The Price Response of Per-acre Yields

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I. Introduction

The object of this brief note is (1) to discuss the price-responsive nature of the per-acre yield of individual agricultural commodities and (2) to present the ridge regression estimates of the price elasticity of per-acre yields for some selected farm products. The work in this note is motivated by the author's desire of obtaining more accurate estimators for the supply elasticity of agricultural products.

The estimation of the supply elasticity for farm products is one of the most time-honored problems which have occupied the attention of many agricultural economists. The review of the literature reveals that it has been a field of interest for about five decades. Nevertheless, one does not seem to have observed any estimates which are reliable in the full sense. The difficulty with the problem is of course manifold. One important aspect of it is clearly associated with a random factor in agricultural production, "weather". No one will dispute that annual fluctuations in farm products are heavily dominated by fluctuations in weather. The original data to be used in the supply

studies naturally contain the effects produced by this random factor. Therefore, it is always necessary to eliminate these effects from data if one wants to clarify the true responsiveness of the supply to the pure economic forces. However, the entire elimination of the weather effects is a task of extreme difficulty, for no effective method is availalbe to date. For example, weather index, which is perhaps the most effective method for this purpose, is not ready for instant use for all the products in all the geographical areas. For these reasons, many investigators have employed acres rather than output in their supply studies of individual farm products. Strictly speaking, however, the estimates derived from these studies are not supply elasticities but acreage elasticities. Then, comes a vital question "how closely can the acreage elasticity approximate the supply elasticity?." The answer to this question lies in the extent of the price response of per-acre yields, i.e. the value of the price elasticity of them. If the value is zero or at least small enough to be negligible, then the acreage elasticity is identical with the supply elasticity or at least a good approximation of it. Conversely, if per-acre yields respond to the price to a large extent, the acreage elasticity will significantly differ from the supply elasticity. This relation can be explained algebraically.

Let Q, A, and B denote output, acreage, and per-acre yields. Then

$$Q = A \cdot B \qquad (1)$$

By differentiation of (1) with respect to the product price, P,

$$\frac{dQ}{dP} = \frac{\partial A}{\partial P} B + \frac{\partial B}{\partial P} A \qquad (2)$$

Dividing (2) by $\frac{Q}{P}$

$$\frac{dQ}{dP} \frac{P}{Q} = \frac{\partial A}{\partial P} \frac{P}{A} + \frac{\partial B}{\partial P} \frac{P}{B} \qquad (3)$$

Equation (3) indicates that the supply elasticity is equal to the sum

of the elasticity of acreage and that of per-acre yields. It is obvious that the acreage elasticity is equal to the supply elasticity if and only if the elasticity of per-acre yields is equal to zero.

The above relation clearly shows that the supply study can be improved by the appropriate information as to the price response of per-acre yields.

II. The Frice Response of Per-acre Yields

The price response of the per-acre yield of individual farm product is based upon the price-responsive nature of three factors; per-acre variable inputs, per-acre durable inputs, and technology. The forces which directly determine the level of the per-acre yield of farm products will be weather, soil fertility, inputs per acre, and technology. Among them the first two forces are unrelated to the price-responsive aspect of per-acre yields with which we are presently concerned. Weather is obviously non-economical factor. Soil fertility (by the term we refer to the fertility which is originally given to every farm land) seems to exert a constant effect upon the level of per-acre yields irrespective of the price level. The fertility which is acquired by some artificial means, such as land improvement, is here considered as a form of technological progress. However, the remaining two forces, per-acre inputs and technology, can be affected by the price change, and consequently, can result in the price response of per-acre yields. Here, let us divide per-acre inputs into per-acre variable inputs and per-acre durable inputs, according to the conventional classification of inputs. Under this view, it is possible to regard the price response of the per-acre yield of farm products as a complex of the price responses of per-acre variable inputs, per-acre durable inputs, and technology.

1. The price responsiveness of per-acre variable inputs

The price response of per-acre variable inputs can be regarded as the short-run response of per-acre yields. In the short-run period,

the use of durable inputs is generally fixed at a certain level and technology makes little progress, and therefore, their effects upon the level of per-acre yields will be negligible.
Hence, the magnitude of the price response of per-acre variable inputs will be equal to that of the short-run response of per-acre yields.

However, the price response of per-acre variable inputs will be slight. The inelasticity of the response must be attributed at least in part to the price uncertaintly of agricultural products. Theoretically, the response contains two stages in its process: (1) The producer forms his expectation as to the price level at which he is due to sell his output at the end of the production period. (2) According to the price level he expects the producer changes the amount of per-acre variable inputs which he intends to utilize in his production. Practically, however, the producer is unable to know — at least at the moment when he decides the amount of these inputs — the exact level of the price which is to be realized at the time when he sends his harveste to the market. Therefore, the producer tends to determine the amount of these inputs so as to maximize his output per acre rather than his total profit. Such his behavior prevents the level of these inputs from moving to a large extent in response to the price change, and naturally, makes their response to the price inelastic.

2. The price responsiveness of per-acre durable inputs

While the short-run price response is represented by the response of per-acre variable inputs, the long-run price response of per-acre yields consists of two responses; the price response of per-acre durable inputs and that of technology. It is evident that the level of durable inputs in the possession of individual farming units is changeable in the long-run period and the change is closely associated with the price of products. For the change in the level of such durable inputs is caused by individual producers' investment which is generally induced

by the profitability of the products they grow. The producer who can afford it financially is likely to invest if he expects that the present value of the net returns to be earned by his investment is greater than the necessary costs for his investment. This sort of investment will naturally lift the level of individual producers' durable inputs, and hence, that of per-acre durable inputs.

The connection between the price and individual producers' investment can be made clearer in the following analysis. In the begining, let π, P, and Q denote the total revenue of a farm producer, the unit price of the product he produces, and the number of units he sells. Then, the following equation is valid.

$$\pi = P \cdot Q \qquad (4)$$

By total differentiation of (6) we obtain

$$d\pi = dP \cdot Q + dQ \cdot P \qquad (5)$$

Equation (7) clearly shows that the producer can increase his total revenue either by increasing the number of units he places on the market or by receiving a higher price for his output. While he can also increase his revenue by means of an appropriate mixing of these two ways, this mixture case is ignored here for the sake of simplicity.

(a) $dP \neq 0, \quad dQ = 0$

This is clearly the case that the producer increases his revenue by raising the product price, holding his output constant. While an individual farmer can not exert a noticeable influence on the market price, he may have a choice in taking the most profitable one among the various possible prices which the market offers to him. In this sense, the producer can raise the level of the price he receives by selecting a new price whice is higher than that he has so far received. A good example of this case will be the glassculture which is incresingly employed recently in the production of some farm products.

Most farm products show somewhat U-shape of price fluctuation

during their market period. That is, the price which is relatively high at the beginning of the market period gradually or rapidly declines and reaches the lowest level somewhere in the middle, and then goes up toward the end of the market period. This sort of price fluctuation gives some farmers, who usually send their harvests to the market at the low-price time, an incentive to increase their profit by shifting their production period so as to market their harvest when the price is high. For this purpose, they invest in building the glass-house and the seed-bed with glass or plastic covers, and in installing electric heating, ventilating, and other necessary apparatus with which they can grow their crops under the less-favorable production conditions. The investment made for this purpose will naturally increase per-acre durable inputs.

(b) $dP = 0, \quad dQ \neq 0$

This is the case that the producer increases his total revenue by means of an output expansion under a fixed product price. Under the assumption that the producer always equates his MC with the selling price of his output, the realization of this case will require the producer to shift the MC curve of his production downward. It is obvious that the expansion which does not meet this requirement reduce his profit by causing the cost increase exceeding the revenue increase. In the practical agricultural production where in general at least one durable input is substantially scarce one effective method to lower the marginal cost will be to add some units of the scarce durable input. Suppose a farm firm, where at least one durable input is very limited, tries to expand its output continuously. It is evident that the firm will soon use up the scarce input; in other words, it reaches the point where the scarce input is fully utilized. Then, for further expansion of output, the firm will be forced to utilize, if possible, some other inputs in substitution for the used-up input. This is the point beyond

which the optimal input combination can not be attained, and the MC curve starts arising more steeply. The situation is depicted in Figure 1.

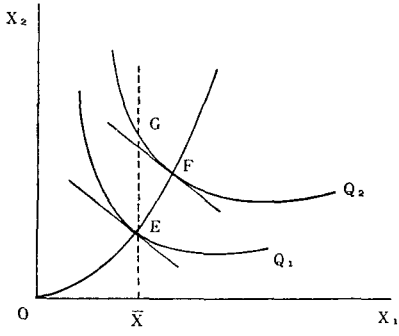

Figure 1 (a)

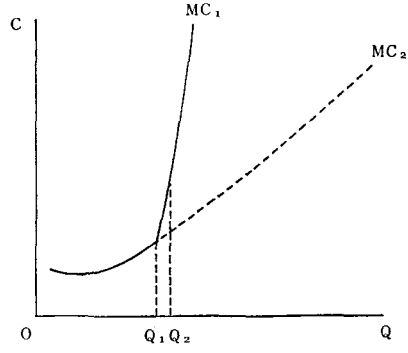

Figure 1 (b)

Figure 1 (a) illustrates the hypothetical isoquants of the firm under consideration; X_1 denotes the scarce input in question and X_2 represents the rest of inputs in the production. $\overline{X}$ indicates the maximum unit of the input which the firm can utilize at the present moment. Up to the output level Q_1 the firm can maintain the least-cost input combination in expansion, but beyond Q_1 it must utilize appropriate substitues, violating the optimal combination. In this case, the expansion path which the firm actually follows is not OEF but OEG. The MC curve of the firm is obviously higher in OEG than in OEF for the output level beyond Q_1. Figure 1 (b) shows this situation. MC_2 drawn in dotted line shows the MC curve which the firm may have when the optimal input combination is attained in the expansion process.

Thus, if the product price is high enough to induce some farmers to expand their output, they may invest in the durable input which is scarce in their production. This sort of investment, unless it is made for the addition of farm land, will help raise the level of per-acre durable inputs, and consequently, that of per-acre yields.

3. The price responsiveness of technology

It seems certain that the level of technology in the production of individual farm products has to do with the price of these products to some extent. Technological progress is often accompanied by the increase in capital inputs which is generally invited by the profitability of individual products. For example, engineering technology, which is represented by mechanization of farming tasks, will be largely dependent upon the price of individual products, as the purchase of machinery is in general motivated by the profitability of the products the farmer produces. Furthermore, chemical technology, which is represented by growth in the use of newly developed or improved fertilizers, insecticides, herbicides, and allied products, will also bear some relation to the price of individual products. While these chemical products are developed outside agriculture irrespective of individual farmers' decisions, it is likely that the diffusion of these products is more rapid in the production of more profitable products rather than in that of less profitable ones.

However, the price responsiveness in this respect should not be overemphasized, for technological progress clearly has the aspect that it raises the per-acre yield of all the products indiscriminatedly rather than that of any particular item. For instance, such technological progress as the spread of education in the rural area does not exert more favorable influence upon any particular product. Taking account of the above two aspects, we may state that technological progress which occurs in the production of an individual farm product can be devided into two portions from the standpoint of whether it is induced by the price of the product in question or it is independent of it. Such a relation can be written algebraically as follows:

$$T = T_1 + T_2 \qquad (6)$$

$$T_2 = f(P) \qquad (7)$$

where T, T_1, T_2, and P denote technology in the production of an individual farm product, technology which is independent of the price, technology which is associated with the price, and the price of the product concerned, respectively.

III. The Empirical Analysis

In the previous section it was discussed that in a certain condition the per-acre yield of individual farm products may respond to the product price. In this section an attempt is made to estimate the price elasticity of per-acre yields for some selected farm products, covering 10 items. The estimation is made by the use of time series data (1953-72) on the whole Japan basis. At the outset, it must be pointed out that the attempt is a highly tentative one with many assumptions and presumptions, some of which are not very realistic. For example, a linear relationship is assumed for the relations of the variables under consideration, while there is no reason to believe that linearity prevails in their relations. Furthermore, an extremely simple method is used to eliminate weather effects from data. Only such a figure of per-acre yields as is 10% above or below the normal average yields is amended by means of the interpolation method based upon the ordinary least squares. Technology is also treated in a very simple way; monotonically increasing numbers are used to represent the technological progress which is unrelated to the price of individual farm products.

(1) Data

All the data used for the estimation are quoted from the statistical yearbooks issued by The Ministry of The Agriculture and Forestry. The prices of the products are deflated by the input-price index. Index numbers (average of 1953, 54, and 55 = 100) are used for the figures of per-acre yields. As mentioned above, a trend number is used for the technological progress which is independent of the price.

(2) Model

Variables

B = The level of per-acre yields

B′ = The level of per-acre yields from which weather effects are eliminated

T = The level of technology in the production of individual farm products

T_1 = The level of technology which is independent of the product price

T_2 = The level of technology which is related to the product price

I = The level of per-acre inputs

P = The price of individual farm products

W = Weather

The model used for the estimation consists of the following four equations.

$$B = \phi\ (W,\ T,\ I) \qquad (1)$$

$$T = T_1 + T_2 \qquad (2)$$

$$T_2 = f(P) \qquad (3)$$

$$I = \phi(P) \qquad (4)$$

The first equation expresses the relation that the level of the per-acre yield of individual farm products is determined by weather, the level of technology, and the level of per-acre inputs. The second equation shows that technology in the production of individual farm products can be divided into two parts; technology which is independent of the product price, and technology which is related to it. The third and fourth equations indicate that technology which is related to the price and the level of per-acre inputs can be expressed as a function of the price of products, respectively.

With the elimination of weather effects and substitution of Equation (2) for T, Equation (1) can be rewritten as

$$B' = \varphi(T_1, T_2, I) \qquad (1A)$$

By the insertion of Equation (3) and (4) into (1A)

$$B' = \psi'(T_1, f(P), \phi(P)) \qquad (1B)$$

Equation (1B) can be simplified as

$$B' = \psi(T_1, P) \qquad (1C)$$

With the assumption of linearity and employment of one year lag for the price Equation (1C) can be expressed as the following statistical equation.

$$B' = \beta_0 + \beta_1 T_{1t} + \beta_2 P_{t-1} + U_t \qquad (1C)$$

where β_0, β_1, β_2, U denote the constant term, the coefficient of T_1, the coefficient of P_{t-1}, and the residual term, respectively.
The actual estimation is made by Equation (1D).

(1) Method

The ridge regression method is employed in the estimation. Since the price of some products shows a remarkable upward trend, it is impossible to estimate the separate influences of the price and technology on per-acre yields by means of the ordinary least squares. Ridge regression is an effective method to reduce the bias arising from the multicollinearity between explanatory variables. It has recently been proved to be a reliable method under the condition that the true regression coefficients are all of the same sign and of about equal statistical importance.*

Ridge regression estimator, β, is defined as

$$\beta = (X'X + k\,\alpha)^{-1} X'Y \qquad (5)$$

where β is a p x 1 column vector, X is a n x p matrix, X′ is the transposed matrix of X, Y is an n x 1 column vector, α is a diagonal matrix of order p consisting of the sum of squares, and k denotes a

* Brown, W. G., & Beattie, B. R., *Improving Estimates of Economic Parameters by Use of Ridge Regression with Production Function Applications*, Am. J. of Agri. Econ. Vol. 57, No. 1., Feb., 1975.

small positive increment. In the current estimation, increasing values, 0.1, 0.2, —, 0.9, 1.0 are assigned for k and such a k-value is selected as the ridge estimates stabilize. The variance-covariance matrix for β is given by

$$\text{var-cov}(\beta) = \sigma^2 (X'X + k\alpha)^{-1} X'X (X'X + k\alpha)^{-1} \qquad (6)$$

Hence, the variance of each parameter may be obtained by taking the term from the principal diagonal of the above matrix and multiplying σ^2.

(4) The results

Applying the available data to the equation (1D) the computations have been performed, and the results are presented below, in Table 1. As shown, fairly good estimates have been obtained for 5 items; rice, cucumber, egg-plant, tomato, and cabbage. Both coefficients of these items seem to be reasonable and their t-values show that the estimates are statistically significant. The Durbin-Watson test also shows good results; the presence of autocorrelated disturbances is not indicated. The coefficients of technology are much greater than the price elasticities. This indicates that the greater part of the increase in per-acre yields is attributable to the technological progress which is independent of the price of individual farm products.

As for the remaining 5 items, however, we have failed to get any highly appreciable results. The fit is not good and the estimates for the price elasticity do not seem to be very reasonable. The t-values of the estimates for the price elasticity are low, and the figures of the Durbin-Watson d statistics show that there may be serial correlation in the residuals.

Table 1.

Product	P_{t-1}	T_t	R^2	D. W.	k
Rice	0.1176 (2.0346)	6.6184 (2.8118)	0.794	1.537	0.2
Kidney bean	−0.0339 (−0.2981)	10.0878 (2.7053)	0.317	2.114	0.2
Peanut	0.0383 (0.3100)	9.8316 (1.8181)	0.215	0.481	1.0
Cucumber	0.2088 (1.9727)	26.4588 (3.6289)	0.665	2.250	0.7
Egg plant	0.1762 (2.2689)	24.9248 (4.3747)	0.777	2.375	0.4
Tomato	0.3471 (2.0058)	40.6108 (3.9382)	0.6272	2.179	0.7
Pumpkin	0.0423 (0.7077)	8.6689 (2.6608)	0.372	2.060	1.0
Water Melon	0.0725 (0.5827)	20.3078 (3.2778)	0.439	1.435	1.0
Cabbage	0.5504 (2.5195)	20.7923 (4.1384)	0.785	1.886	0.4
Carrot	−0.0596 (−0.5265)	25.9160 (7.1370)	0.827	1.600	0.2

IV. Concluding Remarks

The acreage elasticity has often been used as an indicator to show the magnitude of the supply response of agricultural products to the price. As we have observed, however, the acreage elasticity can not be a good approximation of the supply elasticity under the condition that the per-acre yield responds to the price to a large extent. The empirical study in this note presents good estimates for the price elasticity of some farm products. While the estimates derived can not be accepted at their face values because of the over-simplified model,

the results seem to be very reasonable; the estimates show fairly large figures and their t-values are significant. The results seem to indicate that the price elasticity of per-acre yields must be taken into account in the estimation of the supply elasticity of these farm products. One method which follows the indication will be to estimate both elasticities of acreage and of per-acre yields, and then add them up together. The method of course may lead us to the bias which is caused by the introduction of the cumbersome weather problems. But if the bias due to weather is smaller than the bias which may be invited by the neglection of the price response of per-acre yields, the above mentioned method will certainly provide us with more accurate estimates than the acreage elasticity. In this connection, some critics might raise the question, " if we dare to get involved in weather, why don't we estimate the supply elasticity directly by using the supply as the dependent variable ? " The question is obviously supported by the assumption that the price which the producer takes into account when he decides acres is the same as the price to which he refers when he decides the level of per-acre inputs. However, the assumption does not seem to be very realistic. For it is very likely that the producer pays more attention to the price of the alternative products than to the price of inputs when he decides acres, and the opposite will be the case when he decides the level of per-acre inputs in his production. Under this view, we may conclude the price response of the five items (rice, cucumber, egg-plant, tomato, and cabbage) is fairly large, and therefore, the acreage elasticities can not be regarded as their supply elasticities. We may suggest for the estimation of the supply elasticity for these products such a method that we estimate both the acreage and the per-acre-yield elasticities, and sum them up.

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