Chapter 3

ELMER W. LEARN
WILLARD W. COCHRANE
University of Minnesota

Regression Analysis of Supply Functions Undergoing Structural Change

BEFORE BEGINNING the discussion of alternatives in incorporating supply shifters and interpretation and evaluation of regression analyses under structural change, it is necessary to reach a common understanding concerning the distinction between a shift in supply and structural changes affecting supply. In spite of the widespread use in the literature on supply of the terms "shifts" and "structural change," there appears to be considerable confusion concerning their exact meaning. Later in this paper it will be argued that much of the difficulty surrounding supply estimation stems from confusion relating to these concepts.

DEFINITIONS AND CONCEPTS

As a means of setting the scene for the more rigorous concepts intended for later development, let us begin with an over-simplified illustration. We will define a supply function as a linear relationship expressing quantity as a function of price and, for the moment, one other variable (e.g., the price of inputs). That is, $Y = a + b_1X_1 + b_2X_2$, where Y is the quantity offered, X_1 is the price of the product, and X_2 is the price of inputs.

The simple graphic representation in Figure 3.1 illustrates this relationship, with the alternative curves S_1S_1 and S_2S_2 representing the price-quantity relationship for alternative values of X_2. The concept of a "supply-shifter" grows out of this elementary exposition of supply. The movement of the supply curve from S_1S_1 to S_2S_2 resulting from a change in the value of the "other" independent variable is conceived to be a shift in supply.

The concept of structural change is not so common at the elementary level, at least not in those terms. The most easily understood result of a structural change is a change in the slope of the supply function, i.e., a change in the slope of S_1S_1 and S_2S_2 in Figure 3.1. However, the concept of structural change is more inclusive. A change in b_2, the shifting effect of a change in the value of X_2, is also a structural change. And, if the value of "a" should change or the nature of the function should be modified (e.g., from a linear to a nonlinear form) this, too, is classified as a structural change.

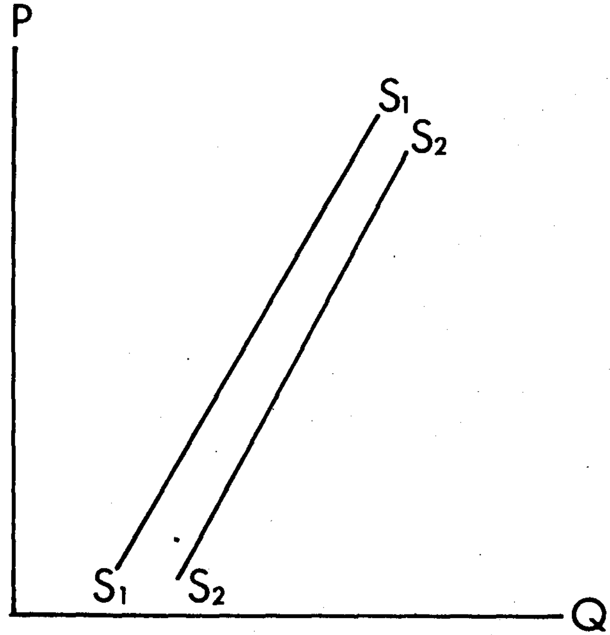

Figure 3.1. Illustration of linear function.

The concepts of shifts in supply and structural change perhaps can be more easily visualized at the micro level. We begin by looking at the concept of shifts in supply and structural change from the viewpoint of the individual firm.

A shift in the supply function for an individual firm is characterized by a change in the planned level of output at a given price without any change in the decision-making environment faced by the firm. As in the aggregate case, the supply shift is a parallel movement in the supply curve.

The requirement of an unchanged decision-making environment used here is analogous to the ceteris paribus condition in the aggregate case. Included in environment are factors such as the production functions faced by the firm, managerial abilities, and the institutional setting in which the firm operates. A change in any of these factors is likely to give rise to something more than a parallel movement of the firm's supply curve. Such a change may and probably does result in a change in the slope of the curve or in a change in the values of other parameters that define the firm's supply function. A new production function, for example, would most likely not only change the position of the supply curve but probably would also change the slope of the curve. ✓ In the same way, a new production function for a competing commodity is likely to alter the effect of a price change in the competing commodity on the firm's willingness to supply quantities of the commodity in question at various prices.

The above concepts are readily extended to an aggregation of all firms within the industry. However, in addition to technological relationships and prices, the number and distribution of firms also must be taken into consideration. Movement of firms in and out of production of a given commodity may be classified as shifting supply, a result of structural change in supply or one of the features which gives the static supply curve its characteristic slope. If, for example, a firm finds it profitable to produce at prices P_1 and higher, but unprofitable at prices below P_1, the entry and exit of this firm from production at P_1 is merely a component of the static supply curve; it is one of the phenomena which give rise to the supply curve's slope. The price (P_1) at which this firm enters production may change, however. If this results from a change in the value of a variable within a fixed enivronment, e.g., from changes in the prices of inputs or of prices of competing products in production, then the modification in the firm's behavior is properly classified as shifting the supply. But, if this change in the critical price (i.e., the price affecting entry or exit) results from a change in environment, e.g., a change in the production function for the commodity in question or of the production functions for competing commodities, or a change in the certainty with which prices may be expected, then the entry or exit is a manifestation of a structural change in supply.

In simple terms, this describes our conception of the distinction between supply shifts and structural change. Let us now consider this distinction under a more complex formulation of supply.

Let supply be a function involving n variables and described by m parameters.

$$\text{Supply} = F\ (x_1 x_2 \ldots\ldots\ldots x_n; \quad \alpha_1 \alpha_2 \ldots\ldots\ldots, \quad \alpha_m).$$

If this formulation is to be meaningful and useful in the usual static sense, we must also attach certain ceteris paribus conditions. These conditions relate to the complex set of factors referred to earlier as the decision-making environment. The most important of the ceteris paribus conditions commonly specified in supply analysis is, of course, a constant state of the arts.

Shifts in supply and structural change in the context of the above formulation are defined as follows: Shifts in supply result from changes in the values of any of the variables other than price and quantity. Structural change, on the other hand, results from some force which brings about a change in one or more of the parameters or a change in "F" (the form of the relationship). Structural changes therefore grow out of changes in one or more of the factors included in the ceteris paribus conditions.

PROCEDURAL PROBLEMS

It is from the background of these definitions that we want to discuss the problems of alternatives for incorporating supply shifters and interpretation of regression analysis under structural change.

A few ground rules should be made before proceeding further. It is not intended to deal specifically with the problem of long-run vs. short-run supply. To the extent that a distinction is applicable within our discussion we will be speaking in terms of the short run. Furthermore, it is not intended to discuss the problem of what specific price is to be used, i.e., the problem of expected price, responsible price, etc., will not be considered. This is not to deny the importance of such problems; they simply fall outside the scope of this paper.

SUPPLY SHIFTERS

Variables uniquely classified as supply shifters are relatively few. In fact, of the variables commonly considered in supply analysis, there are only two categories of variables which would qualify for such a classification within our definitional framework. These are (1) prices of inputs or factors, and (2) prices of commodities competing in production. Other variables often included as independent variables in supply analyses are either structural or quasi-structural in nature. In other words, we are arguing that strict interpretation of the static supply model presented earlier would restrict the variables to include only price and quantity of the commodity in question and prices of inputs and factors.

The problem of how to include prices of inputs and competing products in regression analysis of supply forces one to consider many interesting alternatives. In general, the alternatives include such things as whether to include individual prices or indexes involving several commodities and whether to include prices in a linear fashion or in some nonlinear manner, the most common of which is as a deflator.

The problem of multicollinearity among price series is such that one seldom attempts to include prices of more than one or two major competing products and more than one or two major inputs. It is assumed that the prices thus included adequately account for other less important commodities which might logically enter into a more complete model. In a hog supply analysis, for example, one might include the price of corn and the price of beef cattle, ignoring all other commodity prices. As an alternative, one could use an index of feed grain prices, or an index of prices paid by farmers for production items and an index of livestock prices other than hogs. A useful guideline to follow might be to use individual commodity price series where there is a single outstanding input or substitute product and to use an index where such a distinction is not well defined.

Whether to include the price series in a linear fashion or some other manner is also a problem for which no clear cut solution can be given. We are speaking here not so much of whether a linear in actual values or linear in logarithms formulation should be used but whether or not the price of the commodity should be included as a relative to some other price. A relative price is often used in studies of hog supply functions, for example. The hog-corn ratio is used as a single independent variable rather than the price of hogs and price of corn as separate variables. In defense of the use of the ratio, one could argue that this practice implicitly removes the influence of variation in the general price level and at the same time conserves one degree of freedom. If another undeflated price is used in a linear fashion, however, it raises additional questions concerning the influence of general price level.[1]

There are other significant questions which may be raised with respect to the use of the ratio. The interpretation to be placed on the regression coefficient for the price ratio forces one to accept that the price of corn has an almost equal effect on hog supply as the price of hogs. Further, it assumes the absolute level of hog and corn prices to be unimportant. This may be true within some range of prices, but it probably is not true over the observable range of prices for a given period of time. In any case, it is probably worth the price of one degree of freedom to let the data determine the separate effects of the individual prices rather than force conclusions such as those indicated above.

Weather is an especially difficult variable to handle in the framework employed here. Although it acts in many respects as a shifter, it also brings about changes in the production function albeit changes that can seldom be known at the time of decision making. Furthermore, weather does not affect supply over time in a perfectly random fashion, so cannot be relegated to the error term. However, it is an important variable in explaining variation in quantities supplied. Alternatives for its inclusion in regression analyses will be discussed now, with an understanding that it is not to be considered in the class of unique shift variables.

Weather is not a phenomenon which lends itself readily to quantitative measurement. This is particularly so in the context that it is used in supply analysis. Until recently, most attempts to include weather in supply studies have involved inclusion of some variable in the equation presumably highly correlated with weather effects, such as crop yields or moisture conditions. Another common and probably more satisfactory method has been to exclude from consideration variability in supplies due to weather. This may be done, for example, by using acreage rather than production as a quantity variable.

Stallings at Michigan State has developed a weather index that shows considerable promise for improving the ability to take account of weather in regression analysis of supply.[2] It is hoped that the USDA

[1]The problem of accounting for changes in general price level are not considered explicitly here. It is essentially a measurement problem as opposed to a conceptual problem. It is important, however, and should not be neglected in any meaningful supply analysis.

[2]J. L. Stallings. Indexes of the Influences of Weather on Agricultural Output, unpublished Ph.D. thesis, Michigan State University, 1958.

will follow up this pioneering effort with further refinements and make the development and publication of comprehensive weather indexes an integral part of their statistical program.

STRUCTURAL CHANGE

A supply equation containing only price, quantity, prices of inputs and substitutes, and weather is not a very meaningful estimating model for any extended period in American agriculture. The ceteris paribus conditions implied in such a model simply are not consistent with the facts of life in modern agriculture. In other words, structural changes are all-important forces in supply considerations for agricultural products.

The standard regression model does not and cannot fully allow for structural change. A basic assumption of the regression model is that the parameters of the system remain constant over the period of analysis. As shown in Figure 3.2, each price-quantity observation is considered a point on a supply curve with a slope equal to that of the "true" supply curve but shifted away from the "true" curve by some other variable. In addition, the very nature of regression analysis forces the assumption that the form of the supply relation does not

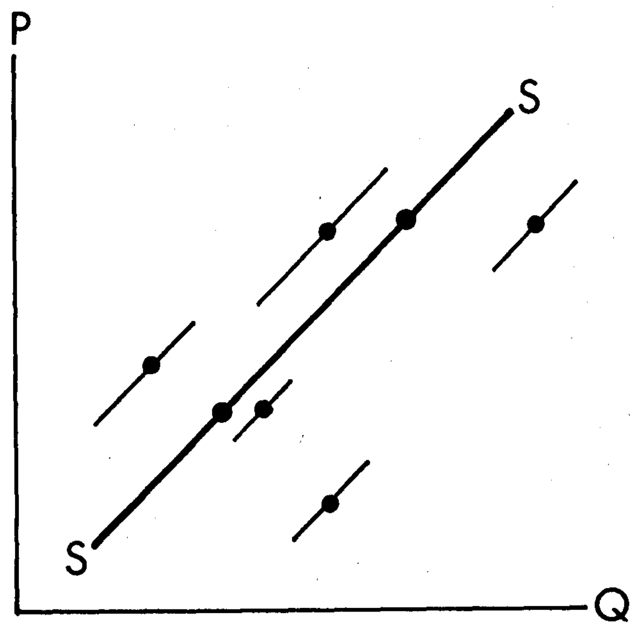

Figure 3.2. Hypothetical scatter diagram illustrating the basic shifting idea in least-square regression.

change over the period of analysis. This problem — the inflexibility of the regression model with regard to structure — is the principal one with which analysts must cope if they are to obtain meaningful supply estimates from time-series data. It is possible to properly account for the effects of changes in the values of variables which are strictly shift variables, but the effects of changes in structural variables can never be completely taken into account within the regression framework.

There are other difficulties. Confusion arises out of the fact that most variables which impinge upon the question of supply cannot be uniquely classified as giving rise to shifts, or to structural changes. Changes in some of the variables which we intend to discuss under the heading of structural change may and often do give rise to supply shifts of far greater significance than whatever structural impacts they might have. (This may be thought of in terms of changing the value of the parameter commonly referred to as the "constant term.") At the same time, variables may be employed in a regression analysis which are not strictly structural in nature but do affect structural variables or reflect structural changes in one way or another. These variables often substitute for nonmeasurable structural variables. For example, yield is often included as an independent variable in supply analysis for crops. This single variable, yield, may be expected to account for a whole complex of structural forces associated with technology and managerial skills.

The structure of an industry with respect to supply may be characterized as consisting of (1) the skills existing within the industry, both managerial and labor, (2) the technology or state of the arts, (3) the number and distribution of firms, and (4) the institutional framework surrounding the industry. We shall refer to these as the highest order structural variables.

Because the highest order variables are broad in scope and are not easily quantified, we typically deal with lower order structural variables which are associated with or influence one or more of the highest order variables. For example, these variables would include educational level of farm operators (associated with managerial skill) and asset position or current income position (associated with and influencing the rate of adoption of new technologies and the distribution of firms).

The most demanding of the structural variables is, of course, technology. Technological change is characteristic of American agriculture. Closely related and almost equally important over time has been the constantly improved level of managerial skills of farm operators. Other factors which have changed over time and have undoubtedly resulted in structural change are the size and degree of specialization among firms, government programs, and varying degrees of market integration. Uncertainty in decision making has been reduced through increased emphasis on outlook information and ability for more timely accomplishment of production tasks (e.g., spring plowing and seeding).

All these changes have had structural implications with regard to the supply of agricultural commodities.

How does one resolve the dilemma posed here? Essentially we have said that structural changes in agricultural production have been ubiquitous and overriding in recent decades. We also have said that structural change as we have defined it cannot be incorporated into a standard regression model.

Several partial solutions to the dilemma are available. The simplest is to ignore the problem, i.e., to assume that structural changes have not taken place or that those which have are relatively unimportant and are properly included in the error term of the regression model. Few would be willing to accept this solution except for very short time periods.

Even within the standard regression model, however, one can take some account of the effects of changes in structural variables. Procedures which make this possible do require, however, some very restrictive assumptions regarding the nature of the structural change.

Structural variables of any order may be incorporated in a supply analysis in the same manner as shift variables. For example, various indicators of the level of technology are often used in this way. This procedure may account for whatever shifting effect changes in the structure may have had on the supply relation. It will not, however, pick up the effect that such changes might have on the values of the parameters. To the extent that the values of the parameters might have changed during the time period studied, one probably obtains some sort of average of the true parameter values as a regression coefficient. If, for example, the true elasticity of supply varied from .5 to .2 during the period of analysis, one would probably estimate an elasticity somewhere between these values.

In addition to including various structural and quasi-structural variables in the analysis, a time variable is often used. This variable presumably accounts for shifting effects not adequately accounted for by other variables in the equation that have shown a relatively constant pattern of change over time. Indiscriminate use of time in regression analysis where the assumption of a linear pattern of change over time for some unmeasurable factor does not have a priori support is not good practice. Such a procedure can result in biased coefficients for other independent variables which exhibit a secular trend. In any case, simply including time as another independent variable cannot account for structural changes other than those that shift the supply curve.

It is possible to incorporate in the analysis an assumption that one or more of the coefficients is linearly associated with time. If, for example, one assumes that the price elasticity of supply has been changing at a reasonably constant rate during the period of analysis, an addition variable TP (time x price) could be included to account for such a change.[3]

[3] In the simple regression Q = a + bP, for example, we assume b = c + RT (i.e., b is a linear function of time). The estimating equation including this assumption becomes Q = a + (c + dT) P or Q = a + cP + d (TP).

Existence of a "once and for all" structural change, e.g., institution of a government program during the analysis period, can often be accounted for by including a "dummy" variable with value zero during the free market period and value one when programs were operating. Again, such a variable will account only for shifting effects and not for any other structural changes.

Another procedure which may be used is to attempt to restrict the period of analysis to years in which it is believed that the structure is reasonably constant. This may involve the division of an original period of study into several subperiods with estimation of a separate equation for each subperiod. This procedure assumes that the pattern of structural change is not smooth over time, but tends to occur in "spurts", and that we can recognize a priori when the periods of relatively limited structural change have existed. It is somewhat more flexible than the earlier alternatives, however, since it permits one to deal with situations where any or all of the α's may have changed and, in fact, to measure such changes.[4]

SUMMARY AND CONCLUSIONS

This discussion suggests that regression analysis of time-series data is an imperfect tool for supply analysis where structural changes have occurred during the time period analyzed. Because structural change is a predominant characteristic of American agriculture, one might be tempted to discard regression from the tool kit of researchers concentrating on supply of agricultural commodities. Such action is not justified.

Regression analysis has rarely provided satisfactory supply estimates in the past, but this is also the case with other procedures. What has been lacking in regression, as in other techniques, has been sufficient understanding of structural changes and their impact upon supply. As this understanding is acquired, continued attempts to incorporate it in regression analyses of time-series data may prove fruitful in the quest for more accurate estimates of fundamental supply parameters.

This raises another question. Assume we are successful in properly accounting for past changes in structure on supply parameters and are able to accurately estimate the necessary parameters. Are we any further ahead as far as predictive ability is concerned? Must not we also be able to adequately predict future changes in structure? In other words, in addition to being able to detect and measure past changes in structure, we must understand the conditions which have given rise to those changes. In the terminology used earlier, we must be able to understand the relationship between the higher and lower order structural variables.

[4] This is, in fact, the type of analysis employed by Cochrane in his aggregate supply analysis. See Farm Prices: Myth and Reality, University of Minnesota Press, pp. 46-50.

This kind of knowledge is not likely to be gained from time-series analysis of macro-type data. It may be learned from micro data gathered over time. This may be exemplified by information of the sort collected in the producer panel research under the Lake States Dairy Adjustment Study. Many conceptual and procedural problems are inherent in such studies. It is hoped, however, that the information gained over time will be usable in future regression analyses. This, in turn, may lead to improved ability to interpret and evaluate regression analysis under conditions of structural change.

GLEN T. BARTON
Farm Economics
Research Division, USDA

Discussion

LEARN AND COCHRANE do a good job in pointing up the problems of the difficult task of incorporating supply shifters and structural change into regression analysis. Under their definitional framework, prices of inputs or factors, and prices of commodities competing in production are the only two categories of variables which uniquely qualify as supply shifters. Structural change, on the other hand, involves change in the ceteris paribus conditions implied in a simple supply equation containing only price, quantity, prices of inputs and factors, and weather. The authors emphasize the importance of structural changes, especially those due to advances in technology, in supply analysis. These definitions of supply shifters and structural change are simple and clear cut, and the emphasis on the importance of structural change is well taken.

The complexity of the problems under consideration was reflected in the authors' difficulty in making up their minds on one important point. At one place in their paper, they state categorically that the all-important structural changes, as they defined them, cannot be incorporated into a standard regression model. They then offer partial solutions for doing what they said could not be done.

None of the suggested alternative partial solutions seems satisfactory to the authors or to me. I am especially dubious of the alternative that involves selection of subperiods of years in which the structure of agriculture is judged to be reasonably constant. To me, it seems reasonably clear from the record that we have had marked changes in the rate of technological advance and in the rate at which other structural changes have occurred. I am reluctant to view these as "spurts" or jumps from the end of one subperiod to the beginning of the next.

The authors recognize the difficulty of handling the important weather variable in supply analysis. As might reasonably be expected, they do not come up with a satisfactory solution. In view of the dominant role of higher yields in our upsurge of farm production in the last two decades, I question particularly their suggestion of using acreage rather than production as a quantity variable.

In developing their paper, Learn and Cochrane were careful to point out the problems encountered in regression analysis and also its limitations as a specific tool in supply analysis. I wish they had chosen to give us a broader perspective that could provide a basis for better research programming in this important area. In the rest of this discussion, I shall give some of my general reactions which may contribute to such a perspective.

I am most concerned with the need for supply analyses which can provide a better basis for policy decisions and program formulation designed to alleviate agricultural adjustment problems. Needed are analyses of <u>output response</u> — how output varies with price under changing structure and other conditions over a given period of time. Analyses of this kind have many facets.

Obviously, the analyses should emphasize positive as opposed to normative aspects. Although of necessity they will need to be based on historical relationships, the analyses should be designed for maximum usefulness for predictive purposes. The latter objective can be served by formulations of models which permit the isolation of important variables and parameters whose future course may be independently projected rather than determined solely by historical relationships. The nonreversibility of the supply relation should be recognized and provided for in the formulation of models.

These are noble objectives for analyses of output response. Nevertheless, I believe that our research should be pointed more in this direction. How may regression analyses which incorporate supply shifters and structural change contribute to the attainment of such goals? Learn and Cochrane point up many of the limitations of regression analysis in meeting these objectives. I believe that more research emphasis should be given to approaches, such as the one outlined by R. H. Day, which synthesize time-series and linear programming models. Such techniques may prove more flexible and fruitful than traditional regression analysis in meeting our objectives.

I do not regret our inability, through regression analysis or other methods, to come up with supply analyses of the classical, <u>ceteris paribus</u> variety. Such supply analyses imply a reversibility which does not exist. Moreover, because of the rapid structural change of agriculture, the usefulness of such supply curves would be of short duration and could easily be subject to misinterpretation in policy decisions.