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International Supply Response

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Abstract

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Long-run aggregate agricultural supply elasticities obtained from conventional supply functions fitted to time series data tend to be relatively inelastic in the range of 0.1 to 0.4. I argue that these estimates substantially understate the true long-run supply response in agriculture. Because of the lack of international input price data, implicit output/input price ratios are estimated from a production function assuming profit maximization. The estimation of an aggregate supply function utilizing these price ratios yields long run aggregate supply elasticities in the range of 0.90 to 1.19. These figures are substantially larger than those obtained from conventional supply functions fitted to time series data, but correspond closely to estimates reported in an earlier cross-country study that used different price data for different points in time. The results imply that policies which distort domestic and/or world market prices of agricultural products cause greater output distortions in both the DCs and LDCs than are predicted by the small supply elasticities obtained from conventional supply estimation.

Introduction

Traditionally the long-run aggregate supply of agricultural products has been regarded as relatively inelastic. The alleged fixity of agricultural inputs in the aggregate provided the intuitive explanation for this hypothesis (Cochrane, 1955). The estimated aggregate agricultural supply elasticities obtained from conventional supply functions fitted to time series data have supported the inelastic hypothesis, most falling in the range of 0.1 to 0.4 (Griliches, 1960; Tweeten and Quance, 1969; Van den Noort, 1969; Herdt, 1970; Pandey et al., 1982; LaFrance and Burt, 1983).

Griliches, however, had misgivings about his 0.15 estimate, stating that it "underestimates severely the 'true' long-run elasticity since much of what is here attributed to trend and technological change is actually due to changes in relative prices that are not caught by the conventional price indexes" (Griliches, 1960, pp. 286).

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Estimates of the aggregate supply elasticity derived from the cross-elasticities of input demand which have generally been greater than 1, also cast doubt on the validity of conventional time series estimates (Griliches, 1959; Tweeten and Quance, 1969; Coleman and Rayner, 1971).

In a previous paper, I reported estimates of the long-run aggregate agricultural supply elasticity from cross-country data that substantially exceeded estimates obtained from conventional supply functions fitted to time series data (Peterson, 1979). I argued that time series estimates understate the true response to expected price changes because much of the observed price variation is transitory, causing actual price to vary more than expected price. Cross-country observations should yield more accurate estimates of long-run supply elasticities because they reflect the response to differences in average levels of expected prices. Agricultural price policies based on the relatively small estimated elasticities run the risk of underestimating their impact on output because policy changes tend to influence long-run expected levels of prices.

Because of exchange rate distortions and the lack of input price data other than fertilizer, real agricultural prices in the earlier study were measured as the ratio of output to fertilizer price. Although fertilizer price is no doubt an important factor affecting fertilizer use and crop yields, it does not necessarily reflect the average level of all input prices for a country. For example, LDCs exhibit relatively high commercial fertilizer prices but have relatively low prices of labor, which in turn leads to more intensive land use and higher yields, especially in densely populated countries where land is relatively expensive.

The main purpose of this paper is to re-estimate an aggregate agricultural supply function from cross-country data using a more complete accounting of input prices. Unfortunately, input price data still are not available. The procedure will be to estimate implicit output/input price ratios from the marginal products of a production function and then to use these prices to estimate an aggregate agricultural supply function. Data are from a cross section of 119 countries which encompass about 94% of the world's agricultural land.

Production function

Similar to the earlier study, output is measured as wheat equivalents (WEQ) per hectare. The procedure for measuring WEQ is summarized below.

$$\mathrm{WEQ}_j = \sum_{i=1}^{n} \frac{P_i}{P_w} Q_{ij} \qquad (1)$$

where WEQ_j is wheat equivalent output in country j, P_w is the world market (export) price of wheat, P_i is the world market (export) price of commodity i; and Q_{ij} is the physical quantity produced of commodity i in country j. To smooth out year-to-year variation in production, the data are 1982–84 annual averages. All agricultural commodities produced in each country are included.

Two precautions were taken to mitigate potential biases in the measure. First, the production of livestock and livestock products were reduced by roughly the proportion of production costs taken up by feed grains.[1] This is to avoid double counting of feed grains, either domestically produced or imported. Second, prices of products that are not traded in the form produced at the farm level, olive oil and sugar crops for example, were adjusted downward to reflect their farm value.

Land is measured as hectares of agricultural land, including both crop and pasture land, as presented in the FAO *Production Yearbook*, 1984. In terms of wheat equivalents per hectare of agricultural land, The Netherlands ranks first in the world and Japan is second.[2] The U.S. comes in 64th, slightly below the world average. Several countries that utilize rather primitive agricultural technology such as Egypt, Papua New Guinea, Malaysia, Mauritius, and Surinam, rank high on the list. Mainly these are countries with substantial irrigated land and/or high rainfall that utilize cheap labor to produce labor-intensive products such as rice, sugarcane, vegetables, and tree crops.

To mitigate the problem of heteroscedasticity due to large differences in country size, a land-intensive production function is estimated whereby both output and inputs are measured on a per-hectare basis. The Cobb–Douglas form is utilized.

The right side of the production function contains four conventional inputs plus a land quality index and measures of schooling and technology.

Conventional inputs

(1) *Labor*: number of people (male and female) age 15 and over in the agricultural population.
(2) *Machinery*: number of tractors and combines weighted by size.[3]
(3) *Fertilizer*: kilograms of plant nutrients of nitrogen, phosphorous, and potassium.
(4) *Livestock*: number of cattle equivalents.[4]

The conventional inputs are measured per hectare of agricultural land.

[1]Pig meat, poultry meat, and eggs are reduced by 0.67, beef and milk by 0.50, and mutton and lamb by 0.10. All production figures are from the United Nations, FAO, *Production Yearbook*, 1984. World market export prices are from the United Nations, FAO, *Trade Yearbook*, 1984.

[2]Country-specific figures are presented in Peterson, 1987b.

[3]The size weights varied from 0.25 (Japan) to 2.00 (United States) depending on the number of people per hectare.

[4]The weights are: cattle 1.0, horses 1.3, mules 1.3, asses 1.0, buffalo 1.3, camels 1.4, pigs 0.25, sheep 0.125, chickens 0.006, ducks 0.0125, turkeys 0.0125.

Nonconventional inputs

(1) *Land quality index*: a measure of growing conditions as determined by long run average precipitation, irrigated land as a percent of cropland, and nonirrigated cropland as a percent of all agricultural land.[5]
(2) *Schooling*: years of schooling, first and second levels, age 15 and over in the country.[6]
(3) *Technology*: years of schooling, third level, age 15 and over in the country.

In regard to the technology variable, it is common in agricultural production functions to utilize some measure of public agricultural research such as experiment station expenditures or publications. While such technology proxies have worked reasonably well in the estimation of production or supply functions for a single country, they are probably too narrow to fully reflect technology differences in cross-country observations. All agricultural research, both public and private if it were available, is a broader measure but probably is still too narrow to capture all of the technology embodied in new machinery, chemicals, transportation equipment and infrastructure, and communications. In virtually every country, the technology mix utilized in agriculture closely resembles that used in the rest of the economy.

The technology proxy adopted here is the third level of schooling. The stock of scholing at the third level is intended to be a proxy for the capacity of a country to develop or modify technology that in turn results in the production of new inputs for agriculture as well as for the rest of the economy. The third level of schooling can be regarded as a measure of the capacity to produce disequilibria, and the first and second levels as facilitating the adjustment to disequilibria. If all countries are in equilibrium, (input prices equal their VMPs), or if all are at the same state of disequilibria, the first and second level of schooling variable will reflect only the "worker effect" (Welch, 1970).

The results of estimating a land-intensive, Cobb–Douglas production function from the cross country data described above are presented in Table 1. The variable measuring first and second levels of schooling per person, age 15 and over, entered with a negative, but statistically insignificant coefficient. Therefore, it was omitted from regressions (2) and (3). Total years of schooling at the third level is deflated in two ways: by the number of people, age 15 and over (denoted by technology, P) and by the number of hectares of agriculture land, (technology, H).[7] There is no strong a priori reason for choosing one deflator of the technology variable over the other, so both are presented. The second deflator is highly correlated with fertilizer ($r=0.86$), however, which is the

[5]Country-specific land quality indexes are presented in Peterson, 1987a. The index for all agricultural land is used here.
[6]Country-specific figures for the first, second and third level of schooling are presented in Peterson, 1987c.
[7]The first and second level of schooling variable also was deflated by number of hectares but the results were virtually identical to the per capita measure.

TABLE 1

Production functions

	(1)	(2)	(3)
Constant	3.92 (4.75)	3.96 (4.84)	4.72 (6.01)
Fertilizer	0.135 (2.92)	0.134 (2.91)	0.094 (2.08)
Labor	0.343 (5.99)	0.347 (6.12)	0.297 (6.13)
Livestock	0.198 (2.97)	0.208 (3.36)	0.183 (3.06)
Machinery	0.205 (5.12)	0.197 (5.50)	0.160 (4.45)
Land quality	0.877 (5.00)	0.842 (5.39)	0.723 (4.73)
Education	−0.067 (-.444)		
Technology, P	0.090 (1.54)	0.077 (5.39)	
Technology, H			0.155 (3.61)
R^2	0.899	0.898	0.907

Figures in parentheses are t-ratios.

likely explanation for the decline in the size and significance of the fertilizer variable in equation (3). Essentially the technology variable serves as a proxy for several omitted nonconventional inputs such as new machines, improved seeds, pesticides, and vaccines as well as the general state of transportation and communications technology. In the third equation over 90% of the variation in land productivity is explained by these six variables.

Differences among countries in land productivity do not necessarily mean that agricultural production in the countries with high ratios is more efficient than those that rank lower. There is an optimal output level for every hectare depending on its quality, output and input prices, and the level of technology. Maximum possible output would occur only if input prices were zero. Generally, countries with low levels of land productivity utilize less conventional inputs per hectare and/or have lower-quality land as well as lower levels of technology.

The application of conventional inputs to land depends on their expected profitability. Higher dosages of these inputs will occur only under favorable output/input price ratios. It might be mentioned in passing that the responsiveness of producers to price changes can be measured by the coefficients of the production function. In the Cobb–Douglas production function $Y=Ax^b$, the corresponding supply elasticity is $b/1-b$.[8] The four conventional inputs of the production function presented in Table 1 can be considered variable, at least in the long run. The sum of their coefficients, 0.734 (column 3) suggests

[8]If $Y=Ax^b$, then $X=(Y/A)^{1/b}$. Total variable cost (TVC) is $WX=W(Y/A)^{1/b}$.
$\text{MC}=\mathrm{d}(WX)/\mathrm{d}Y=(1/b)WY^{(1/b)-1}A^{-(1/b)}$.
Assuming profit maximizatin, let P, output price, equal MC, and solve for Y:
$Y=(bP)^{b/1-b}W^{-b/1-b}A^{(1/b)(b/1-b)}$.
The supply elasticity $(\mathrm{d}Y/\mathrm{d}P)P/Y=b/1-b$. With more than one variable input, b is the sum of the coefficients.

a long-run supply elasticity of 2.76 – about double the already high figure reported in the previous study.

This figure represents the theoretical maximum response to price changes. But the implied underlying assumptions are rather extreme: variable input supplies facing agriculture are perfectly elastic, producers know the production function with certainty, and adjustments to price changes are instantaneous. In reality, input supplies facing agriculture may not be perfectly elastic, and adjustment to relative price changes requires a certain amount of experimentation for most producers to arrive at the new profit maximizing level of input use. Also expectations that relative price movements are temporary, may preclude an immediate adjustment. Because of these limitations, the actual response to relative price movements is expected to be less than the theoretical maximum obtained from the production elasticities.

Supply function

Most of what we know about producer response to price changes comes from empirically estimated supply functions with prices rather than quantities on the right hand side. Such estimates are not subject to the above limitations.[9] Although output prices are available for many of the countries in the sample, input prices generally are not.[10] There are some fertilizer price data but the variation in the price of a given plant nutrient from alternative sources within countries raises a question of which price to use. Also there is the problem of measuring fertilizer subsidies and black-market prices. Transportation costs present an even greater problem. In primitive areas without good roads, the full cost to the farmer of a sack of fertilizer, for example, is considerably greater than its retail price if it has to be carried to the farm on his back or transported by animal power. The same is true of output. A relatively high cost of transport from farm to market can make the net price received substantially lower than the quoted market price. Since LDCs tend to have more primitive modes of transport, the difference between market price quotes and net after transport price paid for inputs and received for outputs will be larger than in the DCs. This will make the net after transport cost output/input price ratios diverge even more for these two groups of countries than the quoted market price ratios would imply.

To overcome these price measurement problems, estimates of the implicit

[9]Supply estimation from price and quantity data requires that product demand and input supplies facing the firm are perfectly elastic. No such requirements are necessary for the industry, except that the price and quantity observations are market equilibrium values.

[10]See United Nations, FAO, *Statistics on Prices Received by Farmers*, 1982, for output prices in units of domestic curencies.

output/input price ratios are made from production function (3) of Table 1. The following well-known expression holds under profit maximization:

$$P_y/P_x = 1/\text{MPP}_x \tag{2}$$

where P_y and P_x are output and input price respectively, and MPP_x is the marginal physical product of input x. In order to take account of shifts in the MPP curve of an input due to differences in the levels of complementary inputs employed, the predicted value of an input's MPP for a country is obtained holding constant the level of other inputs at the 119 country sample mean. For input X_1 it is:

$$\text{MPP}_{1j} = Ab_1 X_{1j}^{b_1 - 1} \bar{X}_2^{b_2} \ldots \bar{X}_n^{b_n} \tag{3}$$

where MPP_{1j} is the marginal physical product of input X_1 in country j, X_{1j} is the observed level of X_1 in country j, and $\bar{X}_2$, ..., $\bar{X}_n$ are mean levels of X_2 through X_n.

Holding other inputs constant at their sample means when computing the country-specific MPP of a given input, is necessary to avoid distorting its computed implicit output/input price ratio. For example, a country that utilized a large amount of labor per hectare because of a low wage would in turn exhibit a large amount of output per unit of machinery. If the actual MPP of machinery were used in computing its price ratio, the country would appear to have a lower output/machinery price ratio than it really has because of the low labor wage.

The MPP of an input and its price is specific to its unit of measure. In order to aggregate the four output/input price ratios for each country, the ratios had to be standardized. This was done by dividing the computed ratio for each input (for each country) by the sample mean ratio of that input to form an index, with the sample mean index equal to 100. The country-specific weighted average output/input price index of the four conventional inputs (P_j) was obtained as follows:

$$P_j = \sum_{i=1}^{n} w_i P_{ij} \tag{4}$$

where w_i is the factor share of input i from the production function (3) standardized to sum to 1, and P_{ij} is the index of the output/input price ratio of input i in country j. The average value of the price index for the top-ten countries in the sample is over 20 times larger than the average for the ten lowest countries.

Land productivity declines as the price ratio declines. This is to be expected. The higher the prices of conventional inputs relative to output price (the lower the price ratio), the smaller their application to each hectare of land, and the lower the land productivity.

The use of the implicit price ratio to estimate a supply function does not impose an unusual assumption on supply estimation since an underlying as-

TABLE 2

Supply functions

	(1)	(2)
Price	1.19 (16.7)	0.90 (10.5)
Land quality	0.72 (5.16)	0.58 (4.49)
Technology, P	0.19 (5.97)	
Technology, H		0.23 (7.65)
R^2	0.892	0.906

Figures in parentheses are t-values.

sumption of all supply functions is profit maximization ($P_Y = \text{MC}$)[11]. This ratio should reflect the net prices paid and received after transport costs are taken into account by farmers. Also because this method measures the actual behavior of farmers, the price ratio reflects expected prices. These prices rather than observed values are the relevant ones for supply estimation.

The results of estimating the aggregate supply function are presented in Table 2.[12] The dependent variable is output per hectare and price is the implicit price ratio described above. Land quality and technology, as previously defined, are treated as exogenous supply shifters. The equation is the standard log–log form. The estimated long run aggregate supply elasticity in equation (1) of 1.19 is close to the estimate from the earlier study (1.3) where the output/fertilizer price ratio is used along with public research publications per hectare as a technology proxy. This estimate probably would have been slightly lower if a broader technology variable had been used, such as the ones in this study. This figure is reduced to 0.90 with the use of the second-technology variables – the stock of schooling at the third level deflated by hectares of land. At any rate, the long-run supply elasticities obtained here correspond closely to the estimates of the earlier study that employed a different set of data for different points in time.

Similar to the earlier study, the estimates in this paper implicitly assume a perfectly inelastic supply of agricultural land in the aggregate. While this assumption is not a gross distortion of reality, there is some opportunity to increase the land input through land reclamation should prices justify the investment. Therefore these supply elasticity estimates are expected to be somewhat lower than those obtained from a supply equation where land also is allowed to vary.

[11] $P_y/P_x = 1/\text{MPP}$, the profit maximizing condition from the standpoint of inputs, is equivalent to $P_y = \text{MC}$. From the first impression, $P_x/\text{MPP} = P_y$. By definition $P_x/\text{MPP} = \text{MC}$. Therefore, $P_y = \text{MC}$. The conditions for estimating supply from implicit prices are the same as those required for supply estimation from observed prices. These are set out in footnote 9.

[12] Simultaneous estimation of demand and supply would have been preferable but distortions of agricultural prices in both DCs and LDCs preclude observations along the demand curve.

Concluding remarks

The results support the hypothesis that the long run aggregate agricultural supply elasticity is in the neighborhood of one. Therefore, policies which distort domestic agricultural prices either above or below the world market equilibrium have a greater impact on the production of food than is implied by the relatively small supply elasticities obtained from time series data.

These results have relevance for both the developed and less developed countries. In the developed countries, agricultural price supports will precipitate greater surpluses than predicted by the small supply elasticities obtained from conventional supply estimates. And in the LDCs, policies which maintain artificially low output/input price ratios reduce agricultural output more than what is expected from the low supply elasticities obtained from time series data. Also the reduction of world market prices of agricultural commodities caused by subsidized exports of surpluses by the developed countries, most likely retards the development of LDC agriculture more than what has been predicted.

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