Estimating the aggregate U.S. agricultural supply function
by Jeffrey Thomas LaFrance

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Applied Economics
Montana State University

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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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 uncertainities. 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 curve:

> "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 avriables 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

(1) $Y_t = \alpha\Sigma_0^\infty\lambda^i X_{t-i} + u_t$, $0 < \lambda \leqq 1$

can be reduced to

(2) $Y_t = \alpha X_t + \lambda Y_{t-1} + u_t - \lambda u_{t-1}$.

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 λ) if the serial correlation is positive, and negative (i.e. underestimate λ) 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

(3) $P_t^* - P_{t-1}^* = \beta(P_{t-1} - P_{t-1}^*)$, $0 < \beta \leqq 1$.

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

(4) $P_t^* = \beta\Sigma_0^\infty(1 - \beta)^i P_{t-i-1}$.

When applied to a model of the form

(5) $Y_t = \alpha + \lambda P_t^* + u_t$,

the Koyck transform can be applied giving

(6) $Y_t = \alpha\beta + \lambda\beta P_{t-1} + (1 - \beta)Y_{t-1} + v_t$, where $v_t = u_t - (1 - \beta)u_{t-1}$.

If this model is operationally correct, then a search procedure over all possible β's on the interval (0,1] will yield maximum likelihood estimators for the parameters corresponding to that value of β which maximizes the R^2 of a linear least squares relation, given β.

Nerlove's partial adjustment model assumes that current values of the independent variables determine the "desired" value of the dependent variable

(7) $Y_t^* = a + bX_{t-1} + u_t$.

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

(8) $Y_t - Y_{t-1} = \gamma(Y_t^* - Y_{t-1})$, $0 < \gamma \leq 1$.

This model reduces to

(9) $Y_t = \gamma a + \gamma bX_{t-1} + (1 - \gamma)Y_{t-1} + \gamma u_t$,

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) $Y_t^* = a + bP_t^* + u_t$

which reduces to

(11) $Y_t = \gamma\beta a + \gamma\beta bP_{t-1} + (2 - \gamma - \beta)Y_{t-1} - (1 - \gamma)(1 - \beta)Y_{t-2} + v_t$,

where $v_t = \gamma u_t - \gamma(1 - \beta)u_{t-1}$, a composite disturbance term. Because γ and β 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 elasticity 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 throughout 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 expectation process. They may actually take into account most of the variables that one should have included explicitly 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

(12) $Y_t = \alpha P_t^{\beta} W_t^{\gamma} Y_{t-1}^{\lambda} \varepsilon^{\theta t}$, 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 α, β, γ, λ, and θ 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 $\alpha' = \ln\alpha$ 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) $\ln Y_t - \ln Y_{t-1} = \lambda(\ln Y_t^* - \ln Y_{t-1})$, $0 < \lambda \leqq 1$.

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