, wages, taxes, and interest is calculated in a manner similar to the prices received indexes. Weight base periods are the same for this index as for the prices received indexes. This index differs from the official "parity index" in the fact that "prices paid for items used in living" are excluded.

The pioneering effort by Stallings to construct indexes for the influence of weather on agricultural output provided the only comprehensive set of such indexes available to analysts to date. The index covers the period from 1900 to 1957. Attempts to update the series have met with little success. The basic method used to derive the indexes was to employ data on yields from experimental plots where all factors other than weather are held as constant as possible in a time series regression with a linear trend accounting for fertility increases or decreases over time.

The first problem associated with employing aggregate data to estimate supply relationships results from the fact that it must be assumed that the aggregated indexes are, in fact, meaningful representations of the desired variables. It is obvious that farmers do not observe the "average price level" for all farm products and attempt to
raise an appropriate mix of all crops and livestocks. The true relationships are defined in terms of individual commodities and the prices for those products as well as for substitutes, factors of production, etc. The aggregate relationship would be defined, then, by a system of simultaneous equations measuring the direct and cross effects of all the variables specified. A relationship between a group of aggregated indexes, with various weights defining incongruent time spans in which the structure of each of the several agricultural indexes is implicitly assumed to hold itself constant, can hardly be regarded as providing anything more than a crude estimate of the order of magnitude of the agricultural supply elasticity for the aggregate.

Estimation of an aggregate national index for the impacts of weather on total U. S. farm production, or all crops production, inherently involves several problems due to the necessity for subjective judgments in the estimation process. This is witnessed by the fact that attempts to reproduce and update the indexes developed by Stallings have met with virtually no success. Nevertheless, the value of such an index for estimation problems is made obvious by the evidence from empirical studies which have consistently found Stallings' weather variable to be significant (statistically) and relevant in explaining the observed variation in farm output levels.

Another problem associated with the manner in which the aggregate
price series indexes are calculated arises from the fact that there is no provision made for the impacts of governmental price supports and subsidy programs in the indexes. Since World War II the federal government has actively participated in farm programs aimed at stabilizing prices and output for agriculture, mainly in the area of the major crops grown in the United States. Two main effects result in the aggregate. The government programs remove much of the risk faced by farmers at planting time, tending to lead to greater farm output. However, the price supports and subsidy programs are not reflected in the calculated indexes of prices received, which creates a problem with regard to the relevant price variables for the total farm output and all crops models subsequent to World War II. The second effect arises from the stabilization programs and their influence on planned output levels. An example of this can be seen in the area of irrigated agriculture, where most federal irrigation projects are heavily subsidized. The additions of low-cost irrigation water to many acres of farmland tends to increase output extensively. This factor is not reflected in the index of prices paid for production items, nor is it accurately reflected in the model for planned output response.

Although the indexes of farm output might reflect to some extent the effects of production control measures and farm subsidy programs, there is a completely spurious effect on the indexes of prices received by farmers. As a result, there is a considerable conceptual problem
associated with estimating an aggregate relationship for total farm output and all crops production subsequent to 1952 to 1953 (Just, [47]: p. 23) when the index of prices received for total farm output, or the index of prices received for all crops, is assumed to be the relevant price variable.

Summary

In this chapter we have developed a dynamic model for estimating agricultural supply in the aggregate. The model is based on the argument that asset fixity, producer momentum, habit persistence, or adjustment costs arise from the systematically explained components of established output levels. It is therefore assumed that only the systematic level of output leads to a dynamic relationship such as the partial adjustment model. Methods were also developed to test for irreversibilities with respect to price in the aggregate agricultural supply relation. The methods are based upon the models of Houck and of Traill, Colman, and Young. The chapter is concluded with a short description of the data employed, the manner in which it was constructed, and a discussion of some limitations on interpreting the results of this study based upon the use of this aggregate data.

The next chapter contains the empirical results from the models employed during this research. The first three sections of the chapter discuss the estimated relationships from straightforward dynamic modeling of total farm output, all crops production, and output of
livestock and livestock products, respectively. The fourth section summarizes the results obtained from attempting to test the aggregate relationship for irreversibilities with respect to price via the models developed from the Houck technique and the Traill, Colman, and Young technique. The final section contains a brief overview of the results and conclusions from this research.
Chapter 4

RESULTS AND CONCLUSIONS

The previous chapter developed the theoretical basis for this study. The distributed lag model for aggregate agricultural supply incorporates lagged values of the mathematical expectation of output to estimate the dynamics of the adjustment relationship. Estimation of the regression parameters is accomplished through the use of a nonlinear least squares algorithm which calculates maximum likelihood estimators under normality assumptions for the disturbances.

This chapter summarizes the results achieved in this study. The chapter is divided into five sections. The first section presents the main results from the estimated relationship for aggregate farm output. The second section contains the results from the all crops production study. The third section then summarizes the livestock and livestock products study. An attempt was made to test the aggregate supply function for irreversibilities with respect to price. The results of this effort appear in the fourth section of this chapter. The final section of this chapter reviews the main results obtained during the course of this research, completing the thesis with a discussion of the possible implications and interpretation to which this research might be subject.
Aggregate Farm Output

Total farm output was estimated with a linear specification and a log-linear specification with a linear trend. The period 1921-1957 was chosen as one sample period in order to make comparisons with the results from the work of Griliches in 1960. The year 1921 appears to represent a reasonable starting point for several reasons. World War I had ended and aggregate demand had been able to reach a more normal level by 1921. Figure 1 presents the "real price" variable employed in this study, the index of prices received for all farm products deflated by the index of prices paid for items used in production, wages, taxes, and interest. Note that this real price index maintained relatively high levels during the periods for World Wars I and II, but remains comparatively low during peacetime periods. It also seems apparent that this price variable lacks much explanatory power subsequent to about 1952. This marks the beginning for active intervention by the federal government in the agricultural market. This makes the choice of 1957 as a relevant endpoint for an agricultural supply sample rather dubious.

The somewhat ad hoc percentage weighting scheme employed by the USDA to extend the price and output indexes backwards from 1919 to 1910 provides another possible reason for starting the sample in 1921. The fact that the second constant weight base period for prices ends in 1951, and for output ends in 1954 provides a basis for ending the
Figure 1. RATIO of the INDEX of PRICES RECEIVED for ALL FARM PRODUCTS to the INDEX OF PRICES PAID for ITEMS USED in PRODUCTION, WAGES, TAXES, and INTEREST 1910-1977.
sample period in 1951. Therefore, a second sample 31 years in length was chosen to be the period 1921-1951.

Griliches attempted to estimate the total farm output relationship for the sub-periods 1921-1934 and 1935-1957, without a great deal of success. Likewise, attempts to estimate a relationship for these periods were not particularly successful in this study. Attempts were also made during this research to estimate aggregate farm output for the period 1921-1941 in order to bypass the abnormal effects of World War II and to estimate a relationship for the period 1947-1975. The model was extremely unstable in both the log-linear and linear specifications for all of these periods, often resulting in coefficients for price, trend, and/or lagged output with theoretically incorrect signs. During the period 1921-1941, the coefficient on lagged output exceeded unity for every specification that was tested, while for the period 1935-1957, this coefficient was negative in the log-linear model but positive and greater than one in the linear model. Therefore, there is no effort made here to estimate elasticities for these periods.

Figure 2 provides a graphical representation of Stallings' index for the impact of weather on total farm output for the period 1910-1957. Figure 3 shows the time path followed by the index of total farm output from 1910 to 1977. The results obtained from estimating the relationship for aggregate agricultural supply are presented in Table 2.

Several characteristics of these results are noteworthy. In both
Figure 2. INDEX of the IMPACT of WEATHER on TOTAL FARM OUTPUT 1910-1957.

Figure 3. INDEX of TOTAL FARM OUTPUT 1910 - 1977 (1967 = 1,00)

Table 2. Aggregate Farm Output Results Summary

<table>
<thead>
<tr>
<th>Linear Model</th>
<th>Coefficients of *</th>
</tr>
</thead>
<tbody>
<tr>
<td>1921-1951</td>
<td></td>
</tr>
<tr>
<td>March Price, $Y_{t-1}$</td>
<td>0.227 (0.037)</td>
</tr>
<tr>
<td>March Price, $E(Y_{t-1})$</td>
<td>0.197 (0.036)</td>
</tr>
<tr>
<td>March Price, $E(Y_{t-1}), 	ext{No Trend}$</td>
<td>0.210 (0.038)</td>
</tr>
<tr>
<td>Annual Price, $Y_{t-1}$</td>
<td>0.219 (0.036)</td>
</tr>
<tr>
<td>Annual Price, $E(Y_{t-1})$</td>
<td>0.207 (0.044)</td>
</tr>
<tr>
<td>Annual Price, $E(Y_{t-1}), 	ext{No Trend}$</td>
<td>0.217 (0.041)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Log-Linear Model</th>
<th>Coefficients of *</th>
</tr>
</thead>
<tbody>
<tr>
<td>1921-1951</td>
<td></td>
</tr>
<tr>
<td>March Price, $Y_{t-1}$</td>
<td>0.189 (0.036)</td>
</tr>
<tr>
<td>March Price, $E(Y_{t-1})$</td>
<td>0.192 (0.036)</td>
</tr>
<tr>
<td>March Price, $E(Y_{t-1}), 	ext{No Trend}$</td>
<td>0.201 (0.036)</td>
</tr>
<tr>
<td>Annual Price, $Y_{t-1}$</td>
<td>0.197 (0.037)</td>
</tr>
<tr>
<td>Annual Price, $E(Y_{t-1})$</td>
<td>0.203 (0.037)</td>
</tr>
<tr>
<td>Annual Price, $E(Y_{t-1}), 	ext{No Trend}$</td>
<td>0.201 (0.036)</td>
</tr>
</tbody>
</table>

| 1921-1957 |                   |       |              |             |                         |               |
| March Price, $E(Y_{t-1})$ | 0.410 (0.062) | 0.007 | 0.502 | -0.388 | 0.04 | 0.08 | 0.961 | 0.952 |
| March Price, $E(Y_{t-1}), 	ext{No Trend}$ | 0.363 (0.067) | 0.002 | 0.819 | -0.771 | 0.07 | 0.32 | 0.952 | 0.942 |
| March Price, $E(Y_{t-1}, 	ext{Trend})$ | 0.388 (0.063) | 0.038 | 1.007 | -0.407 | 0.04 | 0.39 | 0.944 | 0.935 |
| Annual Price, $E(Y_{t-1})$ | 0.385 (0.064) | 0.007 | 0.472 | -0.405 | 0.08 | 0.15 | 0.963 | 0.955 |
| Annual Price, $E(Y_{t-1}, 	ext{Trend})$ | 0.372 (0.073) | 0.039 | 0.699 | -0.130 | 0.11 | 0.37 | 0.953 | 0.942 |
| Annual Price, $E(Y_{t-1}, \text{No Trend})$ | 0.404 (0.069) | 0.058 | 0.980 | 0.352 | 0.06 | 0.53 | 2.90 | 0.942 |

*Numbers in parentheses indicate standard errors. Elasticities are calculated at the sample means for the linear model. Ten-year elasticities are the products of the short-run elasticities and the sum (I9 X1), where x is the coefficient for lagged output.
the linear and log-linear models for the period 1921-1951, the coefficient of determination ($R^2$) and the adjusted coefficient of determination ($\bar{R}^2$) decreases somewhat when the mathematical expectation of lagged output is employed relative to the models using the observed value of lagged output. Although this appears to be somewhat suggestive that the observed output model may be a more precise specification, the two models are not members of a nested family of hypotheses and a statistical test for the correct model does not appear feasible (other than a subjective comparison of the $R^2$'s).

In the models employing the observed value of lagged output, serial correlation enters significantly negative. This implies that a positive disturbance in one period is likely to be followed by a negative disturbance the next period. It is important to note that serial correlation is an important factor in the models with lagged observed output, while it is generally not significantly different from zero in the models employing expected values of lagged output and including trend. Although positive serial correlation is often interpreted to indicate omitted explanatory variables, there is no commonly accepted explanation for negative serial correlation. This consideration seems to lend more credence to the model employing the mathematical expectation of lagged output.

Another important comparison between the two models arises from the statistical precision achieved in estimating the impacts of the
explanatory variables. The price variable consistently seems to lack statistical significance in the set of models using observed output for both March and lagged average annual prices and in both the linear and log-linear specifications. However, when the expected value of lagged output is employed, both the price coefficient and the coefficient on lagged output increase in magnitude and statistical precision, while the trend coefficient generally moves toward zero and becomes less important in terms of explanatory power. The weather variable remains remarkably stable and quite important throughout the entire series of model specifications.

The high degree of collinearity between trend and lagged output found by Griliches is increases when the expected value of lagged output is employed. Because of this collinearity, the calculated standard error for trend is not of much use for testing the statistical significance of the trend coefficient in small samples due to the nonlinear nature of the model. Some evidence from Monte Carlo experiments (see Gallant, [28]) indicates that a likelihood ratio test provides a superior approximation to the asymptotic linear normal distribution theory than the linearly approximated T-ratio. Therefore, regressions were estimated for each period and price variable (March and lagged average annual) with trend omitted in order to calculate an F-statistic based upon the difference between the residual sum of squares without trend versus with trend. The likelihood ratio formed by taking this
difference and dividing by the residual sum of squares for the model with trend (divided by the number of degrees of freedom for that model) can be tested against the relevant table value for the F distribution. In every case the null hypothesis that the models with and without trend are identical was tested at the 5 percent significance level. The critical values for the F-statistics are as follows:

\[ F_{.05,1,24} = 4.26 \quad \text{and} \quad F_{.05,1,31} = 4.16 \]

The hypothesis was rejected at the 5 percent confidence level for the annual price model in the period 1921-1951 for both the linear and log-linear specifications and in the period 1921-1957 for the log-linear specification. The hypothesis was rejected for the March price model in the period 1921-1957 for the log-linear specification only.

Because the price and lagged output coefficients both tend to increase in magnitude when the expected value of lagged output is employed in the regression model, both short-run and long-run price elasticities tend to increase relative to their estimated values with lagged output. The omission of the trend variable further tends to increase the coefficients for the lagged output variable, resulting in even greater estimates for the long-run elasticities. In the period 1921-1951, this effect resulted in an unstable model due to the fact that the coefficient on lagged output exceeds unity, which implies that the long-run elasticity is infinite.

The results in Table 2 do not appear to prove any significant differences between a linear specification and a log-linear specification,
nor does there seem to be an unreasonable change in the results when the lagged average annual price is employed rather than March prices for the current year. The argument that farmers attempt to predict fall prices in the spring based upon current price developments seems quite plausible for crop production. For livestock production, however, the lagged average annual price seems to be the relevant price variable. Because total farm output is a combination of crops and livestock production, this researcher leans more favorably on the use of the lagged average annual price variable, particularly since the results are quite comparable.

It seems quite clear that the use of observed output to represent planned output in a regression equation will usually result in errors in variables bias on the coefficient for lagged output, and therefore on the estimated values for long-run elasticities. It also seems evident that the use of an infinite adjustment horizon to estimate long-run elasticities does not produce very useful results in terms of the length of time a given price change is maintained and the amount of time required for adjustments to be completed in response to a single change in prices. Therefore, the elasticity estimates for an infinite number of years ought to be discounted severely when the results of this analysis are interpreted.

Assuming that we can accept the errors in variables argument when observed output is used to estimate planned output, then the model using
expected values of lagged output might be acceptable as a reasonable approach to estimating the upper limit of the bias introduced by using observed output to estimate planned output. The results contained in Table 2 would represent estimates of the range that the elasticity of supply for total farm output is contained in under these conditions. For the period 1921-1951 and the linear model, the short-run elasticity falls within the interval 0.05 to 0.12, while the price elasticity after ten years have passed and adjustments have been made is between 0.12 and 0.43. For the log-linear model during the period 1921-1951, the short run elasticity lies between 0.04 and 0.11, while the ten-year elasticity falls in the interval 0.08 to 0.39. For the period 1921-1957, the upper limit on the ten-year elasticity might be as high as 0.44 if we accept the linear model, or 0.42 if we accept the log-linear model. Combining these estimates into a single pair of elasticity ranges, it appears that the price elasticity of aggregate agricultural output is between 0.05 and 0.10 in the short-run and between 0.10 and 0.40 after ten years have been allowed for adjustment lags.

Several attempts were made during the course of this research to modify the specification of the aggregate agricultural supply function. Output was lagged two and three years, prices were lagged up to three years, and technology was estimated through the use of lagged expected output divided by the index of total farm inputs, all without significant improvement in the results reported here. Perhaps this inability to
distinguish between model specifications is largely attributable to the fact that the aggregate output indexes are often only two digit figures and are not extremely precise measures of the desired variables. Attempts were made in the crops and livestock studies to estimate more general distributed lag relationships in a manner similar to that employed while analyzing total farm output. Results from these attempts did not prove to provide significant improvements over the results with a first order difference equation in output, and are not discussed in the following sections.

**All Crops Production**

Figure 4 shows the graphical relationship of the time path for the "real price" series employed in the all crops study. Figure 5 presents the index of the impact of weather on all crops production, while Figure 6 shows the index of all crops production. The same problem as to how to select a sample period appropriately presented itself in the all crops study as in the total farm output study. Stallings' weather index covers the period from 1900 to 1957. The price and output series begin in 1910 and continue to the present, although the first nine years of data are of dubious value. The urge is strong to employ as much data as possible in a single sample, as did Griliches in his use of the period 1911-1958. However, it has been asserted by Just [47] that governmental intervention in the crop producing sector accelerated rapidly after 1952 (Just, [47]: p. 23). This
Figure 4. RATIO of PRICES RECEIVED for ALL CROPS to PRICES PAID for ITEMS USED in PRODUCTION, WAGES, TAXES, and INTEREST 1910-1977.
Figure 5. INDEX of the IMPACT of WEATHER on ALL CROPS PRODUCTION 1910-1957

Figure 6. INDEX of ALL CROPS PRODUCTION 1910-1977  
(1967 = 1.00)

intervention, coupled with the fact that subsidies are not measured in the index of prices received, eliminates the explanatory power of the price index calculated by the USDA, as is witnessed by the steady and rather smooth downward path of the real price variable represented in Figure 4 subsequent to 1952. The weight base period for calculating the price indexes also changes in 1952. The manner in which the price and output indexes are extended back to 1910 causes some doubt to exist as to whether the first nine years of data are relevant. When all of these factors are taken into consideration, it seems reasonable to select a sample period that covers the period 1921-1951. Therefore, two periods were specified, 1911-1957 and 1921-1951. The results are summarized in Table 3.

The hypothesis that trend is not significantly different from zero is rejected in every case at the 5 percent significance level. The critical values for the F-statistics are as follows:

\[ F_{0.05,1,24} = 4.26 \quad \text{and} \quad F_{0.05,1,40} = 4.08 \]

The calculated values for F exceeded the critical values by a considerable amount for every model specification in which trend was tested. Therefore, the results from the models omitting trend should be discounted heavily when interpreting the results presented in Table 3.

Note that the models employing the mathematical expectation of lagged output perform comparably with the models employing the observed values of lagged output in terms of "goodness of fit", particularly
Table 3. All Crops Production Results Summary

<table>
<thead>
<tr>
<th>Linear Model</th>
<th>Coefficients of *</th>
<th>1921-1951</th>
<th>Real Weather Price Trend Legged Output Serial Corr. S.E.</th>
<th>10 yr.</th>
<th>00</th>
<th>908</th>
<th>889</th>
</tr>
</thead>
<tbody>
<tr>
<td>March Price,</td>
<td>.319 (0.093)</td>
<td>.004 (0.009)</td>
<td>.003 (0.009)</td>
<td>.003 (0.009)</td>
<td>.003 (0.009)</td>
<td>.003 (0.009)</td>
<td>.333 (0.105)</td>
</tr>
<tr>
<td>E(T&lt;sub&gt;-1&lt;/sub&gt;)</td>
<td>(.004)</td>
<td>(.004)</td>
<td>(.004)</td>
<td>(.004)</td>
<td>(.004)</td>
<td>(.004)</td>
<td>(.004)</td>
</tr>
<tr>
<td>March Price,</td>
<td>.340 (0.096)</td>
<td>.006 (0.017)</td>
<td>.012 (0.0058)</td>
<td>.006 (0.017)</td>
<td>.006 (0.017)</td>
<td>.006 (0.017)</td>
<td>.333 (0.105)</td>
</tr>
<tr>
<td>E(T&lt;sub&gt;-1&lt;/sub&gt;)</td>
<td>(.006)</td>
<td>(.006)</td>
<td>(.006)</td>
<td>(.006)</td>
<td>(.006)</td>
<td>(.006)</td>
<td>(.006)</td>
</tr>
<tr>
<td>March Price,</td>
<td>.409 (0.046)</td>
<td>.018 (0.043)</td>
<td>.108 (0.043)</td>
<td>.018 (0.043)</td>
<td>.018 (0.043)</td>
<td>.018 (0.043)</td>
<td>.333 (0.105)</td>
</tr>
<tr>
<td>E(T&lt;sub&gt;-1&lt;/sub&gt;)</td>
<td>(.046)</td>
<td>(.046)</td>
<td>(.046)</td>
<td>(.046)</td>
<td>(.046)</td>
<td>(.046)</td>
<td>(.046)</td>
</tr>
</tbody>
</table>

Elasticities:
- 10 yr. 00
  - T<sub>-1</sub> March Price, (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022)
  - E(T<sub>-1</sub>) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022)
  - Serial Corr. (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022)
  - Price S.R. (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022) (.022)

- 10 yr. 00
  - March Price, (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076)
  - E(T<sub>-1</sub>) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076)
  - Serial Corr. (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076)
  - Price S.R. (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076) (.0076)

Numbers in parentheses indicate standard errors. For the linear model, elasticities are calculated about the sample means. Two-year elasticities are estimated as the products of the short-run elasticities and the sum (∑<sub>t=1</sub><sup>T-1</sup>)<sup>−1</sup>, where 1 is the coefficient for lagged output.
when March price is specified. However, in the models with lagged observed output, serial correlation is significantly different from zero in every case and negative in three of the four cases presented in Table 3, whereas serial correlation is not a significant factor in any of the models employing the expectation of lagged output and including trend. This consideration tends to indicate that the models using expected values of lagged output are somewhat superior at least with respect to the properties of the error terms. The March price series appears to be significantly superior to the lagged average annual price series for the all crops model, although no attempt is made here to "accept" or "reject" either specification as representing the "true" model.

As with the total farm output study, there does not appear to be evidence for distinguishing between the linear and log-linear models. Both appear to perform in quite remarkably similar manners, particularly with respect to elasticity estimates. For this study, the long-run price elasticities appear to be very similar to the ten-year elasticities. When the results from the models omitting trend are ignored, the range for the short-run elasticity of supply appears to be 0.05 to 0.08, while the range for the price elasticity of supply after ten years has been allowed to pass for adjustment lags appears to be 0.10 to 0.30. These results seem to hold quite well for the entire set of models and sample periods.
Several other sample periods were analyzed, much the same as for the total farm output study. Also, several attempts were made to estimate a more general distributed lag functional form. The results of these efforts were very similar to the results for the total farm output study, and are therefore not included in this summary.

Livestock and Livestock Products

The livestock producing sector of agriculture has remained considerably freer from government intervention throughout the recent few decades than crop production has. Also, the production of livestock is much less dependent upon weather than crop production. Because of these factors, efforts to estimate the supply function for livestock and livestock products subsequent to World War II were much more successful than efforts to estimate a relationship during this period for total farm output or all crops production. The choice of sample periods is much less restrictive for the livestock study than the total farm output and all crops studies. Although several periods were analyzed with reasonably good results, only four periods are included in this summary: 1911-1958, 1921-1951, 1921-1975, and 1947-1975.

Figure 7 presents the graphical representation of the time paths for the "real" price of livestock and the "real" price of feed, both lagged annual averages, for the period 1910-1977. Both the index of prices received for livestock and the index of prices paid for feed
Figure 7. RATIO of INDEXES of PRICES RECEIVED for LIVESTOCK and LIVESTOCK PRODUCTS and PRICES PAID for FEED to INDEX of PRICES PAID for ITEMS USED in PRODUCTION, WAGES, TAXES, and INTEREST 1910 - 1977 (lagged one year).
are deflated by the index of prices paid for items used in production, wages, taxes, and interest. Figure 8 shows the time path of the ratio of the index of prices received for livestock to the index of prices paid for feed 1910-1977, lagged one year. One regression model for the index of the output of livestock and livestock products treated prices received for livestock and prices paid for feed separately, while another model employed the ratio of prices received for livestock and livestock products to prices paid for feed as the relevant price variable. The time path of the index of the output of livestock and livestock products is presented in Figure 9.

The results from the analysis of livestock and livestock products are summarized in Table 4. As in the total farm output and all crops studies, both linear and log-linear models were employed. The hypothesis that trend is not significant from zero was tested for each specification via an F-statistic calculated from the likelihood ratio formed by taking the difference of the residual sum of squares between the model with and without trend (divided by one) and dividing this value by the residual sum of squares for the model with trend over the degrees of freedom for this model. The critical F-statistic values at the 5 percent significance level are as follows:

\[ F_{0.05,1,40} = 4.08 \]  
\[ F_{0.05,1,41} = 4.08 \]
Figure 8. RATIO of PRICES RECEIVED for LIVESTOCK and LIVESTOCK PRODUCTS to PRICES PAID for FEED LAGGED ONE YEAR 1910-1977.
Figure 9. INDEX of the OUTPUT of LIVESTOCK and LIVESTOCK PRODUCTS 1910-1977, (1967 = 1.00)

Table 4. Livestock and Livestock Products Results Summary

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Lvstk</td>
<td>Feed</td>
<td>Lvstk/Feed</td>
<td>Feed</td>
</tr>
<tr>
<td></td>
<td>Price</td>
<td>Price</td>
<td>Price Ratio</td>
<td>Price</td>
</tr>
<tr>
<td>Separate Prices</td>
<td>.106</td>
<td>-.126</td>
<td>.0033</td>
<td>-.126</td>
</tr>
<tr>
<td>Without Trend</td>
<td>(.041)</td>
<td>(.046)</td>
<td>(.0027)</td>
<td>(.046)</td>
</tr>
<tr>
<td></td>
<td>.0048</td>
<td>.610</td>
<td>.839</td>
<td>.839</td>
</tr>
<tr>
<td></td>
<td>(.027)</td>
<td>(.270)</td>
<td>(.080)</td>
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Table 4, continued. Livestock and Livestock Products Results Summary

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* Numbers in parentheses indicate standard errors. Elasticities are calculated as they are in the Aggregate Farm Output and All Crops studies above.
1921-1951 and 1947-1975

Separate Prices, \( F_{05,1,24} = 4.26 \)
Price Ratio, \( F_{05,1,25} = 4.24 \)

1921-1975

Separate Prices, \( F_{05,1,48} = 4.05 \)
Price Ratio, \( F_{05,1,49} = 4.04 \)

In the linear model, the hypothesis that the coefficient on trend is not significant from zero is rejected at the 5 percent level in all cases except for the period 1911-1958 where it cannot be rejected for either price specification and the period 1947-1975 where it cannot be rejected for the separate prices specification. In the log-linear model, the hypothesis is rejected in all cases except for the separate price specification in the period 1947-1975. These results differ substantially from the inferences based only upon T-ratios since the estimated coefficient on trend was seldom enough larger than the corresponding standard error to result in a T-test rejecting the hypothesis that the trend coefficient is insignificant from zero. Due to this result and the result previously that trend is consistently significant from zero in the all crops models, the results for the aggregate farm output study in which trend was omitted should most likely be discounted severely. This follows directly from the fact that total farm output is merely the aggregation of all crops production and the
output of livestock and livestock products, both of which are characterized by significantly positive trends. Even if trend were insignificant statistically, it ought to remain in the model because technology is such a theoretically important factor of supply.

For the period 1921-1951, estimates were made employing the observed value of lagged output in order to make a comparison between models. The results of this effort are presented in Table 5.

In comparison with the results from the model employing the expected value of lagged output for the same period, the results in Table 5 seem to verify the assertion that the distinction between planned and observed output is more important for crop production than for livestock production. This seems to make a good deal of sense, at least heuristically. Livestock production is much less dependent upon weather than crop production. Also, even though unanticipated disease and death losses are likely to vary somewhat across firms, the average for the entire country is probably quite stable over time, resulting in a much smaller difference between planned and actual output levels for livestock than for crops. Therefore, the livestock model ought to perform similarly, except for the nature of the disturbance term, when observed or expected values of lagged output enter the relationship as an additional explanatory variable. This appears to be at least somewhat verified by the results of this study. The implication is that the nature of the individual problem at hand and the
Table 5. Livestock and Livestock Products, 1921-1951

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<td>Price Ratio, $Y_{t-1}$</td>
<td>.155 (.048)</td>
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Log-Linear Model

| Separate Prices, $Y_{t-1}$ | .282 (.080) | -.257 (.089) | 0.0044 (.0024) | .605 (.134) | .166 (.276) | .28 | .70 | .71 | .960 | .951 |
| Price Ratio, $Y_{t-1}$ | .273 (.079) | .0046 (.0024) | .608 (.130) | .160 (.275) | .27 | .69 | .70 | .959 | .953 |

*Numbers in parentheses indicate standard errors.
theoretical basis for the adjustment process ought to play an important role in the selection of a dynamic specification.

There does not appear to be any large distinction between the results obtained with a linear model and the results from a log-linear model. The livestock model remains remarkably stable throughout the analysis under both specifications, except for the period 1947-1975 with prices received for livestock and prices paid for feed treated separately and trend included. For the period 1911-1958, the short-run elasticity is about 0.17-0.2 and the long-run (ten-year) elasticity lies between 0.4 and 0.8. For the period 1921-1951, the short-run elasticity appears to fall between 0.27 and 0.31, while the long-run elasticity is in the neighborhood of 0.69-0.84. During the period 1921-1975, the short-run elasticity ranged between 0.17 and 0.19, while the long-run elasticity fell within 0.37-0.40. Subsequent to World War II, the price elasticity of livestock supply seems to have fallen to about 0.11-0.12 in the short-run although the long-run elasticity remained at about 0.37-0.38. However, the distributed lag model was very unstable when separate prices were specified for this period, indicating that these estimates are not likely to be very reliable for the period 1947-1975.

An attempt was made to further estimate the aggregate livestock relationship for the period beginning in 1940 and ending in 1975. The ratio of total farm assets to total liabilities as of January 1 of the
current year was included as an explanatory variable. Figure 10 shows the time path of this variable. Table 6 presents the results of this regression for the periods 1940-1975 and 1947-1975. The asset to debt ratio appears to contain considerable information for the period 1940-1975 and for 1947-1975 when trend is excluded from the model. When trend is specified, it takes on a negative coefficient and the model becomes unstable, mainly because trend and lagged output are nearly perfectly collinear (parameter covariance -0.997). Without trend, results stabilize and appear to fall within reasonable range of the other periods specified.

Although a negative coefficient for trend seems to make very little sense, it may be possible to rationalize a negative coefficient on the ratio of assets to debts. What this variable may be tracking is a structural change in the livestock industry toward more intensive capitalization. As capital is accumulated, total debt increases relative to total assets, causing a decline in the ratio of assets to debts at the same time that output is expanding. In this respect, the ratio of assets to debts may also explain in part the role of trend, or technology, in the livestock industry since the Second World War.

Irreversibilities With Respect to Price

All three aggregate output series were tested via the Houck model and the Traill, Colman, and Young model for irreversibilities
Figure 10, RATIO of TOTAL ASSETS to TOTAL LIABILITIES on FARMS as of JAN. 1, 1940-1977.

Table 6. Results Summary for Livestock and Livestock Products with Asset to Debt Ratio

| Linear Specification | coefficients of * | 1940 - 1975 | | 1947 - 1975 | |
|----------------------|-------------------|-------------|-------------|-------------|
|                      | Lvstk Price       | Feed Price  | Lvstk/Feed  | Ratio of     | E(\(X_{t-1}\)) | Serial  | Price Elasticities | Mult | Adj. R² | R² |
| Separate Prices      | 0.069             | -0.184      | -.0071      | 0.0014       | 0.637        | 0.148     | 0.07        | 0.20  | 0.20    | 0.987 | 0.984 |
|                       | (.027) (.054)     |             | (.0019)     | (.0009)      | (.073)       | (.170)    |             |       |         |      |
| Separate Prices      | 0.068             | -0.216      | -.0062      | 0.0019       | 0.729        | 0.286     | 0.07        | 0.26  | 0.27    | 0.968 | 0.983 |
| Without Trend        | (.029) (.056)     |             | (.0019)     | (.0019)      | (.036)       | (.164)    |             |       |         |      |
| Price Ratio          | 0.053             | -0.010      | 0.0022      | 0.0009       | 0.614        | 0.228     | 0.08        | 0.24  | 0.24    | 0.985 | 0.982 |
|                      | (.020) (.0015)    |             | (.009)      | (.0009)      | (.085)       | (.167)    |             |       |         |      |
| Price Ratio          | 0.063             | -0.012      | 0.0012      | 0.0020       | 0.740        | 0.603     | 0.09        | 0.34  | 0.36    | 0.982 | 0.980 |
| Without Trend        | (.025) (.0020)    |             | (.0019)     | (.0020)      | (.044)       | (.137)    |             |       |         |      |
| 1947 - 1975          | 0.102             | -0.173      | -.010       | -.0059       | 1.129        | -0.083    | 0.10        | 1.83  | 0         | 0.991 | 0.988 |
| Separate Prices      | (.020) (.041)     |             | (.0026)     | (.0021)      | (.148)       | (.192)    |             |       |         |      |
| Without Trend        | 0.093             | -0.154      | -.011       | 0.0040       | 0.707        | 0.126     | 0.09        | 0.30  | 0.31    | 0.987 | 0.984 |
| Price Ratio          | 0.078             | -.020       | 0.0012      | (.0050)      | 0.573        | -0.186    | 0.11        | 0.26  | 0.26    | 0.991 | 0.989 |
|                      | (.014) (.0050)    |             | (.0059)     | (.0059)      | (.057)       | (.189)    |             |       |         |      |
| Price Ratio          | 0.069             | -.015       | 0.676       | 0.0029       | 0.127        | 0.10      | 0.30        | 0.31  | 0.987   | 0.985 |
| Without Trend        | (.017) (.0029)    |             | (.058)      | (.191)       |             |           |             |       |         |      |

* Numbers in parentheses indicate standard errors.
with respect to price. The model developed by Traill, Colman, and Young turned out to be rather infeasible for this study because the absolute maximum price appears very early in the data for total farm output and all crops production, while the straightforward model for livestock performed better than the model including a series of the historical maximum price. Therefore, this model is not discussed further here.

The results from estimating the modified Houck model for total farm output, aggregate crop production, and aggregate output of livestock and livestock products are presented in Tables 7, 8, and 9, respectively. Although these results appear suggestive that farmers respond differently to price increases than to price decreases, it was not possible in any of the estimated relationships to statistically infer that the hypothesis that the coefficient for increasing prices is significantly different from the coefficient for decreasing prices.

In the analysis of aggregate farm output, the trend variable was continuously negatively correlated with the decreasing price variable, had a negative coefficient in every case but one, and was not statistically significant in any specification. In fact, the adjusted coefficient of determination was not diminished when trend was omitted from any of the specifications. For these reasons, the models omitting trend are analyzed here. It appears that the short-run elasticity for
## Table 7. Modified Houck Model, Results Summary for Total Farm Output

**Linear Specification**

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*Numbers in parentheses indicate standard errors.

## Table 8. Modified Houck Model, Results Summary for All Crops Production

**Linear Specification**

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<td>.876</td>
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</tbody>
</table>

*Numbers in parentheses indicate standard errors.
Table 9. Modified Houck Model, Results Summary for Livestock and Livestock Products

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<tbody>
<tr>
<td>1911 - 1957</td>
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</tr>
<tr>
<td>Separate Prices</td>
<td>.216 (.069)</td>
<td>-.176 (.064)</td>
<td>-.100 (.059)</td>
<td>-.0016 (.0057)</td>
<td>.683 (.220)</td>
<td>.723 (.102)</td>
<td>.34 1.05 1.07</td>
<td>--- ---</td>
<td>.977</td>
<td>.973</td>
<td></td>
</tr>
<tr>
<td>Without Trend</td>
<td>.206 (.066)</td>
<td>-.185 (.059)</td>
<td>-.092 (.049)</td>
<td>.632 (.170)</td>
<td>.735 (.103)</td>
<td>.32  .86 .88</td>
<td>--- ---</td>
<td>.977</td>
<td>.974</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price Ratio</td>
<td>.100 (.039)</td>
<td>.700 (.086)</td>
<td>.818 (.086)</td>
<td>.19  .62 .62</td>
<td>.19  .62 .62</td>
<td>.62 .62 .976</td>
<td>.976</td>
<td>.973</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price Ratio Without Trend</td>
<td>.099 (.031)</td>
<td>.862 (.088)</td>
<td>.876 (.088)</td>
<td>.18 1.01 1.30</td>
<td>.15  .84 1.06</td>
<td>.976 .973</td>
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<td></td>
<td></td>
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<tr>
<td>1921 - 1951</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Separate Prices</td>
<td>.243 (.085)</td>
<td>-.118 (.091)</td>
<td>-.382 (.113)</td>
<td>-.0075 (.0067)</td>
<td>.789 (.166)</td>
<td>.519 (.156)</td>
<td>.38 1.63 1.80</td>
<td>.41 1.76 1.94</td>
<td>.956</td>
<td>.943</td>
<td></td>
</tr>
<tr>
<td>Without Trend</td>
<td>.178 (.071)</td>
<td>-.154 (.088)</td>
<td>-.299 (.113)</td>
<td>.681 (.129)</td>
<td>.645 (.140)</td>
<td>.28 .86 .88</td>
<td>.41 1.26 1.30</td>
<td>.955</td>
<td>.943</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price Ratio</td>
<td>.195 (.055)</td>
<td>.678 (.060)</td>
<td>.669 (.130)</td>
<td>.37 1.13 1.14</td>
<td>.26 .79 .79</td>
<td>.79 .957 .948</td>
<td>.957</td>
<td>.948</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price Ratio Without Trend</td>
<td>.188 (.041)</td>
<td>.665 (.124)</td>
<td>.673 (.135)</td>
<td>.36 1.05 1.06</td>
<td>.27 .79 .80</td>
<td>.79 .957 .950</td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

*Numbers in parentheses indicate standard errors.
increasing prices lies within .09-.14, the long-run elasticity for increasing prices is between .45 and .62, and the aggregate farm supply function is characterized by a short-run elasticity for decreasing prices of 0-.05 and a long-run elasticity for falling prices of at most .3. It is important to note, however, that these are extremely subjective estimates based only upon the estimated coefficients, and not upon statistical inferences.

Elasticities were calculated for those price coefficients found to be statistically different from zero at the 5 percent significance level. The dashes in the spaces for those elasticities not estimated imply that the respective price coefficient was not significantly different from zero at this level. The decreasing price series are always negative in sign, so that the coefficients on increasing and decreasing prices should both be theoretically positive, implying that output increases as prices rise and decreases as prices fall.

The all crops production sector of agriculture does not appear to be characterized by unresponsiveness to falling prices as much as total farm output, although there is some suggestion that irreversibilities do exist. Again basing estimates solely on the size of the estimated coefficients, it appears that the supply elasticity for crop production is about .06-.10 in the short-run and .27-.44 in the long-run for increasing prices, while the supply elasticity is 0-.08 in the short-run and at most .34 in the long run for decreasing prices.
In the analysis of livestock and livestock products, as in total farm output, trend was generally not significant, usually had a negative coefficient, and was highly correlated with the segmented price variables. Goodness of fit was not diminished when trend was omitted from the model. However, the results appear to produce conflicting evidence in regard to irreversible supply response. For the longer period, 1911-1957, output seems to be more responsive to livestock and feed price increases than decreases, while for the shorter period, 1921-1951, the opposite seems to be the case. When the ratio of livestock to feed prices is used, there does not appear to be any significant difference in response to increasing versus decreasing "real" prices. The overall test for livestock and livestock products is very inconclusive.

Conclusions and Implications

In this study an attempt has been made to estimate a dynamic relationship for the aggregate agricultural supply function and two sub-aggregates, all crops production and the output of livestock and livestock products. A theoretical model developing the approach whereby the mathematical expectation of lagged output rather than observed output enters the dynamic relationship was employed, and results indicate greater elasticity estimates than previous dynamic models. This approach ought to provide an estimate of the upper limit for the bias introduced by the use of lagged observed output in the model as an
estimate for planned output. In this respect, the results from the model developed in this thesis may represent an upper bound for the long-run elasticity of supply, while results from a model employing lagged observed output may represent a lower bound for the long-run elasticity of supply. If we can accept this assumption, then the results of this study tend to lead to the following estimates for aggregate agricultural supply elasticities:

<table>
<thead>
<tr>
<th>Elasticity Estimates</th>
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<tr>
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<tr>
<td><strong>Elasticity Estimates</strong></td>
</tr>
<tr>
<td><strong>Short-Run</strong></td>
</tr>
<tr>
<td>Total Farm Output</td>
</tr>
<tr>
<td>All Crops Production</td>
</tr>
<tr>
<td>Livestock and Livestock Products</td>
</tr>
<tr>
<td>1911-1951</td>
</tr>
<tr>
<td>1947-1975</td>
</tr>
</tbody>
</table>

These results compare with those achieved by Griliches in 1960 quite favorably. From his reported multiple correlation coefficients, we can infer the following coefficients of determination from his study:

<table>
<thead>
<tr>
<th></th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Farm Output 1921-1957</td>
<td>.958</td>
</tr>
<tr>
<td>All Crops Production 1911-1958</td>
<td>.882</td>
</tr>
<tr>
<td>Livestock and Livestock Products 1911-1958</td>
<td>.980</td>
</tr>
</tbody>
</table>

The results for this study are somewhat superior in terms of "goodness of fit", although this is largely due to the estimation of serial correlation in the models employing observed values of lagged output and to
the increased statistical significance of the price variables and of lagged output when expected values are employed. The results for livestock and livestock products are remarkably similar for the two studies.

The estimated long-run elasticities from Griliches' study are:

<table>
<thead>
<tr>
<th>Category</th>
<th>Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Farm Output</td>
<td>0.15</td>
</tr>
<tr>
<td>All Crops Production</td>
<td>0.23</td>
</tr>
<tr>
<td>Livestock and Livestock Products</td>
<td>0.70</td>
</tr>
</tbody>
</table>

All of these elasticity estimates fall within the range of the estimates for this study, tending to be towards the lower end of the ranges estimated through the use of the two separate models in this study. This seems to be appropriate, both from the standpoint of the downward bias in the results from Griliches' study due to the use of observed output to estimate planned output, and from the standpoint that the models employing lagged values of observed output were characterized by negative serial correlation in the total farm output and all crops studies, which leads to downward bias in the estimated coefficients.

It seems apparent that there is considerable theoretical justification for the use of distributed lag models employing the mathematical expectation of the lagged dependent variable as an explanatory variable. The results of this study seem to verify this model as a feasible and logical approach. However, there is no attempt made here to claim that this type of model is appropriate for every distributed lag model study. The major determinants of whether or not to use the type of model proposed in this study are the theoretical basis for the dynamic adjustment
and the nature of the specific problem at hand.

Attempts to test the three aggregate supply functions for irreversibilities, although somewhat suggestive, were largely inconclusive. However, it does seem that there is greater short-run response for the total farm output and all crops relations. The major conclusion of this research with regard to irreversibilities is that it can neither substantiate nor disprove the hypothesis that the aggregate farm supply function is characteristically more elastic for increasing prices than for decreasing prices. Much work is needed in this area, particularly towards accurate specification of technological change and development of a theory and estimation procedure that will permit a nonreversible adjustment relation for the agricultural supply curve.

A major implication of this study is that although the aggregate agricultural supply function seems to be highly inelastic, both in the short-run and the long-run, there is adjustment made on the part of farmers in response to changing prices. This study contributes much if it can be accepted as strong evidence against the hypothesis that farmers are totally unresponsive to changes in prices in either the short-run or the long-run.
BIBLIOGRAPHY


LaFrance, Jeffrey T
Estimating the aggregate U.S. agricultural supply function