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Part V. Agricultural Price Analysis and Outlook

This paper reviews the literature of agricultural price analysis between 1946 and about the middle of 1973. Only brief reference is made to the literature published before World War II. We were offered the opportunity to update the review in January 1976 but did not have sufficient time to make an exhaustive review of additions to the literature since 1973.[1]

Agricultural price analysis is defined, for purposes of this review, as the study of agricultural product and input prices over time, space, form or quality, and market levels. In this context articles written in English, especially those appearing in United States publications, receive disproportionate attention. Even with these self-imposed restrictions, we found it impossible to summarize all of the literature, especially the numerous articles which report on empirical studies. Our major criteria in selecting literature for review are to indicate the major issues that have emerged in price analysis studies, to call attention to important empirical and theoretical results, and to illustrate the range of contributions made by agricultural economists in the subject of price analysis and outlook.

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Agricultural Price Analysis and Outlook

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Recursive and Simultaneous Equations Systems

The theoretical basis for price studies is usually some variant of the competitive model of price determination; that is, price is assumed to be determined by the point of intersection of demand and supply functions. One theoretical view is that prices and quantities are determined simultaneously, and this model may be empirically relevant when sufficient time is allowed for interdependence to take place. An alternative view is that prices and quantities are determined sequentially, and this model may be empirically relevant when time lags between changes in variables are long or when the time unit over which variables are observed is short. An important issue in the price analysis literature of the 1940s and 1950s was the question of when and under what circumstances it is appropriate to use single-equation methods (based on the assumption of recursive relationships) to estimate supply and demand functions. Therefore, before turning to empirical studies of supply and demand, let us review the literature on recursive and simultaneous models as used in price analysis studies.

Before World War II price analysts commonly estimated demand and supply equations separately using least squares regression procedures. However, computation of multiple regression coefficients was tedious using desk calculators, and consequently emphasis was placed on simple linear regression or small multiple regression models. Warren and Pearson's work [350] is illustra-

tive of the rather ingenious use of deflators and functional forms to construct simple regression models of supply-price relationships.[2] Prewar contributions in demand analysis culminated in Henry Schultz's *The Theory and Measurement of Demand* [292].

Although early empirical studies involved least squares estimates of single equations, E. J. Working's classic paper [370] did stress the implications of the simultaneous competitive model for the identification of supply and demand equations. Subsequently, Haavelmo [124] emphasized the inconsistency between using theoretical models which assume simultaneous determination of variables and using least squares estimation which assumes one-way causation from explanatory variables to a single dependent variable. This, of course, led to the development and use of simultaneous equations models and estimating procedures.[3]

The sequential nature of price determination in agriculture was also recognized in the prewar period and was incorporated in what has become known as the cobweb model. Bean [9] stressed the lagged relationship between price changes and the supply response of farm products. Thus, early studies supported the hypotheses that current production is a function of lagged prices and that current production is, in turn, an important determinant of current price. A statement of the cobweb theorem was provided by Ezekiel [77] in 1938.

The prewar literature provided a basis for the use of both simultaneous and recursive models in agricultural price analysis. In the postwar period Wold [366], among others, emphasized the importance of the recursive concept. If the values of the endogenous variables in a model are determined sequentially (in a recursive chain) and if certain assumptions about the disturbances of the equations are met, then the structural equations are identified and ordinary least squares applied singly to each equation provides consistent estimates of the parameters. These conclusions justify the use of single equations for some research problems.[4]

In the early 1950s Fox [87] stressed this point in slightly different language. If, for example, the quantity supplied and available for consumption in a particular time period is predetermined by prior events, then that quantity can be treated as an explanatory variable in a single price-dependent demand equation. Fox estimated, on the basis of 1922-41 data, that 95 percent of the production of pork in a calendar year was determined by events which had occurred in the previous year.

The cobweb model is perhaps the classic illustration of a recursive system. The simplest cobweb model assumes that (1) producers are price "takers" and supply response is based on price; (2) a clear time lag exists between a price change and a production change; (3) the total quantity planned to be pro-

duced is realized; (4) the quantity supplied in time t is sold in t, hence, determining price in t; and (5) the supply and demand functions are linear and do not shift.

Some of the assumptions of the elementary cobweb model, such as the static nature of the functions, are not particularly critical and can be modified in a more realistic model. Modifications to make cobweb models more realistic may include adding variables to each equation and adding equations to the model which capture the detail of the sector of the economy under study. Harlow's six-equation model [130] of the pork sector illustrates the manner in which the simple cobweb concept has been expanded in an attempt to specify a realistic model. The sequence of equations in this model explains (1) the number of sows farrowing, (2) the number of hogs slaughtered, (3) the pounds of pork produced, (4) the pounds of cold storage holdings of pork, (5) the retail price of pork, and (6) the farm price of hogs.

The cobweb model leads to a cycle in price and quantity with a period which is twice the length of the lag in the supply relation. Depending on the relative slope parameters of the supply and demand equations, the cycle may diverge, converge, or be continuous. As a result, two inconsistencies between the behavior of the model and reality have been noted. First, most cycles in agricultural prices and production neither converge nor explode. Second, some cycles are twice the length suggested by the model. For example, a market-weight hog can be produced in about twelve months from the time a breeding decision is made, suggesting a twenty-four-month period from peak to peak. However, the hog cycle has averaged four years from peak to peak [130].

Numerous explanations have been given for the continuity of agricultural price cycles in the context of the cobweb model [351]. Perhaps the least plausible is that the slopes of the functions are in fact equal and hence the special case of a continuous cycle is realized. A more plausible explanation for the observed inconsistencies is that actual production seldom equals planned production. Consequently, before a cycle can converge, a "random" shift in supply could start a new cycle. Shifts in the functions, however, have the potential to speed convergence to equilibrium as well as to prolong the cycle [3]. Thus, an argument based on the violation of assumption (3) is a two-edged sword. In any case a divergent cycle could not persist for long [285, p. 339], and by definition convergent cycles would inevitably die away so that only continuous cycles could be observed.

The assumption of straight line functions also may be violated. Continuous oscillation is possible with any pair of curved functions that go through points of a rectangle [351, p. 739]. Whether small deviations from the rectangle would converge back to the rectangle or not (stable or unstable oscilla-

tions) depends on the derivatives at the four corners. Nerlove [237] has developed the implications of a geometric form distributed lag supply equation for the possible alternative cycles.

Larson [199, 202] takes the view that the cobweb is not an appropriate model of price behavior. He proposes a "harmonic motion" model in which supply response is a *rate of change* in planned production through time (t):

$$\frac{dX_t}{dt} = kp_t,$$

where X is planned production. In this model, since the rate of change rather than the total level depends on price, the maximum in planned production is achieved only after a one-period lag following the price maximum. A second lag occurs between the maximum in planned production and actual production. Hence, this model produces a cycle twice the length of the one implied by the cobweb.

Assuming plans are realized, the level of production modifies price, and the cycle continues. However, a constant amplitude cycle would occur only with special slope conditions [199, p. 378]. In this respect, the harmonic motion model seems no more satisfactory than the cobweb model.

The harmonic motion model does recognize the "pipeline effects" (inertia) in the production process for livestock and livestock products, but it does not seem applicable to crops with periodic production. Also, the model assumes a fixed period in the cycle, but in fact producers have some discretion in modifying production plans. McClements [221] provides a critical examination of studies which have rejected the cobweb theorem in favor of a harmonic motion model.

Recursive models have been used to estimate structural coefficients, to forecast, and to explore the dynamic properties of certain commodity subsectors. Reutlinger [273], drawing on the work of Zusman [379], describes the analysis of time paths of endogenous variables in dynamic models. Research by Crom [58] and Walters [348] further illustrates applications involving description and projection and simulation of cycles for agricultural prices and output. Meadows [225] provides a summary of research as well as a simulation model of price behavior.

True cyclical behavior in prices and quantities is a self-generating process. High prices lead to larger quantities supplied which result in lower prices and so on. The recursive models discussed to this point attempt to capture this type of behavior. However, some agricultural economists believe that the so-called cycles in prices and quantities are not self-generated. The argument, as summarized by Breimyer [28] for the cattle cycle, is that random factors,

such as weather, affect livestock production and prices through its effects on feed supplies.

Conditions sometimes exist under which a simultaneous specification may be preferred to the recursive alternative. First, in situations where the total quantity available for harvest is predetermined, the quantity actually harvested may still be simultaneously determined with current price and its relation to harvesting costs. For instance, Suits and Koizumi's model for onions [316] contains an equation in which unharvested production and current price are simultaneously determined.

Time lags exist in the production process for all farm products. However, a second condition exists when the lag is short relative to the time unit of observation. This situation obviously prevails for turkeys, broilers, and eggs; production of these commodities can be modified in response to price changes within a year. Hence, if interest centers on annual relationships, then a simultaneous equation model may be appropriate. Third, for some commodities, current supply need not equal current production. Quantities can be drawn from or placed in inventory. The supply in one country or region likewise may be influenced by imports and exports. Thus, current price and total supply may be simultaneously determined even when production is predetermined.

Another need for simultaneity arises from the fact that, although total production is predetermined, allocation among different uses is not. The current apple crop, for example, is fixed at a particular size by prior events, but the utilization of that crop as fresh fruit, canned applesauce, frozen slices, and juice depends in part on the relative prices of these uses. Hence, the quantities going into alternative uses and the corresponding prices are jointly determined.

Based on the foregoing distinctions, most simultaneous equations models in agricultural price analysis can be grouped into two categories. One type assumes demand and supply (or some important part of supply) are simultaneously determined; the second takes current supply as predetermined but treats the allocation of total supply to alternate uses as jointly determined with prices.

The earliest simultaneous price analysis models are of the first type. Girshick and Haavelmo [99] specified and estimated a five-equation model for all food in which price and quantity are jointly determined. Using 1922-41 observations, they estimated, by the limited information maximum likelihood method (LISE), the retail price elasticity of demand to be -0.25 and the comparable elasticity of supply to be 0.16, both seemingly reasonable numbers (see [19] for the sensitivity of these results to changes in model specification).

Tintner [328] estimated several two-equation (supply and demand) models for all meat. Nordin, Judge, and Wahby [246] specified a twelve-equation model involving a supply and a demand equation for six interrelated products. These early models sometimes provided illogical results in the sense that the estimated price elasticities of demand were much too elastic relative to what was known of the characteristics of the commodities. For example, in Tintner's overidentified demand equation for all meat, the estimated elasticity is -2.69. Such results may be attributed either to model misspecification or to multicollinearity.

Several studies made by USDA economists in the middle and late 1950s were based on simultaneous equations models [97, 226, 283]. Meinken's model [226] of the wheat sector is an example of the second general type of simultaneous equations model. Domestic production and carryin stocks of wheat for a given crop year are predetermined. This total supply is specified in Meinken's model as being allocated to four uses (domestic human food, domestic livestock feed, net exports, and end-of-year stocks).

In 1959 Cromarty [61] presented an econometric model of United States agriculture, which contains thirty-nine equations for eleven product categories. Since the model is constructed for the purpose of estimating aggregate behavior, index numbers of prices received and other variables are constructed from the disaggregated (product) estimates.

The specification and use of simultaneous equations models in the 1950s tended to have an experimental character; a contribution of this research was the experience gained in model building. Analysts hoped that the results would be better than those obtained from single equations, but the empirical results obtained from simultaneous equations models were often unreasonable or not useful. These experiences led to the recognition that the definition of a "correct" model (and the corresponding estimation method) depends, in part, on the problem under investigation. For example, a single price-dependent equation can provide useful predictions of the farm price of apples. But, to estimate the demand for apples for fresh use for a particular season of the year, a simultaneous equations model, such as the one specified by Pasour [252], seems preferable.

More recent simultaneous equations models have been designed to answer specific rather than general questions. Pasour's model was constructed to determine the optimal allocation of apples over the marketing year. Houck and Mann [159] used their model of the soybean industry to project the quantity and value of soybeans and soybean products into the 1970s "on the basis of alternative assumed combinations of prices and government operations in the market." Kip and King [188] estimated demand equations for selected deciduous fruits and projected the demands to 1980 in order to evaluate the po-

tential effects of expanded supplies of these fruits in the San Joaquin Valley on prices and returns. A Washington State University project is developing a comprehensive model by product groups "to evaluate the effects of alternative government policies on the agricultural economy" [217, p. 1].

Simultaneous equations models have at the same time become more complex in the sense that they contain more equations and more variables (hence more information) than earlier models. The Houck-Mann soybean model [159] makes the commercial supply of beans predetermined, but the demand side contains thirteen equations – six identities and seven behavioral equations. The Langemeier-Thompson beef model [198] considers both the fed and nonfed subparts of the beef sector in twelve equations. The model contains margin, demand, and supply functions for both quality levels of beef.

If the objective of the research is to obtain the best possible estimates of certain structural coefficients and if the model involves simultaneity, then from the viewpoint of econometric theory a simultaneous equations estimation technique is preferred to ordinary least squares. One continuing problem in comparing estimates of structural coefficients from single and simultaneous equations models, however, is whether or not simultaneity is the dominant statistical problem and whether or not the alternative estimation procedures constitute the principal reason for contrasting empirical results.[5] The nature of the problem is illustrated by the alternative estimates of price elasticities of demand for beef (table 1).

Simultaneous equations models can have practical problems, other than multicollinearity, which perhaps have adversely influenced the quality of parameter estimates. Since estimation methods for simultaneous systems require a large number of observations relative to estimating single equations by least squares,[6] analysts have used long time series to estimate the models (for example, [61, 327, 347]). The use of a lengthy series can be treated as estimating the average structure, but such estimates may not be useful for current applications. Moreover, statistical analysis for a period containing structural change can give significant results by conventional tests (even though the coefficients are hybrid values not applicable to any period).

A second problem is that specifications usually limit the simultaneity to variables within the sector (for example, soybeans [159]) under study with other variables treated as predetermined. This treatment is often a necessary simplification to limit the scope of the model and to achieve identification. As a consequence, however, interrelationships among sectors are ignored or minimized, and some variables are treated as if they are predetermined when they are essentially endogenous.

Problems of contrasting estimation methods and time periods are, to some extent, illustrated in table 1. Three studies [27, 211, 352] of the demand for

Table 1. Selected Price Elasticities of Demand at Retail for Beef

Sources	Time Period	Estimation Method[a]	Elasticity
Nordin, Judge, and Wahby [246]	1921-41	ILS	-0.77
		OLS	-0.96
Fox [87]	1922-41	OLS	-0.94[c]
Wallace and Judge [347]	1925-55	LISE	-1.36
		TSLS	-0.77
		OLS	-0.76
Maki [214]	6/1947-12/56	OLS	-0.85[d]
Logan and Boles [211]	1/1948-12/59	OLS[b]	-0.65
Breimyer [27]	1948-60	OLS	-0.65[c]
Waugh [352]	1948-62	OLS	-0.69[c]
Tomek [329]	4/1949-3/56	OLS[b]	-1.00
	4/1956-3/64	OLS[b]	-0.90
Langemeier and Thompson [198]	1947-63	TSLS	-0.95

[a]ILS = indirect least squares; LISE = limited information maximum likelihood; TSLS = two-stage least squares; OLS = ordinary least squares.

[b]Elasticity derived from several OLS equations to take account of cross effects as described in [227]; this may be viewed as ILS estimates of system of demand equations, with supply predetermined.

[c]Elasticity computed as reciprocal of flexibility in price-dependent equation.

[d]Direct estimate from quantity-dependent equation.

beef, using a similar time period (within the period 1948-62) and single equation procedures, give similar estimates of the price elasticity. The Langemeier-Thompson [198] simultaneous equations estimates for a similar time period suggest a somewhat less inelastic demand. But, breaking the 1949-64 period into two parts and using least squares also gives estimates which are less inelastic than the single equation studies for the total period [329]. The unanswered question is how a simultaneous equations model would have performed for the shorter time periods.

Demand Analysis

The basic unit of demand theory is, of course, the individual consumer, but most empirical studies of demand consider market relationships. Research problems are usually concerned with aggregate behavior, such as predicting the national demand for beef, and data are more readily available for markets than for individuals. Analyses based on the behavior of individual consumers, however, have helped to provide useful simplifications and insights.

In this section demand studies are considered in two broad categories: those based on aggregate market behavior and those based on individual household or consumer behavior. We start with a review of conventional aggregate time-series studies and models of long-run demand. The second sub-

section covers miscellaneous topics related to parameters of demand models; these topics include structural change, the concept of total elasticity, and the relationship of flexibility coefficients to elasticities.

Two types of contributions related to individual consumers are reviewed in the third subsection. One type includes empirical studies using cross-section observations on individual households or consumers; the second type includes studies using restrictions on elasticities derived from basic demand theory as an aid in estimating empirical elasticities.

Analyses Based on Aggregate Time-Series Data

Certainly an important contribution of the post-World War II literature is the vast number of estimates of demand and price functions. This research provides estimates of structural coefficients and the basis for forecasts of levels of demand and prices. The studies cover numerous products at various market levels and degrees of aggregation. This literature also provides substantial insights into questions of model building. Foote [84], Rojko [284], and Waugh [352] summarize the state of the art as it existed in the late 1950s and early 1960s.

Work by Fox [87] and Stone and his colleagues [313] is representative of early postwar studies of demand. A "typical" equation fitted by Fox makes retail price a function of per-capita consumption (or production), per-capita quantity of a competing product, and per-capita disposable income. With respect to model specification, the selection of functional forms in demand analysis has been determined mainly on empirical grounds. Straight line and double logarithm forms are the most frequently used.

Disposable income is perhaps the most common shift variable used in demand analyses, with population reflected in per-capita variables. Income is usually treated as predetermined, though it is influenced both by prices and quantities sold. Analysts have argued that, for the most part, the error is not serious since the retail value of individual foods is small relative to total income in industrialized countries [84]. But this is not true in less developed countries. Moreover, even if the absolute size of the bias is small, the coefficient attached to the income variable also is likely to be small; hence, the relative bias can be quite large [189].

The measurement of the effects of substitutes is one of the more difficult problems in time-series analyses of demand. A potential lack of degrees of freedom and multicollinearity preclude using numerous variables for substitutes, and in any case their individual effects are often small and unmeasurable. Analysts (for example, [327]) have tried measuring the effects of all substitutes in one variable by using a sum, average, or index number to represent all substitutes.[7] Of course, if the commodity has just one or two close

substitutes, then they may be represented in the model by separate variables. In recent years the theoretical restrictions on elasticities have been used to help estimate cross elasticities of demand (discussed in a subsequent section).

Another difficulty is the lack of a general, fundamental explanation for abrupt shifts in price-quantity relationships, which are sometimes observed with the passage of time. Such shifts are illustrated by Waugh [352, p. 41, figure 5.1] for beef, pork, lamb, and veal within the 1948-62 period. Changes in income and in population have been smooth, and hence cannot account for the abrupt shifts. Such changes might be explained by changes in the supply of close substitutes; but changes in substitutes do not appear to explain all of the abrupt changes in demand.

Goodwin, Andorn, and Martin [103] stress the idea of an irreversible demand relation for beef. Perhaps tastes and preferences change abruptly.[8] Larger production and lower prices, if they persist for some period of time, may induce a permanent increase in demand [330]; consumers come to prefer the product when price is low and do not switch away (in the sense of movement along the old demand function) when prices subsequently rise. Conversely, small production and high prices may induce permanent shifts away from a commodity. Uvacek [341] makes an analogous argument in associating demand shifts for beef with changes in the beef cattle cycle. It is unclear at present whether or not similar arguments are applicable to the abrupt shifts in relationships for other commodities.

Many demand studies are based on annual observation, and the demands for individual farm products, based on such data, tend to be price inelastic at both farm and retail levels in the United States. An increasing number of demand analyses are conducted using daily, weekly, monthly and quarterly data. Such functions may be considered short-run or seasonal demand curves, and hence they might be thought to be more price inelastic than annual functions. Pasour and Schrimper [253] point out, however, that shorter period functions may involve the demand for storage (speculative demand) as well as the demand for current use. A price special on beefsteak could induce housewives to buy steak both for current use and for the freezer. At harvesttime, supplies move into storage as well as into current use. Thus, demand functions in the very short run can be highly price elastic relative to functions based on annual observations. Leuthold [209] obtained estimates which suggest a highly price elastic farm-level demand for hogs on a daily basis.

One method of estimating short-run elasticities is through the use of controlled experiments. This was done for fresh skim milk by changing prices in a particular location [13]. The point estimate of the elasticity based on the first two-day period following a price change was essentially zero. The elasticity tended to increase (in absolute value) and generally remained greater

than 1.0 after the eighth two-day period. The elasticity was -0.86 for the first month and -1.29 for the second.

Among the studies based on monthly data are those conducted by Brown [35], Hayenga and Hacklander [139], and Farris and Darley [80]. Brown's paper summarizes a relatively comprehensive study for the United Kingdom based on the years 1953 to 1958. He also compares his results with those of Stone and his colleagues [313]. Quarterly data were used by Stanton [307], Logan and Boles [211], and Stent [308] to estimate demand relationships for meat. Logan and Boles, Stent, and Farris and Darley each accept the hypothesis of equal slope coefficients for each quarter (or month), but they found significant differences in the levels of the functions by seasons.[9]

Summaries of estimated demand elasticities for agricultural products are available in Buchholz, Judge, and West [37] and a committee report [360]. Manderscheid [216] has pointed out that estimated coefficients can reasonably be expected to differ from model to model and that correct comparisons among studies require that differences in models be taken into account. Less effort has been devoted, it seems fair to say, to summarizing ex post evaluations of forecasts for agricultural products (for an example for one commodity, see [142, pp. 73-89]). Beef, for example, is perhaps the most studied agricultural commodity, but the models available in 1973 did not appear to do a very good job of predicting beef prices.

There was some feeling in the early 1950s that traditional demand analyses based on annual observation were short-run in character. As a consequence, models to measure long-run demand were introduced. However, various definitions of long-run demand were in use (for a brief review, see [330, pp. 717-719]). A commonly accepted definition now is that the long run is the time required for a complete adjustment in quantity demanded to a one-time change in price, holding other variables constant. The idea of a delayed response of quantity to a price change is consistent with the concept of a distributed lag model.

Numerous potential reasons exist for delayed adjustments in quantities demanded [238, pp. 5-7], including imperfect knowledge, habit, technological factors, institutional factors, and uncertainty. Given these possible reasons for delayed adjustments, the long run might seem rather lengthy in terms of months. Tomek and Cochrane [330] argue, however, that the long run for individual foods need not be a long time period. Many foods are purchased frequently and food prices are well advertised; hence, knowledge of price changes should be relatively good. Technological and institutional factors seem to be relatively unimportant for foods. In a controlled experiment for skim milk (cited above), complete adjustment to a price change appears to have occurred within three weeks.

Elmer Working's study [369] of the demand for meat is perhaps the first empirical study of the long-run demand for a food product. Working took a rather ad hoc approach to model building, and he considered one year as the short run and periods longer than a year as the long run. Ladd and Tedford [196] show that the Working model is a special case of a linear form distributed lag model. Consider

$$Y_t = a + \beta_0 X_t + \sum_{i=1}^{n} \beta_i X_{t-i} + e_t,$$

where

$$\beta_i = \beta_1 + \lambda\,(i-1),\ i = 1, 2, \ldots, n.^{10}$$

By substitution,

$$Y_t = a + \beta_0 X_t + \beta_1 \sum_{i=1}^{n} X_{t-i} + \lambda \sum_{i=1}^{n} (i-1)\, X_{t-i} + e_t.$$

The simple and weighted sums of X may be replaced by the corresponding simple and weighted averages with parameters β_1^* and λ^*, respectively, where

$$\beta_1^* = n\beta_1 \text{ and}$$

$$\lambda^* = \Sigma\,(i-1)\,\lambda.$$

The short-run coefficient is defined as β_0 and the long-run coefficient as the sum of all the β's.

As Ladd and Tedford point out, Working implicitly assumed $\lambda^* = 0$ by omitting the weighted average of X. Working selected n equal five and ten and found differences in the short-run and long-run price elasticities of demand for beef, pork, and all meat. Ladd and Tedford apply the more general model to the demand for meat using n equal three, five, and nine years. They found essentially no differences in short-run and long-run elasticities for any of the alternate values of n, and they concluded that the long run for meat does not exceed one year.

Waugh's model [352] of the long-run demand for cotton also uses simple averages of lagged prices, but by using three averages centered three, six and nine years previous to the current year, the lagged effect is specified as occurring in steps. Waugh estimated that the long-run price elasticity of demand for cotton is -1.84; a common estimate of the short-run elasticity is -0.3. Nerlove and Waugh's model [245] to measure the long-run effect of advertising on the demand for oranges is of the Working type with n equal 10. Other advertising studies have used geometric and polynomial form models.

Geometric form distributed lag models have been used quite frequently in

studies of both demand and supply of farm products, their popularity stemming in part from papers by Nerlove [239, 241]. A partial adjustment model assuming static expectations, which is analogous to stock adjustment and flexible accelerator models, may be written

$$\bar{Q}_t = \alpha + \beta P_t + e_t \text{ (long-run demand equation), and}$$

$$\gamma = \frac{Q_t - Q_{t-1}}{\bar{Q}_t - Q_{t-1}}, \; 0 < \gamma < 1.$$

This model (in a demand context) assumes (1) that the response in quantity demanded to a price change is delayed by factors such as imperfect knowledge and technological considerations but (2) that expectations are static so that changes in P_t are accepted as appropriate signals of price change and (3) that the adjustment process, given a price change holding other variables constant, is a specific proportional one as defined above, where γ is the coefficient of adjustment. $\bar{Q}_t$ is the unobservable long-run quantity demanded with complete adjustment, and P_t is the observed price. The two equations can be solved to obtain a relationship in observable variables. Namely,

$$Q_t = \alpha\gamma + \beta\gamma P_t + (1-\gamma)Q_{t-1} + \gamma e_t.$$

The adaptive expectations model is an alternative approach that emphasizes expectations as the major factor in the lag process. Observed quantity is made a function of expected price, and in the adaptive expectations model, expected price is defined as the geometric average of current and past prices [239]. The model leads to an equation in observable variables which is analogous to the equation derived from the partial adjustment model; that is, the lagged dependent variable is one of the regressors.

Nerlove [239] argues for models of the partial adjustment or adaptive expectations type because they are derived from explicit hypotheses of consumer (or producer) behavior. The analyst may simply specify, however, that the form of the lag is geometric for whatever reason, and alternate geometric form models may lead to estimating equations with identical regressors (including the lagged dependent variable).

Tomek and Cochrane [330] use geometric and linear form models with quarterly observations to estimate long-run elasticities for beef, pork, and all red meat. The estimated lengths of the adjustment periods to price changes are three quarters, one quarter, and three to four quarters, respectively. The estimated long-run price elasticities are -1.0, -0.75, and -0.55 for beef, pork and all meat; this contrasts with estimates of -0.89, -0.73, and -0.44 using a conventional (non-lag) model with quarterly data.

The question of whether or not the adjustment parameter and length of

lag might differ for quantity responses to changes in price and to changes in income was also considered [330]. It is quite easy to allow for different adjustment periods in a linear form model, but it is more difficult in a geometric form model. Martin [218], however, explicitly derives the model which permits different geometric form lags for two variables (price and income). Martin reports a lag of about four and a half years in quantity adjustments for pork to income changes and one year or less to price changes.

Griliches [117] provides a survey of literature for distributed lag models. Papers by Brandow [25], Ironmonger [167], Fuller and Martin [95], Ladd [195], and Mundlak [233] discuss specification problems related to applications in agricultural price analyses. The emphasis of these papers is on the sensitivity of estimates of parameters in geometric form models to specification error, autocorrelated disturbances, aggregation over commodities, and aggregation over time.

The omission of a relevant explanatory variable from an equation containing a lagged dependent variable can seriously bias the estimates of the remaining coefficients, such as the coefficient of adjustment [25]. In sum, there are many reasons why the estimates of parameters of geometric form models may be biased or misleading. Thus, while such models have been quite popular, particularly in estimating agricultural supply equations, the results from such studies, in the author's judgment, should be interpreted with caution.

Parameters of Demand Functions

The demand structures for farm products can change with the passage of time. Basic tastes and preferences change; a new government program is introduced; the income distribution of a population changes; or new substitutes become available. Experienced price analysts know that estimates of demand (or supply) functions frequently are sensitive to the time period selected for analysis, though few published comparisons are available (but see table 1). Moreover, if the time period selected for analysis included more than one structure, the resulting estimated coefficients represent an average which likely is not applicable to the problem under analysis but which may perform well in terms of conventional tests, such as the t-test or size of R^2 (see, for example, [332, p. 350ff.]). Thus, structural change presents a serious problem.

Basically, two approaches have been made to the problem: a search for and selection of a time period with a relatively homogeneous structure relevant to the research problem and the use of additional explanatory variables in the model [84, pp. 20-23; 284, pp. 43-44]. A trend variable may account for changes in tastes and preferences, at least when preferences have changed in a smooth, systematic way through time. Analysts have sometimes sug-

gested using first differences of observations when a long time series is involved [26]; the intercept parameter then becomes a measure of trend [84, p. 43]. Foytik [89] used a model which permits the slope parameters to change systematically with the passage of time.

Zero-one variables can also be used. A common example is the differentiation between wartime and peacetime. Zero-one variables are more flexible than a time trend in the sense that a trend constrains shifts in the function (which may be viewed as changes in the intercept parameter) to a fixed and equal amount each time period, and zero-one variables can account for abrupt or other uneven shifts with the passage of time. The analyst, however, must have sufficient knowledge to define the zero and one values properly for the appropriate time periods. The slope coefficient of a particular continuous variable can be permitted to change by using the concept of interaction between the zero-one and the continuous variable [11]. If a new substitute becomes available, a variable representing the substitute can be defined with values of zero in the earlier period (before introduction) and the observed values in the later period (after introduction). The effect of the substitute on the slope coefficients of other variables can be tested [84, p. 23]. Some novel methods of allowing for structural change in supply analysis are discussed later.

The selection of a structurally homogeneous time period has the advantage of permitting the use of a simpler model (fewer variables), which implies fewer opportunities for multicollinearity. But the number of observations may be severely limited,[11] and the methodology for selecting a suitable time period can present problems. Two recent theses [114, 299] have considered the time-period selection problem. It is rather common to delete wartime or other years involving effective price controls and/or rationing. In this situation the analyst is able to base the deletion of observations on a priori reasoning.

Given the sensitivity of some estimates to the deletion or addition of one or two observations, one might also argue that a random coefficients model is appropriate for certain price analysis problems. In this model the coefficients of the explanatory variables are specified as fluctuating randomly from one observation to the next (rather than being fixed numbers), and the mean and variance of the unknown random coefficients are estimated [325, pp. 622-627]. As of mid-1973 this model had not been used for agricultural price analysis problems.

Another important aspect of demand analysis is relationships among substitutes. The degree or closeness of substitution relationships depends on the physical or biological attributes of commodities and on relative prices. For instance, Armore [5] and Nyberg [247] point out that fats and oils (for exam-

ple, coconut oil) often have certain special uses for which no good substitutes exist because of the physical properties of the oils; however, in other uses, food fats and oils can be viewed as essentially identical commodities. If the supply of an oil does not exceed the demand for it in the special use, then the price of this oil can be relatively high. As supplies increase, price declines, and at lower prices a high degree of substitutability becomes apparent.

The disaggregation of a commodity group, such as wheat or beef, into grades or classes represents a special case of closely substitutable products. Price elasticities of demand are much more elastic for the components than for the aggregate. Langemeier and Thompson [198] consider both the fed and nonfed components of the beef sector. Studies of demand by grade, variety, or quality groups have, however, been relatively limited in number (but see, for example, [166]).

If the price of a commodity remains at a relatively high level for a considerable period of time (say, because of a price support program), this may induce the development and use of new substitutes. Some analysts, for instance, believe that high prices of cotton stimulated the development of man-made fibers [352, p. 58]. It is difficult empirically to separate the long-run effects of a given price, which assumes other things constant (as defined above), from the price-induced changes in structure.

Close substitutes have large positive correlations among prices. Thus, while the price elasticity concept assumes "other things" constant, with the passage of time, other things cannot remain constant among close substitutes. If one price changes, the resulting chain of events results in new prices for all of the substitutes. The price elasticity measure alone is a poor predictor of the final net effect of a given price change on quantity. Buse [43] highlights this problem in his article on "total elasticities." He defines the elasticity of total demand response as "the percentage change in the quantity of a commodity demanded due to a one percent change in the price of the commodity, allowing all other variables in the market to vary as they must." This concept differs from the long-run price elasticity, which still assumes other things constant; total elasticity measures the price-quantity relationship after permitting other variables to respond as well to the initial price change.

Buse obtains the total elasticity measure by using an example for beef and pork. For pork, the following relationship is derived:

$$E_t = E_{ii} + E_{ij}S_{ji},$$

where

E_t = elasticity of total demand response for pork,
E_{ii} = price elasticity of demand for pork,

E_{ij} = cross elasticity of demand for pork with respect to price of beef, and

S_{ji} = effect of a one percent change in price of pork on the price of beef.

For substitutes, E_{ij} is positive, and its absolute value is less than E_{ii}; S_{ji} is positive and less than one [43, p. 889]. Thus, E_t is negative, and its absolute value is less than E_{ii}, which is the commonsense result.

Still another aspect of the literature on parameters is the relationship between elasticities and flexibilities. When price analysis models use price dependent demand equations, price flexibility, rather than elasticity, coefficients may be computed.[12] Houck [158] summarizes the general relationship between direct-price and cross-price flexibilities and direct-price and cross-price elasticities. In an earlier paper Meinken, Rojko, and King consider the special case for two substitutes, beef and pork, and provide details for computing elasticities from flexibilities, given the estimated price dependent equations [227, pp. 733-735].

The general relationship between flexibilities and elasticities is

$$FE = I, \text{ or } E = F^{-1},$$

where

F = n x n matrix of price flexibilities,

E = n x n matrix of price elasticities for the n commodities, and

I = n x n identity matrix.

Letting f_{ii} be the direct-price flexibility for the ith commodity and e_{ii} the corresponding elasticity, then from the logical signs of the parameters Houck [158, p. 792] states

$$| e_{ii} | \geq | 1/f_{ii} |.$$

Coleman and Miah [51], however, provide a detailed critique of the Meinken and Houck papers.

An implication of the above relationship is that the elements of F would be estimated from price dependent functions, and then $E = F^{-1}$. In contrast, Waugh [352, p. 29ff.] argues for obtaining the elements of E directly by estimating quantity dependent functions by least squares. This approach often may mean treating a current endogenous variable (price) as predetermined in a least squares regression, giving biased estimates of the parameters. If R^2 is near one, the bias is small [84, p. 68]. Waugh [354] also was a strong proponent of least squares estimation of single equations in forecasting problems, where the variable to be forecast determines the dependent variable.

Analyses Based on Individual Consumer Behavior

In aggregate time-series data estimates of parameters are based on the variation of variables with the passage of time, and the attendant problems of analysis are well known. A sample of interindividual observations (cross-section data) provides different and useful information to the analyst. Prices and consumer preferences can be taken as fixed at a point in time, and the effects of inter-individual differences in income (and other factors) on consumption can be estimated.

Prais and Houthakker [263] provide a comprehensive treatment of Engel functions. The preface to the second impression of their monograph (1971) includes citations of recent literature, which in general are not repeated here. Houthakker [164] also has summarized the results of household expenditure studies from a number of different countries. Three handbooks by Burk [39, 40, 41] include a survey of literature relating to the analysis of food-expenditure relationships in the United States. The latter two publications are devoted to sources of data and their interpretation; the first deals with social and economic factors affecting food consumption in the United States.

The responsiveness of food expenditures to a given change in income generally has been found to be greater than the responsiveness of quantity [104, p. 6]. George and King [96, p. 73] provide a useful summary of quantity and expenditure elasticities for forty-three food items, based on an analysis of the 1965 household consumption data for the United States (see also [278]).

Among the issues that arise in consumption function analysis is whether the analysis should be based on current incomes or total expenditures (or averages of incomes or expenditures). In some cases total expenditures are used as an estimate of income simply because income figures are not available. But, since total consumption expenditures may be viewed as simultaneously determined with expenditures for each product, least squares estimation is inappropriate with such data [317]. It is rather common in estimating Engel curves from cross-section observations to group the observations and to base the estimates on the averages of the groups. This greatly reduces the number of observations and need not cause problems in estimating the parameters of the equation, provided appropriate estimation procedures are used [263, pp. 59-62].

Evidence exists that within the observable range of household sizes, there are economies of scale; for a given level of income per person, per-capita expenditure on food decreases as the size of household increases [104, p. 5]. Household size is perhaps the most important explanatory variable other than income in Engel curve analyses of food consumption [189, pp. 56-57; 148, p. 827]. Other potential explanatory variables include the age distribution of members of the household, racial composition, rural-urban location, and the

occupations of household members. Herrmann [148], using data from the 1955 United States household consumption survey, identified interactions between household size and income, between household size and urbanization, and among household size, urbanization, and income. Significant differences appear to exist between consumption functions for farm and urban consumers and between farm and rural nonfarm consumers. For example, Lee and Phillips [206] found that the income elasticity for all food consumption by farmers is less than the comparable elasticities for the other two groups (see also [278]).

The functional form of Engel curves has received considerable attention [104, 208, 263]. Factors to consider in selecting a functional form include (1) the simplicity and convenience of estimation, (2) the validity of the function over the plausible range of total expenditures (the elasticities implied should be logical), (3) the possibility of an initial income below which a commodity is not purchased, and (4) the possibility of a satiety level [208; 263, p. 82]. Prais and Houthakker, after considering alternatives, use a semilogarithmic form for food products; Goreux [104] uses mainly logarithmic, semilog, and log-inverse functions in his analysis.

Leser [208] also places considerable emphasis on functions meeting the "adding-up criterion." This is the constraint, when expenditure data are used, that the sum of the expenditures on all individual goods and services must equal the sum of total expenditures, the explanatory variable [263, p. 83].[13] Prais and Houthakker [263] argue, however, that the importance of the criterion can be overestimated and that "it may be unwise to restrain the formulation by imposing the same algebraic form on the curves for all items of expenditure." The algebraic form selected can influence the estimated income elasticity to an important degree. In the Prais-Houthakker study [263] the income (expenditure) elasticity for meat at the mean ranged from 0.44 for a hyperbola to 0.69 for the double-log form (see also [300, p. 114]).

Wold and Jureen [367] argue that income elasticities from cross-section studies are more nearly long-run coefficients than are those from time-series studies. Klein [189] believes that, in a carefully designed study, these differences can be overcome. Goreux [104] found the income elasticity for all food computed from time-series observations somewhat higher than that from cross-section data. This was attributed to the changing nature of food (the added services) through time. For individual products, income elasticities sometimes were smaller for time-series data, but this was not consistently true [104, p. 10].

Income elasticities for all food and for individual food products apparently have declined as incomes have increased. This assumption is, in fact, explicity built into the algebraic form of most Engel curves, and massive amounts

of empirical evidence confirm the idea of declining income elasticities for foods [104, 263, 268, 278, 309]. Harmston and Hino [131] also compare elasticities at alternative income levels but emphasize changes in elasticities for *given* income levels in two time periods.

Burk [38] points out that the small income elasticity for food and the high degree of urbanization in the United States weakens the usefulness of these variables for forecasting changes in demand. Burk argues for concentrating analyses on moderately high income families who may act as forerunners of changes in demand.

Food at retail can be split into a farm origin and a marketing service component. The service component has grown, but in the late 1950s and early 1960s economists disagreed about the magnitude of the income elasticity for marketing services for food. Anschel [4] summarizes the alternate results, which ranged from less than 0.5 to over 1.0. Anschel believes that the income elasticity for food marketing services is nearer 0.5 (see also [345]).

The development of consumer surveys on a regular basis, as in Great Britain, and the use of consumer panels also has permitted the use of individual household information to estimate price elasticities of demand (for example, [35, 267]). The Purcell and Raunikar study [267], based on an Atlanta consumer panel, indicates that the demand for food tends to become less elastic as the time interval over which prices change is lengthened, say from a weekly change to one that occurs over a year.

Most empirical studies of demand do not consider fully the interdependent nature of demand; few cross elasticities are estimated in a typical time-series analysis, and prices are treated as fixed in Engel functions. Yet, as previously observed, a change in the price of one commodity sets in motion events that influence the consumption and prices of other goods and services. A "complete" matrix of elasticities can be useful in answering price policy questions. There are at least two reasons, however, why such a large set of elasticities cannot be estimated directly from available data. One is the degrees of freedom problem. Given n commodities, there are n^2 direct-price and cross-price elasticities as well as n income elasticities. Second, the cross-price elasticities are often very small and, hence, unmeasurable by conventional econometric methods; but the aggregate cross effects for a group of products may not be negligible.

Certainly one of the important developments in agricultural demand analysis has been the use of restrictions on elasticities (derived from basic theory) as aids in obtaining estimates of elasticities. These restrictions, while derived from theory which applies to the individual consumer, are usually used in studies of market demand.[14] Thus, the results of applications of theoretical constraints must be treated either as applicable to a representative consumer

Table 2. Selected Relations from Demand Theory

	Name of Relation	Statement
(1)	Homogeneity condition (or row restraint)	$\sum_{j=1}^{n} e_{ij} + e_{iy} = 0$
(2)	Symmetry condition (or Slutsky condition)	$e_{ij} = \frac{w_j}{w_i} e_{ji} + w_j (e_{jy} - e_{iy})$
(3)	Engel aggregation	$\sum_{i=1}^{n} w_i e_{iy} = 1$
(4)	Cournot aggregation (or column restraint)	$\sum_{i=1}^{n} w_i e_{ij} = -w_j$ (for the jth column)
(5)	Frisch equations	$e_{ij} = \frac{1}{\emptyset} e_{iy} e_{jy} w_j - e_{iy} w_j$, $i \neq j$, and $e_{ii} = -e_{iy} w_i - \frac{1 - w_i e_{iy}}{\emptyset}$
(6)	General expression for ordinal separability assumption	$\frac{\partial U_i/U_j}{\partial q_k} = 0$ for some $k \neq i, j$.

e_{ij} = price elasticity; $i = j$, direct; $i \neq j$ cross;
e_{iy}, e_{jy} = income elasticities for i and j;
w_i, w_j = expenditure weights;
$\emptyset$ = money flexibility coefficient (see [93]);
U_i, U_j = marginal utility of i and j, respectively;
q_k = quantity of k.
Adapted from George and King [96].

that meets the underlying assumptions or as approximations which still are useful for policy analyses and decisions [24, p. 14].

A classical approach to demand theory involves a consumer with a given income making choices from a commodity space of n items with given prices. The choice problem is stated as maximizing a utility function subject to the restriction that total expenditures equal income. Appropriate algebra gives n demand functions with each quantity a function of n prices and income. These functions satisfy a number of important relationships, which are briefly summarized in terms of elasticities in equations (1) - (4) in table 2. Bieri and de Janvry [14] and George and King [96] provide more complete summaries, including references to relevant theoretical literature.

Wetmore et al. [361, pp. 66-71] make use of equations (1) - (4) in their study of policies for expanding the demand for food. The homogenity, symmetry, and Engel conditions reduce the number of parameters to be esti-

mated to $1/2(n^2 + n - 2)$, still a large number [96, p. 21]. Thus, Wetmore and colleagues also relied on reasonable assumptions (for example, the sum of cross elasticities is positive or zero) and judgment to complete a matrix of demand elasticities for foods.

Constraints such as the homogeneity condition also help analysts to appraise estimates obtained in applied research. For instance, if the income elasticity for food grains in India is estimated to be 0.5 and if the sum of the cross elasticities is zero or larger, then the direct-price elasticity is equal to or larger (in absolute value) than -0.5 [228, p. 973].

Separability concepts provide additional information for estimating a matrix of demand elasticities.[15] Frisch [93] proposed the assumption of "want independence" as a basis for computing all price elasticities.[16] This assumption permits Frisch to obtain equation (5) in table 2 for want-independent goods from the symmetry relation [96, pp. 22-23].

Brandow [24, p. 14] assumes food and nonfood are want independent and uses Frisch's conditions as a guide to obtaining cross-price elasticities between food and nonfood. George and King [96], expanding on Brandow, compute a complete set of elasticities for forty-nine foods as well as nonfood. They start by making estimates of direct-price and income elasticities for each commodity. The forty-nine foods are divided into fifteen separable groups, and "cross elasticities for commodities belonging to the same food group basically are obtained through direct estimation process" [96]. Extensive use is made of conditions (1) through (5) to complete the matrix of elasticities. In particular, the Frisch equations are used as guides to obtaining cross elasticities among groups [96, pp. 43-44].

In empirical analyses the grouping adopted necessarily has some degree of arbitrariness. George and King [96] describe briefly and use a grouping developed by de Janvry (see review in [14]). The groupings tend to be the "natural" ones such as meats (beef, pork) and fruits (apples, bananas).

Frisch assumes the marginal utilities of i and j are unaffected by the consumption of k (where k does not belong to the i, j group), but separability more generally requires only that the ratio of marginal utilities remain unchanged (that is, $U_i = U_j$) for a change in consumption of the kth commodity (equation (6), table 2).[17] Boutwell and Simmons [21] explore the implications of weak and strong (ordinal) separability for reducing the number of parameters to be estimated and apply a model to seven commodities (aggregates) divided into two groups. The restrictions derived from the separability assumptions are imposed on the demand functions. The final model is nonlinear in the parameters, requiring an iterative estimation procedure. Bieri and de Janvry [14] review alternative approaches to estimation which assume separability.

The implications of alternate models for the degrees-of-freedom problem can be illustrated by the Brandow study [24]. Brandow's elasticity matrix for 24 foods and one nonfood category contains 625 own and cross elasticities plus 25 income elasticities. These 650 coefficients can be reduced to 324 by the use of constraints (1) - (4). With two groups, as in Brandow, Boutwell and Simmons show that the assumption of weak separability requires the estimation of 301 parameters. Hallberg [126] asks whether or not saving 23 coefficients justifies the use of the more complex iterative estimation procedure implicit in the Boutwell-Simmons approach [21]. Hallberg also points out that for pragmatic reasons the functional form of the demand equation is restricted to the logarithmic type. In principle, however, the savings in degrees of freedom can be greater with a larger number of groups.

A recent study [14], using observations from Argentina to estimate demand elasticities, illustrates the simplifications made in a two-stage utility maximization-type model. Since, by assumption of the model, the total expenditures to be made for each commodity group is determined in the first step by the consumer, the group expenditure for individual demand functions is predetermined; that is, the consumer is assumed to determine the expenditures for the particular groups in the first step. Thus, the group expenditure is a predetermined variable for the demand function of an individual product within the group. Also, since the theory is related to individual consumers, prices are exogenous. If the assumptions are correct, least squares estimation is justified [14, pp. 20-22]. Of course, when aggregate market data are used, prices probably are endogenous.

The theoretical restrictions on elasticities derived from utility theory have counterparts for flexibility coefficients. Waugh [352] derives the conditions for an n equation model in which prices are on the left-hand side of the equal sign. Houck [155] provides a similar derivation, but starting with the traditional elasticity restrictions imposed on functions with *quantities* on the left.

Supply Analysis

The literature related to supply analysis for agricultural products can be conveniently divided into three main categories: (1) studies of the supply of individual commodities based on time-series data, (2) studies based on budgeting techniques or linear programming models using typical farms or regions as units of analysis, and (3) studies of aggregate supply including both the development of theoretical concepts and the estimation of the response of total farm output to changes in product and factor prices. Since studies of farm inputs have often been linked to analyses of product supplies, we review the literature on the supply and demand for inputs in a fourth subsection.

Fortunately, a number of excellent review articles covering both methods of supply analysis and empirical results are already available. Two of these [56, 244], which were written in the early 1960s, are still relevant and provide a useful summary of the contributions made by agricultural economists to the study of supply. More detailed descriptions of alternative techniques of supply analysis and summaries of empirical studies can be found in the book *Agricultural Supply Functions: Estimating Techniques and Interpretations* [140]. Some additional observations regarding supply analysis based on experience gained during the 1960s are contained in a series of papers presented at the December 1968 meetings of the American Agricultural Economics Association [175].[18]

Time-Series Analysis

Like many demand analyses, most studies of the supply response of individual commodities are based on time-series data using single-equation models and ordinary least squares estimation. Indeed, the similarity of the problems faced in time-series analysis of demand and of supply permit this subsection to be relatively short.

The most significant single contribution to time-series supply analysis in the postwar period undoubtedly has been the work of Nerlove. The concepts which he introduced in the late 1950s led to renewed interest in supply analysis [239, 240, 241, 243]. His distributed lag models (discussed earlier), in principle, make it possible to obtain separate estimates of short-run and long-run elasticities. These models, which have a rather elegant simplicity, frequently produce higher R^2 values than alternative models and in some cases appear to reduce or eliminate the problem of serial correlation in the residuals. In short, the marginal gains in terms of additional information (two elasticity estimates) and seemingly improved statistical properties are high in relation to the marginal costs. Under such circumstances, it is not surprising that this innovation was quickly adopted by agricultural economists.

The routine, and indeed almost universal, use of Nerlove-type models to obtain short-run and long-run estimates of supply has not escaped criticism, however. A number of agricultural economists have expressed reservations about the quality and interpretation of the estimated coefficients. Criticisms of the model run along the following lines. First, the equation contains the lagged dependent variable (usually acreage planted in supply equations for crops), and the coefficient of this lagged variable may very well embrace a collection of influences, including those associated with trends in the dependent variable such as technological change. This is simply a special case of the general problem of omitted variables which are correlated with included variables and hence bias the coefficients [25, 119]. In addition, multicollinearity

may exist between the lagged dependent and other explanatory variables. For these reasons, great care must be exercised in interpreting the coefficients. As Griliches points out [116], such coefficients may measure more than an adjustment or expectation process.

A second major criticism is that the expectations model assumes price expectations are formed in a particular way (a geometrically diminishing lag). Clearly, farmers do not base their plans solely on past prices (for example, outlook statements may also play a role in their decisions); nor is it necessarily realistic to assume that weights are assigned to past prices in a geometric fashion. Equations with large R^2's and statistically significant coefficients may be obtained even though a geometric-form model is not applicable. Ultimately, additional experience with different lag forms (such as the Almon lag [45]) may place the geometric lag model in a clearer perspective.[19]

In order to have a reasonable number of degrees of freedom, supply analysts have been forced to select only a few of the many possible explanatory variables. Typically, analysts have used the product price (with varying lags and weights), lagged values of the dependent variable sometimes as an alternative or in addition to using a trend variable, either prices or an index of prices paid for inputs (such as fertilizer, machinery, or feed), and if appropriate some measure of the prices or returns from alternative crops or enterprises. In some cases, a variable reflecting off-farm job opportunities has been included. Reutlinger [274] suggests that supply may respond to the variance as well as the average level of price, though he concedes it is difficult to test this hypothesis empirically.

One of the more difficult problems in agricultural supply analysis is the specification and estimation of relationships for tree crops. French [91] made apple production a function of a simple average of price ratios lagged twelve years. French and Matthews' [92] supply model for perennial crops cites and builds on previous studies (see [12] for another approach).

The unexplained variance in supply equations is frequently large and usually greater than with demand equations. Moreover, coefficients, especially those attached to product and factor prices, tend to be unstable and are frequently small in relation to their standard errors [190, pp. 96-97]. Price elasticities, for example, vary depending on which years are used and whether or not trend or other variables are omitted or included. Elasticity estimates are also influenced by the functional form used. One automatically places certain restrictions of elasticity estimates if a straight line function is used [157]. In most equations shift variables account for a much higher proportion of the explained variance than the product price. Thus, own-price elasticity estimates obtained from time-series data are often weak.

The relatively large unexplained variance in supply equations can usually

be attributed to one or more of three elements. First, random disturbances are associated with natural or biological phenomena such as variation in moisture availability or insect and disease damage. Second, abrupt or irregular changes in technology may occur which alter yields and the relative profitability of products. Finally, government programs have had a profound effect, especially in the United States, on the acreages planted to such crops as grains, cotton, and tobacco.

Agricultural economists have shown great ingenuity in devising variables to take account of these shifts in supply. For example, Stallings [306] constructed a weather index which could be incorporated in supply equations (for alternatives see [72, 249, 326]). Hathaway [135], G. Johnson [173], and Houck, Ryan, and Subotnik [160, 161] are among those who have incorporated variables to account for the effects of changes in government programs. Efforts to find a suitable proxy for technolgoy (other than trend) have been less successful. Halter [127] argues that the predictive power of supply equations will always be limited because the most critical factor in long-run supply is technology, and this is precisely the variable most difficult to incorporate into models and to forecast.[20]

Until the early 1960s supply analysis was limited mainly to the more developed countries, but work by Krishna (summarized in [192]), in which he successfully estimated supply equations for cotton, wheat, and other grain crops in the Punjab region of India, encouraged others to make similar studies. Krishna used the Nerlove model to estimate both short-run and long-run elasticities of supply based on annual data essentially for the period between the two world wars. The supply elasticities for cotton turned out to be somewhat larger than those estimated for the United States before the introduction of supply control programs. Somewhat smaller elasticity estimates were obtained for grain crops. Other published studies based on time-series analysis of supply in less developed countries include one on rubber in Malaya [363], wheat and rice in Pakistan [78], and rice and corn in Thailand [10]. The results of many of these studies have been conveniently summarized by Krishna [191]. These studies support the hypothesis that peasant farmers in poor countries respond positively to prices and particularly to changes in relative prices of cash crops. Supply elasticities generally are much smaller for subsistence (food) crops, especially if only a small proportion of the crop is sold, than for fibers or other cash crops.

For less developed countries, elasticities have been used, not only to test alternative hypotheses regarding farmers' production response to price but also to ascertain whether quantities sold are likely to diminish as prices rise. Several methods of estimating the response of marketings to changes in product prices (the elasticity of marketed surplus) have been devised. It is diffi-

cult to obtain reliable data on what happens to home consumption on subsistence farms when product prices (and hence real incomes) change. This problem has been circumvented by first estimating the response of total output to a change in price (own-price elasticity of supply) and then estimating the relationship between quantities marketed and produced (the elasticity of sales with respect to output) using either time-series or cross-section data. The price elasticity of marketed surplus is estimated by multiplying the elasticity of sales with respect to output by the price elasticity of supply. The empirical evidence suggests that elasticity of marketed surplus is positive even in subsistence agricultural economies [191, pp. 511-512].

Budgeting and Linear Programming Techniques in Supply Analysis

Time-series analysis is least useful for prediction when technology, government programs, or other supply shifters change abruptly or discontinuously. The limitations of time-series analysis led John D. Black to suggest building synthetic supply schedules from budget studies of "typical" farms. The logic of deriving supply schedules from firm data is appealing, but the practical problems of carrying out the analysis are enormous. Great care is needed in selecting farms for analysis, specifying input-output relationships on such farms, and deciding what alternatives to consider. Judgment obviously is involved at every step, and particularly in deciding what the farmer is most likely to do. Budgeting was the normal method of determining the most profitable level of output at alternative prices, but as Mighell and Allen [229] emphasized, "The step from the most profitable (output) to the most likely is a difficult one and cannot be entirely objective." Finally, there is the problem of how data from representative farms should be aggregated to reflect the response from a region. The results of one of the early studies which analyzes the effect of changes in milk prices on production of milk are reported by Mighell and Black [230].

The derivation of supply relationships from studies of individual farms probably would not have been pursued by very many economists if it had not been for the development and popularization of linear programming techniques in the 1950s. Unquestionably this innovation, along with the development of high-speed computers, was responsible for a renewed interest in the late 1950s and early 1960s in deriving supply schedules from farm data. Linear programming made it possible to test the effects of changes in prices, costs, and technology on the optimum output relatively inexpensively and rapidly. By using price-mapping techniques, boundary prices (those at which alternatives were equally profitable) could be readily identified (for an example of this type of analysis, see [224]).

But, as with budgeting studies, the practical problems of deriving useful estimates from programming representative farms proved to be very great. The difficulties involved in such studies are well summarized by Sharples [298]. Among the major problems encountered are the difficulty of allowing for changes in farm size and technology, induced changes in input or factor prices (externalities), deciding what assumptions regarding the behavior of decision makers should be built into the models (for example, whether simple profit maximization is an appropriate assumption), and the familiar problems of farm selection and aggregation. In addition, users of this technique found themselves overwhelmed in some cases by the multiplicity of results obtained. As more farms and alternatives were analyzed, straightforward conclusions were difficult to draw from the mass of computer outputs.

In an attempt to make the results of linear programming models more predictive (rather than normative), additional constraints designed to reflect behavioral or technological limitations to changing output from one year to the next were introduced. The research of R. H. Day [69, 70], building on the work of Henderson [146], unquestionably gave impetus to the use of "recursive programming." The technique involves only a simple modification of the traditional linear-programming model – namely, the introduction of "flexibility constraints" which impose upper and lower bounds to the expansion or contraction of each activity.

The flexibility constraints can be derived in a number of ways, but usually the coefficients are based on regression analysis of time-series data. The objective is to find the coefficient which expresses the relationship between, say, acreage in the current year and the preceding year – that is, $X_t = (1 \pm B) X_{t-1}$, where B is defined as the flexibility coefficient. Separate coefficients are customarily calculated for years of increasing and decreasing acreage. The model, in contrast to the traditional unrestrained linear programming solution, makes it possible to trace the path of adjustment in response to a change in the price of the product, a technological improvement, or an institutional modification such as a change in government programs. In the recursive model each successive solution is conditioned by the solution obtained for the preceding year.

The recursive programming model has been used mainly in attempts to explain or predict regional changes in the acreages planted to crops. The results obtained from recursive programming models and time-series analysis have been compared in several studies [289, 378]. These and other studies indicate that unrestrained linear programming models, and even recursive models, tend to overstate changes in acreage in relation to those that actually occur. In most cases regression equations based on time-series data have proved to be more accurate for forecasting than the results obtained from programming

models; however, when large, discontinuous changes occur, such as with the introduction of new technology or modifications in government policies, programming results sometimes provide the basis for improved forecasts over those made using regression analysis. In general, supply elasticity estimates derived from programming models are too high for predictive purposes although such analyses are useful in calling attention to the probable direction of change in supply in response to a major change in structure.[21]

A review of supply analysis would not be complete without mentioning the efforts that have been made to derive supply elasticities directly from production or cost functions. In theory, of course, only the shape of the production function plus information about factor prices (or factor demand and supply equations) are needed to obtain an estimate of how output is likely to respond to changes in either product or factor prices (for a review of the formal theory of deriving supply relationships from production functions, see [140]).

In practice, differences in production functions between farms, attributable in part to differences in the quality of land resources available and in part to differences in capital constraints and managerial ability, have made it difficult to obtain usable results from production function analysis. Likewise, specifying useful cost functions, especially when alternative opportunities must be considered, is difficult. For the most part, supply analyses based on cost or production functions have been confined to single-product firms or data obtained from experimental plots (for example, see [141, pp. 143-153; 291]). However, Wipf and Bawden [365] attempted to derive supply elasticities from whole farm production functions separately for all crops and livestock products. The general conclusion emerging from these studies is that supply elasticity estimates derived from production functions are not reliable.

Powell and Gruen [261] demonstrate considerable ingenuity in attempting to derive estimates of cross elasticities of supply based on the principles of production economics. Their method involves the derivation of a constant elasticity of transformation production frontier from time-series data. The assumption of constant elasticity of transformation, they reason, is realistic if only modest changes in product/product price ratios from existing or average ratios are to be considered. Using the results obtained from the constant elasticity of transformation frontier, they calculated a complete matrix of supply elasticities, including all cross elasticities for six major agricultural commodities produced in Australia (wool, lamb, wheat, coarse grains, beef, and milk).

Greater use of producer panels to determine the response of farmers to changes in price or other factors affecting supply has been suggested on several occasions, notably by Nerlove and Bachman in 1960 [244] and more re-

cently by Schaller [288]. Research by Conneman (see citations in [53]) illustrates the use of producer panel data in the economic analysis of milk production in the northeast. Conneman used Markov chains to analyze the implications of exits and entries of firms for milk supply,[22] but the translation of producer panel data into specific supply projections appears to be difficult. The same problems of sampling and aggregation apply to this technique as to linear programming analysis of supply.

Micro-Theory and Aggregate Supply

The concept of aggregate supply is especially important in agriculture, both for policy analysis and for forecasting. A knowledge of how total output is likely to change in response to an increase or decrease in the average level of farm product prices is necessary in order to predict the consequences of a change in price policy. Information concerning shifts in aggregate supply is essential in forecasting farm income since the average level of farm product prices is determined to a large degree by the shifts in aggregate supply over time relative to demand. As T. W. Schultz [293] emphasized, it is extremely difficult to match the growth of aggregate supply with demand. For this reason most countries are faced with one of two types of problems, either too much (a surplus problem and relatively low prices for farm products) if the growth of output exceeds that of demand or a food problem (deficits and high prices) if the reverse occurs.

Most of the concepts of aggregate supply now widely accepted by agricultural economists were developed in the 1950s and are embodied in papers by D. Gale Johnson [171], Willard W. Cochrane [47], T. W. Schultz [295], and Glenn Johnson [174]. These articles and especially the lengthy footnote to Glenn Johnson's paper, combined with the comments following it by Cochrane [49], provide a convenient summary of both the contributions and the controversies that have emerged regarding the concept of aggregate supply.

D. Gale Johnson's paper [171] emphasizes the critical role which factor supply elasticities play in explaining changes in factor/product price ratios (hence, factor use and output) when the average level of farm product prices declines. He argued, in conformity with the profit-maximizing principles of microeconomic theory, that a fall in product prices will be accompanied by a decline in the prices of at least some factors, particularly those with inelastic supply schedules. He found the empirical evidence consistent with his hypothesis, at least during the early 1930s. Since family labor, land, feed, and livestock had few alternative uses outside of agriculture during this period, the prices of these factors declined about as much as the prices of farm products. As a result, farmers found it economic to maintain the use of these factors at about the same level despite a substantial drop in farm product prices.

In contrast, the use of purchased inputs such as fertilizer, machinery, building materials, and hired labor declined because prices of these factors did not fall as much as average product prices.

Johnson cautioned against drawing general inferences about the elasticity of factor supplies, and hence the elasticity of total farm output, based on the experience of the depression years. Under conditions of more nearly full employment, the supply of labor undoubtedly would be more elastic, and hence the price elasticity of aggregate supply would be greater. Also, the analysis of the depression experience was based on the assumption of constant technology. A change in technology which shifted the production function upward could result in an increase in output despite a fall in average product prices.

Two contributions by Cochrane are especially noteworthy [47]. First, he drew a distinction between the static (ceteris paribus) supply function and a more general "response relation," which he conceded was a hybrid or mongrel relationship. The response relation perhaps is more useful for forecasting because it includes, among other things, the effect of technical change adopted in response to rising prices. Second, Cochrane was among the first to emphasize the importance of technical change in accounting for shifts in the aggregate supply function for farm products in the United States. As had other economists, he hypothesized that the aggregate supply response of producers to a fall in prices would be less than to a corresponding increase in prices. Cochrane's reasoning, however, was based more on the role of technology (as opposed to factor prices) and the differential rate at which technology was likely to be adopted in periods of rising prices in contrast to periods of declining prices. During periods of rising prices farmers have both the incentive and the necessary capital (out of retained earnings) to invest in output-increasing technology, but the process is not reversible. Once the new technology is adopted, it will not be abandoned. In periods of falling prices the output of the typical farm firm (and hence the total output) does not decline because of the lack of alternative uses for some factors of production, induced changes in the prices of factors with inelastic supply schedules, and a general commitment on the part of many of those in agriculture to continue farming despite low returns.

Technology, according to Cochrane [47], is the "dynamic force in agriculture, being involved in almost all production adjustments and explaining net increase in output on individual farms and in the aggregate." In Cochrane's view the modern farmer does not typically vary the proportions or quantities of existing factors over time; rather he changes to a new input mix based on a different technology. Since the rate of adoption of new technology is more likely to increase during periods of rising prices, the aggregate supply function

is likely to shift to the right discontinuously, mainly during periods of prosperity for farmers, and to remain static and severely price inelastic during periods of depression.

Cochrane dismisses two other factors as being relatively unimportant, at least in the United States, in shifting the supply curve for farm products—namely the weather (which shifts the curve temporarily but not permanently) and the increased use of conventional inputs. His analysis seems to fit much of the twentieth-century experience in the United States, but not necessarily that prevailing in many less developed countries. In Brazil, for example, during the 1950s and 1960s, increases in total farm output were mainly a function of an increase in the land area and a corresponding increase in the amount of labor devoted to agriculture without any major changes in technology.

T. W. Schultz [295] also emphasizes the role of technology in shifting the aggregate supply function in the United States. Increases in conventional inputs, he points out, do not account for the sharp rise in aggregate output which has occurred in the United States. Hence, the increase must have been due to the addition of what he calls "unconventional inputs," mainly associated with improvements in the quality of the labor force and new technology. Since these appear to be the critical variables in increasing output, he stressed the importance of devoting more attention to methods of producing and distributing such inputs.

Glenn Johnson's contribution to the concept of aggregate supply has been to emphasize the role of fixed assets in limiting supply response to a change in product prices. An asset can be defined as fixed, according to Johnson [171], "so long as its marginal value productivity in its present use neither justifies acquisition of more of it or its disposition." The use of a factor is likely to remain constant over a wide range of product prices if the salvage value or opportunity cost of that factor outside of agriculture is much below the acquisition cost.

The Johnson model implies that the supply schedule for the fixed factor is a stepped function, highly elastic at the salvage value, and again at the price at which additional units can be purchased, but highly inelastic in between. The greater the length of the inelastic or vertical segment of the function, the less responsive factor use will be to changes in product prices (that is, the marginal value product or demand curve for the factor can move up or down over this range without affecting factor use). Johnson argues that the salvage value of such inputs as family labor, previously acquired machinery, and land is relatively low and likely to be less in most cases than their value in use; hence, such inputs remain employed even when a substantial decline occurs in farm product prices. While the conceptual model is useful in categorizing inputs,

the conclusions drawn from the model are no different from those reached by other agricultural economists. Namely, the lack of profitable alternative uses for certain inputs such as family labor limits the response of supply to a fall in farm prices, at least in the short run, and especially in periods of general depression.

Empirical studies of aggregate supply are limited both by the lack of data in many countries and by the presence of strong trend factors in the dependent as well as the major explanatory variables. This makes it difficult to identify and separate the effects of shift variables such as technology from the effects of changes in relative prices. Despite the difficulties involved, agricultural economists have obtained what appear to be reasonable and useful estimates of the aggregate supply relationship for the United States. Among the empirical studies most frequently cited are those done by Cochrane [46, 48], Griliches [116, 118], Heady and Tweeten [141] and Tweeten and Quance [336]; for critiques of [336], see [42] and [368].

Cochrane's analysis is based on scatter diagrams with an index of per-capita food production for sale on the horizontal axis and an index of "responsible" prices on the vertical side. He determined by inspection approximately when the supply schedule had remained stable and when it had shifted. This analysis suggested that the schedule shifts to the right in a hopping or skipping fashion rather than smoothly and continuously. The two major shifts which appear to have occurred between 1910 and the early 1950s are attributed by Cochrane to the introduction of tractors in the early 1920s and the sharp rise in farm product prices during the war years of the early 1940s [48].

Griliches [116] was among the first to attempt to estimate the elasticity of aggregate supply based on an analysis of the response of factor use to a change in farm product prices. The elasticity of aggregate supply is simply a product of the weighted average of changes in factor use induced by a change in average farm prices. The weights are determined by the response of total output to a change in the quantities of each factor employed or simply by the elasticities of production. Algebraically, the relationship can be expressed as

$$E_{op} = \sum_{i=1}^{n} E_{oi}E_{ip}.$$

E_{op} is the elasticity of total output with respect to product prices; E_{oi} is the elasticity of production with respect to the ith factor; and E_{ip} is the elasticity of factor use with respect to product prices. Griliches used time-series data and a form of the Nerlove distributed lag model to estimate the response of several categories of inputs to a change in farm prices. He then multiplied the

separate estimates of short-run and long-run elasticity of factor use by estimates of production elasticity based on factor share (the proportion of total value of output attributed to each category of inputs) to obtain aggregate short-run and long-run supply elasticities for United States agriculture.

Tweeten and Quance [336] used a similar procedure to estimate the aggregate elasticity of supply for the United States.[23] They also obtained direct estimates using time-series data. The most important variables in explaining changes in total output were the stock of productive farm assets (the value of real estate, machinery, livestock), lagged values of the ratio of prices received to prices paid by farmers, and a productivity index closely related to time or trend. The results, in general, confirm the hypotheses outlined earlier, namely that the elasticity of aggregate supply for the United States is positive but low, at least in the short run, and slightly greater during periods of rising prices than in periods of falling prices. Tweeten and Quance did not find any evidence of a significant change in elasticity in the postwar years as compared with the interwar period. This is contrary to the views of some economists who reasoned that aggregate supply should now be more elastic because of greater reliance on purchased inputs which are likely to have relatively elastic supply schedules.

Demand and Supply of Farm Inputs

Since changes in farm output depend on changes in the quantity and productivity of resources employed in farming, it is not surprising that the interest in product supply has led to the study of variables which are thought to explain the levels of resource use. The "farm problem" of surplus production and low prices generated substantial interest in the demand and supply of agricultural inputs in the 1950s and early 1960s (for example, [60, 115, 290]). T. W. Schultz [293], in particular, stressed the relationship of factor markets to the farm income problem. The zenith of such research in that period was Heady and Tweeten's *Resource Demand and Structure of the Agricultural Industry* [141]; this comprehensive book emphasizes estimates of demand relationships for numerous resources, including fertilizer, labor, machinery, plant and equipment, and certain operating inputs. In a limited amount of space it is impossible to examine all of the topics and issues related to the study of farm inputs. Our discussion focuses on traditional, as well as more recent, approaches to the estimation of structural relationships.[24]

Economic theory suggests that one could begin by estimating a production function and proceed to derive factor demand relationships. Heady and Tweeten [141, chapter 6] explored this approach, but in practice it is rarely used. Problems in deriving factor demand functions from production functions are similar to those discussed above in deriving product supply curves

from production functions. Consequently, most estimates of input relationships have involved direct least squares regressions using time-series data. The models have often used a geometric-form distributed lag specification. The functional form of the demand equation is sometimes suggested by assuming a particular shape of the underlying production function [115]. Thus, the price of the input under analysis, prices of other inputs, and price of the relevant product (or products) are plausible explanatory variables in a demand equation for an input.

Renshaw [272] discusses the problems of specifying demand shifters and functional forms as well as the difficulties associated with geometric-form distributed lag models in the context of Griliches's study of the demand for fertilizer [115]. For instance, how does one take account of the effect of the adoption of hybrid corn on the demand for fertilizer? Notwithstanding Griliches's rather sharp reply [272], the difficulties of estimating and interpreting equations with a lagged dependent variable, particularly when this variable is trending, are now well documented.

Schuh's analysis [290] of the market for hired labor treats wages and employment as being simultaneously determined by the supply and demand for labor. The predetermined variables in the demand equation are an index of prices received by farmers, an index of technology, and the lagged dependent variable; the predetermined variables in the supply equation are the size of the civilian labor force, deflated nonfarm income, and the lagged dependent variable. This research was subsequently extended to a six-equation model involving the supply of and demand for hired labor, unpaid family labor, and operator labor [337].

Price (wage) elasticities of demand for hired labor were found to be inelastic in most studies, even in the long run. Recent work by Hammonds, Yadav, and Vathana [128] suggests, however, that the wage coefficient is becoming more elastic with the passage of time and perhaps is now about -2.0.

Two papers [147, 335] in 1966 were concerned with the puzzle of why farm real estate prices had risen in the face of low farm incomes. Herdt and and Cochrane [147], using a two-equation simultaneous model, conclude "that the expectation of rising income from technological advance in conjunction with supported farm prices . . . has been important in contributing to the rise in farm land prices." Tweeten and Martin [335], based on a recursive system of equations, reach a similar conclusion, though they use different terminology and attribute higher land prices "to pressures for farm enlargement and capitalized benefits from government programs."

Technological advance and changes in the quality of inputs create questions and problems beyond how a technological change may influence the demand for an input or how that change may be incorporated into the demand

function. For example, the nature of the input itself can change. Studies of the demand for farm tractors have tried to take account of the important changes in the quality of tractors [271]. Fettig [81] discusses the problem of constructing an index of tractor prices which attempts to hold quality constant.

Since the demand for a durable input like tractors is a derived demand for a flow of services from the input, a problem exists in defining the price of the service. The price of a tractor represents the price of providing the stock of tractors from which services come. Another question in model specification for durable inputs is how to account for replacement investment. Rayner and Cowling [271] provide an excellent review of literature on the demand for farm tractors and the issues of model specification. Such variables as lagged farm income and the stock of tractors appear to be important explainers of gross investment in tractors in the United States, but "the parameter estimates are not well determined" [271].

Despite a considerable amount of research in the 1950s and early 1960s, agricultural input markets were considered a neglected area of research as late as 1962 [64]. In the past five to ten years there has been an increase in work in this subject area, but relative to product price analysis input prices still might be considered a neglected topic. A bibliography by Dahl, Anderson, and Peterson [64] provides a useful set of citations of research on purchased farm inputs, and a report edited by Nelson [236] gives additional references. Recent work covers such diverse inputs as feed, farm building, farm credit, and machinery.

Recent research continues to include conventional time-series analyses [143]. However, the newer work has also involved different data sources, such as farmer panels, and different research tools, such as probit and variance component models. Some recent developments in input research are summarized in [236].

An analysis by Daniel and Havlicek [67] illustrates the use of data from a farm panel to estimate fertilizer demand functions. Monthly observations were obtained from nine hundred Illinois farmers for the years 1961-65. The variables included in the models can be classified as economic factors, characteristics of the farm, characteristics of the farm operator, and trend, adjustment, and weather factors. Prices of fertilizers generally were statistically significant in the various equations, and the short-run demand for straight nitrogen was estimated to be price elastic while the short-run demands for phosphate and potash were inelastic.

Daniel and Havlicek [67] also compared their results with other studies, and the differences are disconcertingly large. While Heady and Tweeten found the demands for all of the various fertilizers to be quite price elastic (-1.24 to

-2.14) in aggregate analyses for the United States, Yeh and Heady reported inelastic demands (-0.40 to -0.45) for the same nutrients. These studies are, of course, based on quite different sets of data, but further research is required if the inconsistent results from aggregate time series, individual farmers, and production function studies are to be explained. In addition, it does not seem likely that the fertilizer models extant in 1973 could have accurately predicted the demand for fertilizer in 1974.

Analysis of Price Relationships

In theory, all prices are interrelated, though in practice some prices are essentially independent. An understanding of relationships among prices is important both for private and public policy decision making. Consequently, agricultural economists have explored a wide variety of price relationships. Those for substitutes were reviewed earlier. In this section we consider relationships under a competitive market structure at different stages of the marketing system, at different points in space, and at different points in time. In addition, the literature on price discrimination schemes in agriculture is briefly reviewed. We conclude this section with a short examination of the literature on farm-nonfarm price relationships.

Marketing Margins

Agricultural economists have devoted particular attention to the integrating role of price and especially to the relationship between prices at the farm level and those at the wholesale or retail levels. Among the questions they have sought to answer are whether or not changes in farm prices are promptly and fully reflected in retail prices, whether margins are too large, whether marketing margins remain constant per unit sold or vary with the volume sold, and whether and to what degree changes in margins influence farm and retail prices.[25]

Both theory and empirical observation suggest that changes in retail prices are likely to lag behind changes in farm prices and that retail prices tend to be somewhat more inflexible. Numerous hypotheses to explain the sticky response of retail prices in the face of increased or decreased farm supplies have been advanced. Inertia in the marketing system unquestionably accounts for some of the delay in transmitting price changes through the system. Breimyer [29] argues, in general terms, that stickiness in retail prices is due partly to the preference of marketing firms for price stability. Parish [251] attributes the same phenomenon to both cost and demand considerations.

Buse and Brandow [44] studied the relationship between marketing margins and quantities marketed for twenty commodities. In one type of equa-

tion [44, table 3] they found an inverse relation between the volume marketed and the farm-retail price spread. However, when quarterly observations were used for a few of the commodities, the results suggested the opposite conclusion. A problem may exist in the specification and identification of such equations; a price-quantity relation might be either a demand for or a supply of marketing services equation. In any case, the empirical evidence on the nature of price-volume relationships is inconclusive. Brandow, in his study of price interrelationships [24], ultimately decided to relate farm to retail prices by an equation which makes the total margin the sum of a fixed value plus a variable amount related to volume.

Among the most useful sources of information on the relationship between farm and retail prices are the publications on price spreads published by the USDA (for a recent summary, see [296]). Ogren [248, p. 1371ff.] summarizes some of the issues in interpretation and the problems of measurement. The National Commission on Food Marketing [235] considered whether or not farm-retail price spreads are too large. They concluded that few, if any, unnecessary physical functions exist in processing and distributing foods, but that some selling costs could be reduced without reducing the value of the final products to consumers.

Freeman [90] has investigated the impact of changes in marketing margins from 1947-49 to 1961-63 on the farm prices of selected commodity groups. His analysis indicates that the incidence of increased margins was on both farm and retail prices.

Spatial Relationships

Price relationships in physical space have been subjected to detailed analysis. A number of studies have been made of geographic differences in prices simply to determine whether or not serious imperfections exist in pricing systems. Such studies have recently included price behavior in less developed countries. (Studies of pricing institutions are reviewed in a later section.)

A knowledge of spatial price relationships is essential if the problem is to estimate the effect of a change in production or in demand in one region or the effect of a change in transfer costs on the competitive position of particular regions. Spatial price equilibrium models provide a framework for the analysis of changes in demand, supply, and transfer costs on the geographic structure of prices and on the volume and interregional movement of the commodity. This analytical technique also has been used to note the presence or absence of market imperfections since the model provides a set of theoretical prices which can be compared with actual prices. Spatial models provide a diagnostic tool, helping to define the existence of a problem rather than explain why it exists [186, p. 5]. These models also have been used to deter-

mine whether regional differences in support prices for grains are consistent with those expected under perfectly competitive conditions [205], and the regional impact of reducing grain production has been studied [57].

Fox and Taeuber [88] made one of the first applications of a spatial price equilibrium model to an agricultural commodity. Subsequently, Judge and Wallace [182] provided a succinct summary of a model and illustrated how internally consistent "shadow" prices can be obtained from the dual solution to the cost minimization transportation problem.

Agricultural economists have used various spatial price equilibrium models to estimate the geographic structure of prices for a number of commodities in the United States, including livestock [180, 183], grain [121, 205], apples [22], and milk [359]. In addition, models have been used to estimate the structure of prices of internationally traded commodities that might be expected to prevail among countries under competitive conditions (that is, in the absence of import restrictions or tariffs). Sugar [7] and oranges [380] are among the commodities that have been studied.

Leuthold and Bawden [210] prepared a bibliography of spatial studies in 1966. The spatial dimensions of market prices are explored in detail by Bressler and King [32]. Takayama and Judge [320] provide numerous spatial models in their comprehensive book; they start with the classical transportation model (supply and demand quantities given), move to models with regional supply and demand functions (quantities endogenous), and also extend the single commodity model to multicommodity formulations.

While spatial price equilibrium models provide a logical basis for estimating the geographic structure of prices, the squared correlation coefficients between actual prices and those computed from the models are usually less than 0.5 [346, p. 16]. The small correlations may be evidence of imperfections in the pricing system, but they also may be due to unrealistic models and inadequate data. The typical model assumes that all units of the commodity are homogeneous and originate or are consumed at a particular point in each region. Furthermore, decisions to move a unit of commodity are assumed to be based solely on an optimizing rule (for example, minimizing transfer costs). Thus, intraregional assembly and distribution costs as well as traditional relationships between buyers and sellers may be ignored. Ultimately, the adequacy of a spatial model must be judged relative to the problem under study [68].

Intertemporal Relationships

Studies analogous to those made for spatial price relationships have been made for seasonal and interseasonal price behavior (studies emphasizing imperfections in pricing systems and the intertemporal aspects of futures mar-

ket prices are cited in a later section). Likewise, spatial price equilibrium models have been extended to include temporal price relationships. King and Henry [187] illustrate how time as well as space can be incorporated into the transportation model. Takayama and Judge [319] incorporate time as an element in a more complex quadratic programming model, which permits the use of regional and seasonal demand and supply functions. The recursive and simultaneous systems discussed earlier are of course models of intertemporal behavior. In this section, however, we limit the review to a brief discussion of the literature of intraseasonal and interseasonal storage rules.

Agricultural price analysis and agricultural price policy are closely associated in studies of storage rules, buffer-stock schemes, and other proposals which have such objectives as stabilizing prices or returns, increasing returns to producers, or increasing consumer welfare. The thrust of much of the analysis has been on the effects of proposed programs on price stability or on the revenue of producers. Eckstein and Syrquin [75] provide a useful summary of the relationship between the price elasticity of demand and returns from storage in the context of output instability.

A very large literature is available on price stabilization programs, buffer stocks, and related topics. Although this literature is not within the scope of our review, it is possible to observe that much of the literature is descriptive and assumes rather simple models of price behavior and that little of it involves empirical work (but see [355]).

Analyses of United States data by Gustafson [122, 123] and by Gislason [100] suggest that returns to producers based on optimal storage rules for year-to-year carryover of grains are very little larger than those obtained from competitive allocations of stocks. In a study of the Canadian Wheat Board Gislason [101] concludes that the board sustained substantial speculative losses in carrying inventories and hence "that the overall price to the Canadian farmers would have been greater if there had been no . . . interference with marketing Canadian wheat." Powell and Campbell [260], however, extend Gislason's paper by examining nonspeculative returns from buffer-stock schemes. Additional price analysis studies of real world data would be useful for appraising the effects of stabilization programs.

Price Discrimination

The principles of price discrimination have a long history of applications in agricultural economics (for example, [357]), and most of the contributions to the current literature involve applications of ideas developed in the 1930s. Forker and Anderson [86] provide a convenient bibliography.

A price discrimination model commonly considered in agricultural economics involves the allocation of a fixed quantity (a given crop) to alternative

markets. The mathematical problem is to maximize revenue (net of allocation costs) subject to the restriction that the total quantity available is sold. With this equality constraint, Lagrangian (classical calculus) methods may be used to obtain the constrained optimum (see [352, pp. 87-91]).

One contribution in the postwar literature is the use of mathematical programming techniques to obtain solutions to the allocation problem. Models may be formulated so that the quantities sold to the alternate outlets are restricted to be equal to or less than the total supply available. With linear demand functions quadratic programming is used to compute the optimal allocations of quantities and the corresponding prices [197, 212]. Louwes, Boot, and Wage [212, p. 314] also illustrate how a policy constraint (to limit relative price changes to some "acceptable" level) can be incorporated into the optimization problem.

Numerous methods of separating markets have been explored in the literature. One approach is through alternate *forms* (say, fresh as opposed to processed forms) of a commodity. Milk [132, 197, 212] is an important example. Fresh fluid milk is treated as the primary market with the relatively price inelastic demand; processed dairy products are the secondary markets with the relatively less inelastic demands. The difference in form can be extended to include allocations based on quality or variety [356]. David Price [266] suggests that returns can sometimes be increased by discarding low-quality fruit even though the demand is price elastic.

Time is a second method of separating markets. Analysts, for instance, have explored the seasonal demands for apples to estimate the seasonal allocation of apples for fresh use to maximize returns to apple growers as a group [12, pp. 30-34]. *Space* is still another method of distinguishing between markets. Export demands are thought to be relatively more price elastic than domestic demand. Abel [1] argues, however, that as minimum-import-price schemes become more widespread it may become more profitable for exporters to charge higher prices in export markets than in their own domestic markets. For example, wheat exporters perhaps should sell wheat to developed countries (with trade barriers and relatively price inelastic demands) at relatively high prices and sell the remainder to less developed countries (with more elastic demands) at relatively low prices.

Lemons [152, 154] are illustrative of a commodity for which space, time and form all might be used in a price discrimination program. This would involve allocations between fresh use and processed products, allocations among seasons, and allocations between domestic and export markets.

The relatively long interest in the use of price discrimination models in agricultural economics has provided insights into the limitations of these models. The optimal allocations are necessarily based on *estimated* demand

functions and allocation costs. Thus, the computed allocations and prices may be incorrect because the estimated information is wrong. (For alternate estimates of demand functions in [154], see [150, pp. 20-22].) Empirical models point to directions of change rather than to precise optimums.

Models often assume that markets are independent when in fact they are not. It may be necessary to take account of the substitutability among markets (for example, processed products are often, to some degree, substitutes for the fresh form). Roy J. Smith [302] outlines some limitations of discriminatory pricing with special reference to the experience with lemons. He argues, among other things, that since 1949 processed lemon products, such as frozen lemon concentrates and lemonades, have become more competitive with fresh products. Thus, elasticities based on earlier data (when the substitution relation was zero or small) do not reflect the current substitutability between fresh and processed lemons.

Closely related to the question of structural changes in demand (from new products) is the question of short-run versus long-run elasticities. A program which raises a price to a new level and holds price at that level should be appraised in terms of long-run coefficients.

Smith [302] also presents data which suggest a substantial supply response to the initial improved returns from the lemon program. With the increased production and the consequent increased diversions to the secondary processing market, average returns are reduced to producers. Thus, without supply control, Smith points out, in the longer run a two-price program does not necessarily increase returns to producers. Jamison [168] draws a similar conclusion in his study of cling peaches.

Farm-Nonfarm Price Relationships

Little of major significance has been added to the literature in recent years regarding the average relationship between prices received for farm commodities and prices paid by farmers for items used in production. This topic, of course, received extensive treatment in the United States during the 1920s and 1930s, and ultimately the parity concept was institutionalized in legislation. Current information on the relationship between prices received and paid is now available for at least nineteen countries. These figures are rereported in the Food and Agriculture Organization's *Monthly Bulletin of Agricultural Economics and Statistics.*

The parity ratio and particularly the continued use of a 1910-14 base period have been widely criticized by agricultural economists in the United States (for example, [332, pp. 195-196; 344, pp. 369-371]). Nevertheless, some who use the figures seem unaware of the deficiencies and insist on using

the parity ratio as a measure of the well-being of farmers and parity prices as indicators of the "fairness" of existing prices. A USDA publication [338] prepared mainly by R. J. Schrimper and B. R. Stauber, provides a concise summary of what parity does and does not measure. In response to a request from Congress the USDA prepared a lengthy report on parity in 1957, which contained a number of suggestions for modifications [259].

Farm prices continue to fluctuate with greater amplitude than the prices of most nonfarm goods and services. Thus, there is great instability in relative prices – the terms of trade of farm products. The factors which contribute to this instability are well summarized by T. W. Schultz [293], Cochrane [48], and Hanau [129]. Short-run fluctuations in farm prices are attributable mainly to fluctuations in supply, often arising from the biological nature of the production process, and to the relatively price inelastic aggregate demand and supply functions. Cochrane [48] and Tweeten [334] are among the authors providing empirical evidence on the inelasticity of aggregate demand. Longer-term trends in prices are often associated with shifts in demand relative to supply.

A number of contributions to the literature have considered relative prices in international trade, in particular the terms of trade of agricultural exporting countries. Prebisch [264] has hypothesized that a long-run tendency exists for the terms of trade to move against agricultural exporting nations. Studies of the relationship between the prices of agricultural commodities exported and manufactured products imported by less developed countries (alternatively, between agricultural imports and industrial exports of such developed countries as the United Kingdom), however, do not show any clearly established tendency for the terms of trade to move against primary products [222, 232, 258]. What the evidence does show is that the terms of trade are unstable and that conclusions drawn with respect to changes in the terms of trade are particularly sensitive to the beginning and ending years used to establish trends.

Analyses of the effects of inflation on agriculture, other than general descriptive studies, are limited. Brandow [23] has pointed out the differing impacts of demand-pull and cost-push inflation on agriculture. He also argues that resource misallocations in farming attributable to inflation are minor in comparison to the magnitude of resource adjustments attributable to technical change and to governmental farm programs. Hathaway [134] has summarized the general economic relationships between the nonfarm and farm sectors. Such interrelationships might be formalized in an econometric model, but most economywide models treat the agricultural sector as exogenous (for a succinct summary of large models, see [94]).

Topics in Quantitative Price Analysis

The literature reviewed to this point emphasizes models in which price and quantity variables are functions of certain explanatory variables. A considerable literature exists, however, on empirical descriptions of time-series variables. Emphasis is usually placed on decomposing such variables into systematic and random components. Another important area, not reviewed elsewhere, is the literature on handling qualitative variables in price analysis models. A qualitative variable, such as seasonality, could appear either in a behavioral equation like a demand function or in a descriptive time-series analysis. In this section we briefly review the literature on time-series models and on qualitative variables.

Models of Time-Series Behavior

An individual variable observed with the passage of time, such as price or production, is sometimes viewed as being composed of trend, seasonal, cyclical, and random (irregular) components. A very substantial amount of empirical price analyses has involved the description or decomposition of a time series into its components, in particular trend analysis. These applications are far too numerous to cite. We review selected developments.[26]

A random walk model is perhaps the simplest model of time-series behavior. This model states that price changes cannot be predicted from past price changes; they are equal to random disturbances.[27] Somewhat more complex models view time series as having moving average and/or autoregressive properties. Bieri and Schmitz [15] review various moving average and autoregressive models and then apply these models to predict wheat yields, daily hog prices, and daily hog supplies. The models and methods used, they argue, are more suitable for prediction than spectral analysis. Fuller [15], in discussing the Bieri-Schmitz paper, indicates that such models are not very new; recent developments emphasize ease of understanding models, estimation procedures, testing, and diagnostic procedures.

Common methods of measuring and removing seasonal and cyclical components, such as moving averages and indexes, are subject to criticism. Traditional seasonal adjustment methods may remove more from a times series than can properly be considered as seasonal [242], and they may introduce nonseasonal (nonrandom) elements into the series. In studying leads and lags between two series, emphasis is placed on subjective evaluation of what constitutes peaks and troughs of cycles and, hence, the length of a cycle. Thus, there has been some interest in using alternative procedures to measure components of time series.

Harmonic analysis, which makes the time series a function of sine and co-

sine variables, is especially relevant when the series contains a cycle with a known period, such as a twelve-month seasonal cycle. Doran and Quilkey [74] provide a useful review of the harmonic model, including relevant references and applications in agricultural economics.

Spectral analysis, an outgrowth of work in the 1940s, was applied to economic time series starting in the early 1960s [107]. It is a method with a rigorous mathematical foundation for decomposing time-series data into components. Spectral analysis decomposes a series X_t into a large number of independent components, each associated with a different frequency; the relative importance of any group of frequencies is measured by their contribution to the variance of X_t; the bands of frequencies which make relatively large contributions can be associated with particular periods (seasons, cycles).

Spectral methods may be used to determine the empirical characteristics of a time series (for example, the existence of a cycle), and they also may be useful in preliminary analyses of data to appraise leads and lags between variables, which in turn may suggest "causal" relationships. A large number of observations (say, larger than one hundred) is required to use spectral techniques. In addition, the spectral model is based on a stationary process (an assumption typically not met by economic time series), and hence some data transformation usually is required as a preliminary step to approximate this assumption [269, pp. 113-114].

Rausser and Cargill [269] have applied spectral analysis to monthly broiler price and supply variables. Traditional methods of time-series analysis imply a broiler cycle of about thirty months. Rausser and Cargill conclude that the spectral results do not support the hypothesis of well-defined cycles in the broiler industry. Weiss and Melnik [358], in a spectral study of monthly egg prices, find evidence for a thirty-two-month cycle, which they call "mild" but significant. Labys and Granger [193] apply spectral as well as other techniques to a variety of price series from commodity futures markets.

Doll and Chin [73] suggest a rather interesting application of principal components in price analysis. If a researcher wished to study the common and independent movements of a set of price series such as farm, wholesale, and retail beef prices, the principal components of the prices could be computed. If, for example, the first component is highly associated with all three series, then this component is related to those factors which "explain" the common movements of the prices, and if the second component (which by definition is orthogonal to the others) is closely associated with only one of the series, then this independent element of variation can be analyzed. Doll and Chin suggest using the principal components, rather than the prices, as dependent variables in regressions in order to analyze the common and independent elements of variation of the three time series.[28]

Analyses Involving Qualitative Variables

Price analysts have frequently made use of models to take account of qualitative explanatory variables; this is usually done by using zero-one variables in regression equations (fixed effects covariance models). Suits [315] provided one of the earlier discussions of dummy variables in the economics literature. A common use is to take account of seasonality in analyses of monthly or quarterly observations [211]; a second area of application involves using such variables to distinguish between regions or race in cross-section data [206].

The zero-one variable specification states that the intercept parameter changes as the alternate levels of the qualitative variable (say, season) change. The slope parameters are assumed not to change. This assumption is consistent with the typical specification of regression models, which assume that the parameters of explanatory variables are not systematically influenced by changes in the size of other explanatory variables. Interaction models are applicable for some research problems, however. Ben-David and Tomek [11] consider the possible interaction between a qualitative and a quantitative variable (hence, a slope change for the quantitative variable), and apply [12] such a model to a seasonal demand equation for apples.

In a study of supply the dependent variable could involve adopters and nonadopters of a new variety; in a study of demand the dependent variable could include buyers and nonbuyers. This dichotomy can be represented by a zero-one dependent variable.[29] While standard least squares procedures have often been used for such models, probit analysis (or a similar method) is usually preferable [325]. Kau and Hill [185] have applied a probit model to the problem of a purchase decision.

Somewhat related to the idea of a zero-one dependent variable is the idea of discriminating between groups. Blood and Baker [16] compare discriminate analysis and linear probability functions as techniques for delineating situations which favor wheat production versus range forage production in the northern Great Plains. This perhaps is one of the earliest applications of these tools in agricultural economics, though the tools certainly have had applications much earlier in other areas.

Time-series observations on a cross section of individual consumers, firms, or political units are becoming increasingly available. This suggests pooling time-series and cross-section observations for empirical analyses. The usual procedure has been to take the time and firm effects into account through a fixed effects covariance model. Recently, economists have turned to so-called variance components models, which have a much longer history in biometrics [297]. Models of this type have a composite error term, which includes ran-

dom components specific to the cross-section effect, the time-series effect, and a component common to both. Girão, Tomek, and Mount [98] use such a model in estimating consumption and investment functions for a sample of farm households observed over seven years.

Supply-Demand and Price Outlook

Agricultural outlook work is, broadly speaking, of two types: short term, including time intervals up to one or two years, and long term. Both types of outlook involve empirical analyses combined with large elements of judgment. One of the potential applications of the models reviewed to this point is to aid in making forecasts. However, in 1970 Haidacher [125] examined the twenty-eight most recent issues of the *American Journal of Agricultural Economics* and found that only five of forty-one price analysis articles gave forecasting as the initial objective. Waugh [352] also argues that forecasting should be the primary objective of a much higher percent of price analysis studies.

Empirical techniques employed by those doing outlook work range from simple tabular analysis to the use of formal quantitative models. Most outlook work until recently has been based on fairly simple analytical procedures. Of the less formal procedures the balance-sheet approach is a way of summarizing large quantities of data to determine whether surpluses or deficits in supplies are likely to exist at some future date if current prices prevail [6]. This enables the forecaster to anticipate the direction of price changes. Graphic methods of analysis are used frequently in outlook work, and Waugh [353] provides a summary of these tools.

A simple but useful procedure in short-run outlook is to take advantage of known data on stocks, size of breeding herds, and biological time lags. For example, the number of beef calves available for placement in feedlots is limited by the size of the beef cow herd. Walters [348] uses this approach in forecasting the components of the beef cattle inventory.

Short-term outlook material prepared by USDA economists is published regularly in the well-known "situation reports." These provide useful summaries of current data and give general indications of prospective changes in prices in the next three to twelve months, but they seldom provide specific forecasts (with the exception of recent issues of *Livestock and Meat Situation*). Occasionally, a section or article is included which reports on specific econometric studies; an example may be found in a recent issue of *Fats and Oils Situation* [220].

Bargaining for prices by farmers and food processors often leads to the development of forecasting models. Work conducted at Michigan State Univer-

sity for apples and red tart cherries [275] and in California for cling peaches and other fruits [153] is illustrative of the response by agricultural economists in land-grant universities to the needs in this area.

Projections made by economists associated with private firms are generally prepared for internal use and consequently are less likely to be published. Outlook-related research of private firms, as well as other work, is considered in a recent series of articles [62].

Criticisms and suggested improvements in outlook are discussed in a series of papers presented in 1966 under the title "Is Agricultural Outlook Meeting Today's Needs?" [8]. Among the topics discussed are data problems, the analytical basis for outlook, the accuracy of forecasts, and the objectivity and independence of analysts. Less attention was devoted to whether outlook statements really influence decisions, and if so, whether there are feedback effects. Smyth [303] provides a theoretical model for considering the effect of public forecasts on price behavior, using a cobweb framework, and includes a brief review of the relevant literature. In theory, public forecasts should be price stabilizing.

Crom [58, 59, 318] stresses simulation as a tool to improve econometric models for making projections. Given the estimated model and the initial conditions, simulations are made both over and beyond the range of the original data. When substantial errors are observed between the simulated and observed data, the potential causes of the errors are analyzed. This analysis is used to make model revisions, to introduce operating rules, such as changing the value of a parameter under certain circumstances, and so forth. At each step the simulations are repeated to determine whether the changes create unexpected errors in an earlier period. This interplay between the model builder and the simulations continues until the historical data are reproduced with "acceptable accuracy" [58].

Agricultural economists have devoted thousands of man-hours during the past two decades to making long-term projections of demand and supply, both for individual products and for food in total. This is a response, at least in part, to a widespread demand on the part of national governments for information that can be used in formulating policies and development plans. For the most part, long-run projections are based on past trends. For demand, the analyst may consider trends in per-capita use (which of course reflect per-capita availabilities) and population; also, some attempt is usually made to estimate the effects of growth in real income on demand through the use of income elasticities. Goreux [105] describes techniques commonly used in making demand projections, summarizes the assumptions, and reviews the results of studies made in seven countries.

Projections of output are usually based on separate analyses of trends in

yields and acreage (or animal units). The initial estimates may be modified on the basis of judgments of scientists regarding future developments in technology, hence changes in yields. Methods employed by USDA economists in making projections are reviewed by Daly [66] and Rogers and Barton [282].

Among the most frequently cited global projections are those published by the Food and Agriculture Organization [82, 83], the USDA [2, 36, 339], and the President's Science Advisory Committee [265]. In addition, a large number of projections of demand and supply, especially for export crops, have been made for particular regions (for example, [213]). Many countries have made similar studies (for a recent United States study see Culver and Chai [63]); some of the results have been published in English [120, 234, 343].

A detailed appraisal of the numerous long-range projections is beyond the scope of this paper, but some general observations are possible. Global forecasts of food shortages or surpluses tend to be conditioned by the situation at the time the forecasts are made. For instance, forecasts for the 1970-75 period made in the early 1960s emphasize the likelihood of surpluses, whereas forecasts made in the mid-1960s, when surpluses disappeared, tend to be much more pessimistic about the possibility of avoiding food shortages.

Another limitation of most projections is their inability to take account of the influence of weather variations. The weather is one of the most critical variables affecting supplies in a particular year and even over a period of years. In the case of tree crops, freeze damage may shift the whole pattern of production. Apple prices in the United States, for example, have not followed the cyclical pattern predicted by French [91], at least partly because a severe freeze killed or injured trees in a major producing area after the projections were made.

Forecasts of production have also been weak because of unanticipated technical improvements. This may also influence forecasts of changes in consumption since consumption is based on available supplies. For example, projections of United States beef consumption for 1975 made in the mid-1950s were much too low [66, p. 82]; similar errors were made in projecting United States corn yields [282, p. 9] and exports [66, p. 85].

Sanders and Hoyt [287], after reviewing four global studies of demand and supply projections for food, pointed out that the demand projections were of similar magnitudes (based on similar estimates of population, income, and income elasticities) but that the supply estimates were inconsistent. Yield projections tend to be much more variable than demand projections.

Most long-run projections do not include adjustments for the possible effects of changes in relative prices, but the study of Bonnen and Cromarty [18] is an exception. They used a two-step procedure in an attempt to incor-

porate price effects into the analysis. They first made tentative estimates separately for demand and supply relying on methods similar to those outlined above. They then resolved the separate projections by using available elasticity estimates.

Unfortunately, no attempt has been made to measure the benefits and costs associated with making long-term projections. We live in a society which needs and wants knowledge of the future, but in view of the inaccuracies of the longer-run projections the question of whether the returns have justified the costs can at least be raised. Short-run outlook statements obviously are useful to processors and other middlemen, but perhaps less so to farmers who generally have longer planning horizons. Hayami and Peterson [137] have attempted to measure the returns of reducing the sampling error of crop and livestock statistics. Benefits are potentially available from adjusting both inventories and production to new and better information. Hayami and Peterson [137, p. 129] conclude that "the investment in increasing accuracy for agricultural production statistics exceeds its cost by a wide margin." In general, additional work to improve short-run forecasts seems justified.

Price-Making Institutions

Price analysts, it seems fair to say, have emphasized the economic forces determining prices and have been less concerned with the influences of pricing institutions on price behavior. Nonetheless, the literature includes classification schemes for pricing methods and evaluations of pricing mechanisms, especially their influence on both the level and the stability of prices. Futures markets are sufficiently unique and have such a large body of literature that this component is reviewed in a separate subsection. Governmental policies and programs are, of course, important institutions, but they are the subject of separate articles by G. E. Brandow and by D. G. Johnson (parts III and IV in this volume).

Alternative Pricing Methods and Price Behavior

Several classification schemes for pricing arrangements in agriculture have been suggested [30, pp. 8-13; 279; 332, pp. 215-217]. Alternative mechanisms include price negotiations between individuals, group bargaining, organized marketplaces (including auctions), administered prices (including governmental regulation), and formula prices. Formulas may in turn be established by individual negotiation, group bargaining, or governmental action. The establishment of a price is sometimes viewed as having two components: the discovery of a base or reference price and the discovery of prices for specific lots of the product relative to the base. Studies have been conducted both with regard to the mechanisms for establishing base prices – say, for a particu-

lar grade of wheat in Chicago – and for specific prices – say, for those paid by elevator operators to farmers for particular loads of wheat.

Pricing institutions unquestionably do influence price behavior. Some provide greater stability than others. Criticisms of pricing mechanisms usually center on one or more of the following: price levels are biased; price fluctuations are too large; or prices fluctuate too frequently. Any of these may lead to the misallocation of resources.

One obvious problem of price analysis is to separate the influences of economic factors from the influences of the institutional factors. The latter effects are difficult to isolate since two different pricing mechanisms for a particular commodity cannot be observed under precisely the same economic conditions. Studies before and after an institutional change are subject to this limitation. Telser [323] did attempt to assess the effect of the United States support program for cotton on the variability of cotton prices. He did this by reconstructing the price behavior that would have existed in the 1933-53 period without price supports. He concluded that the support program reduced price instability for cotton, but he acknowledged that "the major difficulty [of the research] is that what actually happened is being compared to what did not in fact happen."

A second problem of research related to pricing institutions is the selection of criteria for evaluating alternative pricing methods. One common approach is to use the perfect competition model as a norm [17, 121, 133, 207] – that is, to observe how actual prices deviate from those expected to prevail under perfect competition. But, competitively determined prices still may not be very satisfactory from the standpoint of guiding resource use because of their instability, or they may yield incomes which for political or social reasons are deemed to be too low. Hence, the competitive norm is not the only criterion to be considered in attempting to evaluate the performance of a given pricing institution.

Among the studies made in the United States using the competitive model as a norm are those conducted by Hassler for manufactured dairy products [133] and for processed feeds. Studies of spatial and temporal price differences also have been made in which actual price differences between markets are compared with transfer costs and seasonal price changes are compared with storage costs. In a study of fresh winter lettuce prices, for example, weekly price changes at shipping points were found to be highly correlated with changes in prices at the twelve major wholesale markets[17].

Lele [207] and Jones[179] have used analogous procedures to analyze market and price performance for certain agricultural products in developing countries. It is commonly alleged that such markets have serious imperfections. Researchers found some evidence of price differences exceeding

transfer costs between markets, but in reviewing the available evidence, it is perhaps fair to say that the claims of market imperfections are exaggerated [179, pp. 238-257; 207, pp. 214-220].

Studies of livestock auctions also have been made in an attempt to assess their performance or the possible biases they may impart to prices. Jack Johnson [172] concluded after studying southern United States livestock auctions that differences between prices at auctions and terminal markets were widest for the higher quality cattle. This was attributed to the small and erratic supply of such animals consigned for sale at auctions. Statistical analyses of price behavior at auctions [364] suggest that variables related to the pricing mechanism, such as size of market, as well as other variables, like weight, grade, and breed, significantly influence prices. Sosnick [305] suggests that on theoretical grounds prices might be expected to travel downward during the course of the auction since the most eager buyers might be expected to purchase first. But he found no empirical evidence to support this hypothesis. Among the possible explanations is that large quality differentials among lots can obscure any trends [305]. Indeed, auctions are a relatively time-consuming type of pricing system, and this pricing mechanism is likely to persist only for commodities with enough quality variation to justify pricing lots individually by inspection of the potential buyers.

Various studies provide empirical analyses of grower-processor contracts and of the effects of marketing orders on prices (for example, [194]). An analysis of contracts for sweet corn and peas suggests that the net price offered to farmers is about the same regardless of the particular contract signed [169]. This relative stability of net prices among contracts is considered to be evidence of a competitive raw product market for the commodities.

Farris [79] examined two aspects of price discovery for wheat in Indiana. He first considered the price paid for a standard grade of wheat, and he then looked at price differences associated with quality for specific loads of wheat. The objectives were to determine whether prices paid for wheat by local elevators were consistent with those prevailing on central markets and whether premiums or discounts for quality were appropriate.

With respect to the first objective, Farris found a range of prices which could not be explained solely by transfer costs. He concluded that these unexplained differences are probably related to local competitive conditions and to imperfect knowledge. With respect to quality differentials, Farris suggests two possible sources of error in pricing specific lots. First, the sample selected may not be representative of the entire lot, and second, the sample may be incorrectly graded. The first source of error could not be checked, but elevator grading was compared with laboratory grading. Apparently, errors in

grading tended to favor farmers on the average, though wide differences existed for individual samples. Elevator grading also appeared to overvalue low-quality wheat and undervalue high-quality wheat. Farris concluded that more effort should be devoted to establishing appropriate price differentials.

A criterion related to the perfect competition norm is to ask how well a particular pricing system is performing particular functions. Some qualitative analyses have considered the implications of certain pricing methods for various roles of prices. For instance, a potential benefit of group bargaining for farm prices may be more stable prices, which may lead to better production and marketing decisions [30].

Another criterion for evaluating pricing institutions is alternative costs. These costs include the resources devoted to discovering prices, such as the time of the participants, as well as possible misallocation of resources associated with a pricing system. Available research seems to say little about relative costs of alternate pricing mechanisms (but see, for example, [177]).

From a commodity viewpoint the pricing of hogs has received considerable attention [138], perhaps because of a belief that prices paid farmers do not adequately reflect consumer demand for lean meat. Pricing systems for milk also have received special attention [34, 215]. An exceptional amount of effort has been devoted to egg pricing mainly because of the decline of trading on organized markets and because the performance of prices was thought to be unsatisfactory. The wholesale market has been studied by a number of analysts, and alternative pricing arrangements have been proposed. These and the possible consequences of using different pricing methods are reviewed by Rogers and Voss [280, 281].

A more fundamental question raised by agricultural economists is whether price is becoming less important as a coordinating mechanism for economic activities and whether existing prices are satisfactory for this purpose. A sequence of papers by Collins [52], Gray [112], and Hillman [151] highlight this issue. Collins argues that the shift from price to administrative coordination has occurred, in part, because the latter system leads to a more stable volume moving through the system and a more homogeneous quality. Gray agrees with Collins in one respect—namely, that administrative and engineering coordination have supplanted price at some intersections of economic activity. But Gray asks whether the importance of price is enhanced or diminished by this shift. He concludes that the change-inducing role of price is enhanced. The informal markets with a proliferation of prices "were not very good," and the development of precise specifications of product and delivery terms enhance the efficiency of price formation at the remaining price junctures.

Futures Markets

This review of commodity futures markets and prices stresses the literature on price behavior. Gray and Rutledge [113] provide a recent and comprehensive survey of the literature on futures markets.

Futures markets first developed for seasonally produced commodities with continuous inventories, such as the grains; thus, it is not surprising that much of the literature deals with price behavior on such markets. Observation of the constellation of futures and cash prices for a commodity indicates that price movements are correlated and that, as a delivery month approaches, the price difference between the futures contract and the cash commodity narrows. This price behavior is explained in an important paper by H. Working [377] as "the price of storage." This price for a particular commodity is defined as the difference between two other prices – namely, between a particular futures price (P_f) and a cash price (P_c). The price of storage is competitively determined by the demand for and the supply of storage, but the literature has tended to concentrate on the supply side.

Negative price differences (P_f-P_c) are associated with small inventories and positive price differences with large inventories. But the supply function, which presumably is related to the marginal cost of storage, tends to be flat over a fairly wide range of inventories. Brennan [31] sought to establish the nature of marginal costs which would lead to the functional form observed for the supply function. He attributes, following Working, negative price differences, in part, to the marginal convenience yield of inventories; some (small) inventories are needed for the sake of "convenience" even when the price of storage is negative.

Paul [255] points out that the flat segment in a storage supply function may merely reflect the fact that an individual commodity has good substitutes for the use of storage facilities. Consequently, he pools all of the commodities that compete for storage space and estimates an equation to explain the price of binspace. Price differences (essentially between futures and cash) are computed for all of the competing commodities, and the largest difference for a particular period for the various products is the basic component of the price of binspace.[30] The price of binspace is made a function of total stocks and of sales of grain (to reflect handling volume), both deflated by the total storage space available.

Working, who analyzed individual commodities, simply made the price of storage a function of the size of current inventory. Weymar [362] argues that the price should be a function of the expected behavior of inventories over the time interval covered by the price difference. Current inventory is probably a good proxy for expected inventory of a commodity harvested

over a relatively short time period. It is perhaps a poorer proxy for a commodity with a long harvest period, such as cocoa.

Since the price of storage concept implies that the constellation of futures prices is linked through inventories, the price of a distant future in a new crop year should be correlated with the current spot price. This is in contrast to the view [342] that cash prices and futures prices are separately determined, the former by current conditions and the latter by expected conditions. Working [373, 374] was loath to treat prices of futures contracts as forecasts. Prices of cash grain, nearby futures, and remote futures are in his view jointly determined.

A futures price obviously cannot remain above the cash price by more than storage costs, but since no theoretical limit exists for the reverse relation, one can expect the variance of futures prices to be slightly smaller than the variance of cash prices when based on annual observations (for example, the year-to-year variability of the May price of the December corn futures versus the cash price in December). At the same time, the prices of futures contracts are closely tied to cash prices (for seasonally produced, continuous inventory products); hence, the two variances should be of roughly similar magnitudes [331].

With the development of new markets in the 1950s and 1960s, interest has turned to price relationships and behavior on such markets. The new markets include seasonally produced commodities with discontinuous inventories (potatoes), continuously produced commodities with inventories (pork bellies), and continuously produced commodities with no inventories in the ordinary sense of the term (fresh eggs).

Tomek and Gray [331] contrast potato futures prices with corn and soybean futures prices. Potatoes have a break in the inventory linkage between crop years. Thus, the daily prices of futures for different crop years are essentially uncorrelated. The springtime prices of new-crop potato futures are, in contrast to the grains, a function only of expected economic conditions, and in the spring, when little is known about the forthcoming crop, new-crop futures prices appear to be mainly an average of past prices. Consequently, the year-to-year variability of the November Maine potato futures price in April is much smaller than the variability of the November spot price.

Paul and Wesson [256] define the price of a relevant futures contract for fed cattle minus the value of feeder cattle and feed as a market-determined price of feedlot services.[31] Ehrich [76] extends this concept to explain the behavior of the price difference between fed cattle futures and spot feeder calves. He shows that price spreads are related in part to the cost of weight gain, particularly feed costs. The price spread can be negative.[32] The fore-

going concept suggests a closer relation between fed cattle futures and spot feeder calf prices than between fed cattle futures prices.

Short-term commodity prices (say, day-to-day changes) seem to follow a random walk. Working's [376] theory of anticipatory prices was designed to explain the random walk nature of price changes. In a perfect market price responds immediately and correctly to new information, and since new information occurs randomly, prices change randomly (see also [286]).

While commodity prices appear to follow a random walk through time, empirical analyses suggest that such price series deviate somewhat from a formal random walk model. For instance, Claude Brinegar [33] observed negative autocorrelations (price reaction) over short periods of time (one or two weeks) and positive autocorrelations (price continuity) over longer periods (four to sixteen weeks) for grain futures prices (see also [165, 276, 301]). One hypothesis is simply that markets are imperfect and that time is required for new information to be incorporated into price changes (for additional hypotheses see [55, 165]). Larson [200] estimates that 81 percent of the appropriate change in price based on new information is incorporated into the price on the first day in the corn market. This is followed by an 8 percent price reaction (incorrect movement) in the next four days with the appropriate remaining 27 percent adjustment occurring over the next forty-five days.

Labys and Granger [193] also analyzed sequences of price changes using spectral analysis. They concluded that "most series obey a random walk or near random walk." Most evidence suggests, however, minor deviations from the random walk hypothesis; the serial correlation coefficients of daily price changes are small and of low order, but nevertheless are nonzero [113, p.97].

One of the long-standing controversies with respect to price behavior on futures markets has to do with the existence of a risk premium (for historical references see [113, pp. 63-71]). In essence, the risk premium theory implies that futures prices are biased estimates of the cash price in the delivery month. In an inventory-hedging market a downward bias is allegedly required to attract a sufficient supply of speculative services. Hedgers are typically short futures to cover inventory holdings, and consequently speculators typically hold long positions. Thus, according to the theory, prices must rise on the average for speculators to profit from the long positions. Presumably there would be an insufficient supply of speculators unless there is some return on the average from the speculative positions. Hedgers allegedly pay speculators to take the speculative risk of adverse price movements. Given this theory, a routine program of purchasing and then selling futures should provide profits.

A substantial amount of empirical research has been devoted to deter-

mining whether or not a risk premium exists. Several researchers find evidence of a small risk premium [54, 162]. The weight of evidence suggests, however, that there is no risk premium [111, 277, 321, 322]. Amateur speculators as a group are net losers in the zero-sum returns from futures trading [149, 310]. In addition, many speculators, particularly professionals, hold positions for very short periods of time, implying that they would not benefit from the trend in futures prices implicit in the risk premium hypothesis.

One of the difficulties in evaluating the risk premium theory, however, is the presence of trends in some price series. If futures prices do not fully anticipate long-term trends, holding long speculative positions in a period of rising prices is profitable and consistent with a risk premium hypothesis. Conversely, long positions are not profitable in periods of declining price levels. Thus, the selection of a time period for analysis can influence results. The existence of governmental support programs also has complicated the empirical analyses (see [113, pp. 72-75]). Moreover, Gray [109] argues that thinly traded futures markets have "characteristically biased prices" which do not represent transfers of risk premiums.

As the preceding discussion implies, the principal motivation of speculators has been the subject of some controversy. Return to speculators could be a payment for accepting risk (risk premium), a return to superior forecasting skill, or a return for providing market liquidity. Working [375] argues persuasively that profits earned by professional speculators are mainly returns for providing market liquidity; scalpers provide the service of temporally spreading the effects of large hedge transactions. While amateur speculators typically are losers, there is a (small) possibility of making a large gain. Thus, Telser [322] writes "to the amateurs speculation in commodities is comparable to the purchase of a lottery ticket . . . "

Research on price behavior also has developed in response to the alleged influence of futures trading on the behavior of cash prices. Trading in futures has been blamed both for low and high prices and for excessive price variability (for citations, see [113, pp. 85-91]). Although futures markets, like any financial institution, are occasionally subject to fraudulent price manipulations, this is not thought to be a serious source of biased prices. Most economists regard futures markets as *recording* the influences of factors affecting price and not as a factor which in itself influences price levels [113, p. 86].

A number of researchers, however, have sought to measure the effect of futures trading on the variability of cash prices. Among the procedures used is the one adopted by Powers [262]. A series of cash prices is divided into two parts: the systematic component and the irregular (random) components. Powers considers in particular whether trading in futures influences the size

of the variance of the random component. Observations on weekly cash prices for pork bellies and beef cattle before and with futures trading are used to test the effect of futures trading on price variability. Tintner's "variate difference method" is used to eliminate the systematic component of the series [328].[33] Powers concludes that the variances are significantly smaller in the time period following the introduction of futures than in the preceding period. He attributes the result, at least in part, to the information role of futures markets.

Aaron Johnson [170] concludes essentially that futures trading did not influence price behavior in the cash onion market. Several previous studies suggested that trading in onion futures had reduced seasonal price variability, but Johnson detected little or no change in seasonal price behavior before, during, and after futures trading in onions. Johnson also concluded that, using the competitive model as a norm, price variation did not seem excessive during the period of futures trading. For certain commodities like potatoes and eggs, futures may provide more stable forward prices and the opportunity to hedge production decisions, thereby contributing to production and price stability [108, 201, 331].

T. W. Schultz [294], however, has maintained that resource misallocation is likely to be more serious for commodities with organized spot and futures markets than for commodities priced in other ways. In Schultz's view prices on organized markets fluctuate excessively (for whatever reason) and therefore do not provide reasonable guides for making production decisions (but see [371, p. 327]). Other economists [163, 223] have argued for the use of futures markets by government authorities as an integral part of price stabilization programs. Holbrook Working [371] concluded that the response of wheat inventories to wheat futures prices were "appropriate," which implies that futures markets, by guiding inventory adjustments, help to reduce price variability.

Implicit in the criticism of futures trading is the idea of excessive speculation. Speculation could be too large in at least two senses: trading by ill-informed persons causes prices to deviate from equilibrium levels, or the volume of trading by speculators exceeds the level required for adequate liquidity (even if equilibrium prices result). There is some evidence that speculation responds to hedging needs [375]. A more serious problem arises if the volume of speculation is inadequate to absorb hedging transactions without large price changes [110].

The literature contains alternative explanations of the motives (incentives) of hedgers. A few authors of research and extension publications have stated that hedging "eliminates" price risks, but this is more likely a poor choice of words rather than a literal theory of risk elimination through hedging. Most

price analysts have observed the lack of perfect correlation between cash and futures prices (for example, [106]), and hence the reduction of price risk is often emphasized as a motive of hedging. Studies have considered basis risk (variation in the basis) relative to price level risk, and such research (particularly in inventory hedging contexts) usually concludes that hedging is useful in reducing risks of adverse price movements. Snape and Yamey [304] are among the stronger proponents of the risk reduction view of hedging.

In contrast, Working [372] stresses that the principal motive of hedging is profit based on changes in the basis (changes in the price of storage). He does not look upon hedging as a form of insurance but rather as "a form of arbitrage, undertaken most commonly in expectation of a favorable change in the relation between spot and futures prices" [371]. A positive basis can provide a return to holding inventory; a negative basis is a disincentive to carrying inventories. In an empirical analysis Heifner [144] concludes that "the information contained in cash-future spreads can be of value in forecasting storage earnings on hedged corn but is of little value in forecasting earnings for unhedged storage."

Agricultural economists have attempted to develop optimum hedging rules. An optimal level of hedging is defined in terms of maximizing returns for a given level of risk or in terms of minimizing risk for a given level of returns. Ward and Fletcher [349] extend L. L. Johnson's results [176] and develop a theoretical model of optimal firm decisions with respect to trading in cash and futures markets. Heifner [145] developed a model which enables the hedger to obtain an optimum combination of expected total profit and variance of total profit and applied it to hedging in cattle feeding. In general, both the theoretical and empirical analyses suggest that optimal decisions do not require a fully hedged position [145].

The concepts of price of storage, price of processing services, and price of feedlot services each imply a profit-increasing or risk-decreasing role of hedging on futures markets. The role of futures markets in forward pricing is closely related. This role is implicit in the forward sale of a commodity through futures, anticipatory hedging of ingredient requirements, and so forth. Alternate hedging uses of futures are summarized in numerous sources (for example, [332]).

Conclusions

One cannot help but be impressed by the large number of alternative models and techniques that have been developed and by the immense volume of empirical results accumulated over the past thirty years. Researchers now have available a much greater assortment of models and estimation techniques than

they had before World War II. These developments probably have improved empirical results, but they also have compounded problems confronting price analysts and users of results. The analyst now has more decisions to make, and the user sometimes finds the results of separate studies inconsistent and confusing. Widely different elasticity estimates are frequently obtained, depending on the model and procedures used. This diversity can prove frustrating, but it also can be salutary if it leads to more critical and discriminating use of results. Clearly, good judgment remains a necessary ingredient in price analyses, both in developing models and in using results.

In agricultural price analysis, as in much of the economic literature, own-price elasticities probably have received more emphasis than is justified by their economic importance. The large changes in consumption, production, and prices have occurred as a result of shifts in demand and supply functions rather than as a result of movements along a static, ceteris paribus schedule. Preoccupation with price elasticities has in some cases led economists to ignore more critical variables. At least in our judgment there is a regrettable lack of empirical analyses of and comparisons among alternative forecasting models and techniques. Theil's imaginative suggestions for analyzing forecasts [324] perhaps have not received the attention they deserve from agricultural economists. While we unquestionably have better tools of analysis available today than a generation ago, it is less certain that forecasts have improved to a corresponding degree.

Forecasts are, of course, conditional on the values of the explanatory variables, and consequently the ability to forecast is constrained by unpredictable shifts in the supply and demand functions. Agricultural production is especially vulnerable to adverse weather, diseases, and pests; future changes in technology also remain something of an unknown quantity. On the demand side, political events such as the lessening of international tensions can open new markets, and modest changes in production in countries like India or the Soviet Union can have a profound effect on export demands and prices. But it is precisely events of this type which are difficult to anticipate. It is important to improve our ability to estimate changes in the explanatory variables, but to the extent these changes are random, a problem will remain.

Unfortunately, the magnitudes of structural parameters may not remain constant with the passage of time, and this also results in poor forecasts. A change in the structure of the demand for beef in the United States, for example, perhaps is responsible for the large underestimation of beef prices in the early 1970s using models based on pre-1969 data. We need a better understanding of structural change and of how to predict when these changes are likely to occur.

Price analysis probably has suffered somewhat from a lack of continuity in

research efforts. Many studies are the product of "one-shot" research projects, often associated with a Ph.D. dissertation. This adds to the multiplicity of results but contributes little to our cumulative knowledge. While a diversity of research viewpoints is essential, it also seems important to have a few researchers doing in-depth studies over a period of years so that they may build explicitly on previous work and update their studies periodically. Analysts working for private companies probably do more of this than their colleagues in universities, but unfortunately their results are usually not published so that the profession as a whole can benefit. Why do equations with high R^2's and seemingly logical coefficients provide poor forecasts? What changes in the model improved the forecasts? These are among the questions we should attempt to answer.

The role of pricing institutions in influencing price behavior is receiving increased attention and probably deserves more. Traditional methods of pricing certain farm products such as fruits, vegetables, and eggs may be unsatisfactory in the light of changes in the location and concentration of production, the number of buyers, and processing technology. The need for research is apparent; however, attempts to evaluate pricing institutions often have proved frustrating. Existing institutions allegedly cause biased or highly variable prices, but these allegations are usually difficult to demonstrate. Moreover, our analytical tools do not seem adequate for the task of determining the economic consequences of adopting alternative pricing methods, and part of the dissatisfaction with existing pricing arrangements is related to conflicting views about the roles prices should perform.

Developments in research are generally influenced by contemporary problems. One of the principal aims of price studies is to provide a framework that policymakers can use to anticipate the consequences of alternative decisions. The demand for this type of analysis unquestionably will expand although the types of questions analysts will be asked to help answer probably will change. More specific, disaggregated models may be required to meet some of these demands. A review of recent literature leads one to be reasonably confident, however, that agricultural economists will demonstrate ingenuity both in adapting older methods of analysis to current problems and in developing new techniques to meet the changing needs of policymakers.

Notes

1. Among the contributions made in the intervening period are articles dealing with the role of risk in supply response models [184] and of marketable surplus functions based on individual farm observations [333]. Quantitative studies have continued to shift their emphasis toward prediction and simulation of policy alternatives (for ex-

ample, [219]). Concern about food prices and world food supplies generated by the events of the mid-1970s is reflected in recent publications [136, 340]. With market prices rising above support levels and greater price instability, commodity futures markets have drawn considerable research attention (for example, [257]), though price-making institutions in general continue to be neglected (but see [85]).

2. Many studies made important empirical contributions. Henry Moore [231] was among the early contributors. Stigler [311] has reviewed the very early (mainly pre-1915) history of cross-section and time-series analyses, and in 1929 Stine [312] reviewed the status of price analysis to that date.

3. Goldberger [102] argues that Sewall Wright is an important early pioneer in econometrics who had much to contribute to the identification and simultaneous equations problems but who has been neglected in the literature.

4. Much of the empirical price analysis is still based on estimating separate demand and supply equations; if such equations are part of a recursive model (perhaps with other equations not specified), then each equation is an identifiable structural equation which can be estimated by least squares.

5. Monte Carlo studies do demonstrate the general superiority of simultaneous equations estimators over ordinary least squares under most circumstances when the model involves true simultaneity [78, pp. 408-420]. But such comparisons hold everything else constant except the method of estimation. Unfortunately, similar comparisons cannot be made for real world results because the true model generating the observations is unknown.

6. Methods are available to reduce the data "requirements" of simultaneous estimators [178, pp. 393-395], but they have been applied infrequently in agricultural price analyses.

7. If, for example, a sum of the quantities of the substitutes for each time period were used, then the model specifies that a one-unit change in the quantity of any substitute has the same effect (regression coefficient) on demand, a tenuous assumption.

8. The measurement of changes in tastes and preferences is still another problem in demand analysis. This topic is considered in the next subsection.

9. Slope coefficients apparently do change seasonally for lamb [211]. Also, even when slope coefficients are equal but the level of the function differs seasonally, the season with the highest level has the most elastic (or least inelastic) demand for a *given* quantity marketed. In the Farris and Darley study broilers appear to have a more price inelastic demand in the summer although the level of the function is higher. This occurs, however, because the elasticities are computed at the mean level of marketings for each month, and marketings are larger in the summer; hence, the elasticity is measured in a more inelastic range of a constant slope demand function in the summer months.

10. Fisher developed the first linear form lag model in 1925 (see [238, p. 7ff.]). (Simpler lag models do not specify the separate effect for X_t.) The linear form model really is a special case of polynomial form models. In this form, the β_i are constrained to follow a polynomial of degree q (for an application in agricultural economics, see [45]).

11. It is obvious, of course, that many more degrees of freedom may be obtainable by "pooling" data and adding one or a few variables.

12. Foote [84, p. 81] states that the term "price flexibility" originated with Henry Moore. The direct-price flexibility is the percentage change in price associated with a 1 percent change in quantity, other variables constant.

13. A theorem states that "if the same form of Engel curve is fitted to all commod-

ities and the form is such as to allow the fulfillment of the adding-up criterion . . . , then the estimates of the curves obtained by the method of least squares will also satisfy the adding-up criterion" [263, p. 84]. The semilog function with individual expenditure as dependent is an example of a function which does not permit the fulfillment of the criterion [208].

14. George and King [96, pp. 3-5] review the basic axioms of consumer behavior that undergird the restrictions.

15. The general idea of separability is that consumers partition the list of n commodities into groups; it is assumed that consumers divide total expenditures into different groups and then further subdivide the amount allotted to a group among individual commodities belonging to that group. To use the two-stage allocation process, the utility function must satisfy certain properties [96, p. 24].

16. If commodities in two different groups are want-independent, then the marginal utility of a commodity in the first group is independent of the quantity consumed of a commodity in the second group.

17. For a more complete discussion of separability concepts, readers should refer to the sources noted in [96].

18. For those who read French, a useful annotated bibliography related to supply analysis was prepared in 1968 under the direction of Boussard [20].

19. A third problem area, not within the scope of this paper, is related to estimation. The model may eliminate autocorrelated residuals for the wrong reason, and least squares estimation is inappropriate if the disturbances are autocorrelated (see also citations in the section on demand analysis).

20. Stout and Ruttan [314] summarize the difficulties of using "output per unit of input" as a measure of technological change.

21. Learn and Cochrane [204] discuss regression analysis of supply functions undergoing structural change.

22. Coleman and Leech [50] evaluate Markov chains as a predictive device for producer numbers and output of milk in England (for other applications of Markov chains in agricultural economics, see [181]).

23. Rayner [270] used the same procedure to estimate the aggregate supply elasticity of aggregate output for the United Kingdom.

24. In considering factors that explain resource use, the question of whether or not farmers allocate resources efficiently, particularly in traditional agriculture, can be raised. Dillon and Anderson [71] provide a recent summary of the important issues, but we consider this topic to be outside the scope of this review. Also, as mentioned in the previous section, much of the growth in agricultural output has been attributed to technological change. Lave [203] has estimated the rate of technical change in United States agriculture, and considerable research effort has been devoted to such questions as returns to research in agriculture, the quality of labor inputs, and so on. We have taken this literature to be outside the scope of price analysis.

25. Dalrymple [65] summarizes one approach to the definition and measurement of margins. The nature of the margin has implications for the relationship between the price elasticity of demand at retail and at the farm for a given quantity marketed [65, pp. 8-9]. Houck [156] considers the relationship of the elasticities for joint products to the elasticity of the commodity from which the products are derived.

26. Granger and Hatanaka [107, pp. 4-9] provide a brief history of time-series analysis.

27. Prices may be predictable from, say, an econometric model which uses informa-

tion about variables influencing prices; a random walk simply says current prices are not predictable from past prices.

28. A much more common application of principal components analysis is to compute principal components for the explanatory variables of a model. Hopefully, the total variation of these variables can be captured in a smaller set of principal components. The principal components are then used as the regressors. There is an obvious saving in degrees of freedom, and since the components are orthogonal, there is no problem of multicollinearity.

29. Padberg [250] and others have used a model to analyze brand preferences for foods in which the dependent variable is a percentage (constrained to the range zero to one).

30. Paul makes a variety of adjustments in the basic component of price to obtain a measure of the concept of a price of binspace. The adjustments are made, in part, to avoid the problem of convenience yields from stocks and the possible negative prices of storage.

31. In an earlier paper Paul [254] considers the concept of a price of processing services. A price of processing services can be defined, for example, by the difference between futures for soybean oil and meal and cash soybeans.

32. Live cattle futures were new at the time of Ehrich's analysis. With a general upward trend in beef prices in recent years, futures have not always fully anticipated the trend. This factor appears to have contributed to the negative margins between fed beef futures and feeder calf prices.

33. The variate difference method assumes that the error term (component) is not autocorrelated, an assumption which may or may not be met for the price series considered. If the assumption is not met, the empirical results are questionable.

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