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## International Supply Response

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A previous paper reported estimates of the long run aggregate agricultural supply elasticity from cross-country data that exceeded normally accepted supply elasticities by a factor of ten (Peterson, 1979). It was argued that the estimates obtained from time series data 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. Therefore, agricultural price policies based on elasticities obtained from observations on actual rather than expected prices run the risk of underestimating their impact on output.

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 doesn't 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 percent 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.

$$(1) \quad WEQ_j = \sum_{i=1}^{n} P_i/P_w \cdot Q_{ij}$$

where $WEQ_j$ is what 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.

Total output of wheat equivalents divided by total area of agricultural land (arable land plus land in permanent pasture) yields the figures in column (1) of the Appendix Table. Netherlands ranks first and Japan second. The U.S. comes in 64th, slightly below the world average.

Several countries that utilize rather primitive agricultural technology rank high on the list. Mainly these are countries with cheap labor that produce labor intensive products such as rice, sugarcane, vegetables, and tree crops.

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.[2]
3. Fertilizer: kilograms of plant nutrients of nitrogen, phosphorous, and potassium.
4. Livestock: number of cattle equivalents.[3]

The conventional inputs are measured per hectare of agricultural land.

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.[4]
2. Schooling: years of schooling, first and second levels per capita, age 15 and over in the country.[5]
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 schooling 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).

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

Table 1. Production Functions*

| | (1) | (2) | (3) |
|---|---|---|---|
| Constant | 3.92 (4.75) | 3.96 (4.84) | 4.72 (6.01) |
| Fertilizer | .135 (2.92) | .134 (2.91) | .094 (2.08) |
| Labor | .343 (5.99) | .347 (6.12) | .297 (6.13) |
| Livestock | .198 (2.97) | .208 (3.36) | .183 (3.06) |
| Machinery | .205 (5.12) | .197 (5.50) | .160 (4.45) |
| Land quality | .877 (5.00) | .842 (5.39) | .723 (4.73) |
| Education | -.067 (-.444) | | |
| Technology (P) | .090 (1.54) | .077 (5.39) | |
| Technology (H) | | | .155 (3.61) |
| $R^2$ | .899 | .898 | .907 |

*Figures in parentheses are t-ratios.

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)).[6] The second deflator results in a stronger and statistically significant technology variable. It is highly correlated with fertilizer (r = .86), however, which is the likely explanation for the decline in the size and snignifcance 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 percent of the variation in land productivity is explained by these six variables.

The ranking of countries by land productivity is not intended to convey the idea that agricultural production in the countries toward the top of the list is necessarily 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. The capacity to transform inputs into output is more accurately measured by total factor productivity. This measure, shown in column (2) of the Appendix Table is the ratio of actual output per hectare (column (1)) in logs over predicted output from equation (3) of Table 1. The downward trend in land productivity is not followed by total factor productivity. 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. 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.[7] 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, .734 (column 3) suggests 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, and the implied underlying assumptions are rather extreme: producers know the production function with certainty, and adjustments to price changes are instantaneous. In reality adjustments 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. Hence the actual response to relative price movements will in all likelihood be less than the theoretical maximum.

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. Although output prices are available for many of the countries in the sample, input prices generally are not.[8] There are some fertilizer price data but the variation in the price of a given plant nutrient within countries raises a question of their accuracy.

Also there is the problem of measuring fertilizer subsidies and black market prices. Transportation costs also present a 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 output/input price ratios are made from production function (3) of Table 1. The following well-known expression holds under profit maximization.

$$(3) \quad P_y/P_x = 1/MPP_x$$

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, the predicted value of an input's MPP for a country is obtained holding constant the level of other inputs at the sample mean. For input $X_1$ it is

$$(4) \quad MPP_{1j} = A \cdot b_1 \cdot X_{1j}^{b_1 - 1} \cdot \bar{X}_2^{b_2} \cdots \bar{X}_m^{b_m}$$

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 $\bar{X}_2 \ldots \bar{X}_n$ are mean levels of $X_2$ through $X_n$.

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

$$(4) \quad P_j = \sum_{i=1}^{n} w_i \cdot P_{ij}$$

where $w_i$ the factor share of input i from the production function (3) standardized to sum to one, and $P_{ij}$ the index of the output/input price ratio of input i in country j. This index is presented in column (3) of the Appendix. The average value of the index for the top ten countries is over 20 times larger than the average for the ten lowest countries. The downward trend in the price ratio as land productivity declines is to be expected. The higher the prices of conventional inputs (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 of supply estimation since an underlying assumption of all supply functions is profit maximization (P=MC). This ratio should reflect the net prices paid and received after transport costs are taken into account by farmers. Also because the ratio measures the actual behavior of farmers it reflects expected prices. These prices rather than lagged or currently observed values are the relevant ones for supply estimation.

The results of estimating the aggregate supply function are presented in Table 2.[9] The dependent variable is output per hectare (Column (1) of the Appendix Table), and price is the ratio in column (3) of that table (both in logs). Land quality and technology, as previously defined, are the two shift variables. 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 where the output/fertilizer price ratio is used along with public research publications per hectare as a technology proxy. This figure is reduced to .90 with the use of the second technology variables--the stock of schooling at the third level deflated by hectares of land. Although these elasticities should be considered long run, they are still several times larger than long run estimates from supply functions fitted to time series data.

Over 90 percent of the variation of land productivity in the 119 country sample is explained by the three variables in equation (3). Of the explained variation, 64 percent is accounted for by price, 27 percent by technology, and the remaining 9 percent by land quality when each is added last in the regression.

## 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

Table 2. Supply Functions

| | (1) | (2) |
|---|---|---|
| Price | 1.19 (16.7) | .90 (10.5) |
| Land quality | .72 (5.16) | .58 (4.49) |
| Technology (P) | .19 (5.97) | |
| Technology (H) | | .23 (7.65) |
| $R^2$ | .892 | .906 |

food than is implied by the relatively small supply elasticities obtained from time series data. The results also suggest that there is still much to be gained by increasing production the old fashioned way--increasing the use of conventional inputs. But for this to occur in the LDCs the output/input price ratios must increase.

## Footnotes

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1. Pig meat, poultry meat, and eggs are reduced by .67, beef and milk by .50, and mutton and lamb by .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. The size weights varied from .25 (Japan) to 2.00 (United States) depending on the number of people per hectare.

3. The weights are: cattle 1.0, horses 1.3, mules 1.3, asses 1.0, buffalo 1.3, camels 1.4, pigs .25, sheep .125, chickens .006, ducks .0125, turkeys .0125.

4. Country specific land quality indexes are presented in Peterson, 1987a. The index for all agricultural land is used here.

5. Country specific figures for the first and second levels and third level of schooling are presented in Peterson, 1987b.

6. 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.

7. If $Y = Ax^b$, then $X = (Y/A)^{1/b}$. Total variable cost (TVC) is $W \cdot X = W \cdot (Y/A)^{1/b}$. $MC = d(W \cdot X)/dY = 1/b \cdot W \cdot Y^{(1/b)-1}A^{-1/b}$. Assuming profit maximization, let P, output price, equal MC, and solve for Y. $Y = (b \cdot P)^{(b/1-b)}W^{-b/1-b}A^{(1/b)(b/1-b)}$ The supply elasticity, $dY/dP \cdot P/Y = b/1-b$. With more than one variable input, b is the sum of the coefficients.

8. United Nations, FAO, "Statistics on Prices Received by Farmers," 1982.

9. 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.

## References


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Appendix
Productivity and Prices
1982-84 Averages

| Country | Output per Hectare (kg. WEQ) (1) | Total Productivity Ratio (2) | Price Ratio Index (3) |
|---|---|---|---|
| Netherlands | 16931 | 1.03 | 354 |
| Japan | 14394 | 0.94 | 286 |
| Egypt | 12896 | 1.02 | 372 |
| South Korea | 12050 | 0.99 | 284 |
| Belgium | 10131 | 1.05 | 245 |
| North Korea | 8052 | 0.96 | 237 |
| West Germany | 7843 | 1.02 | 332 |
| P. New Guinea | 7601 | 1.03 | 201 |
| Denmark | 7544 | 1.03 | 242 |
| Italy | 6932 | 1.02 | 199 |
| Israel | 6573 | 1.11 | 91 |
| Malaysia | 6479 | 1.10 | 102 |
| East Germany | 5949 | 1.01 | 171 |
| Norway | 5717 | 0.95 | 382 |
| Hungary | 5370 | 1.06 | 125 |
| France | 5280 | 1.03 | 185 |
| Poland | 5245 | 0.99 | 190 |
| Mauritius | 5079 | 0.99 | 174 |
| Surinam | 4926 | 0.97 | 109 |
| Switzerland | 4787 | 1.05 | 108 |

| Country | Output per Hectare (kg. WEQ) (1) | Total Productivity Ratio (2) | Price Ratio Index (3) |
|---|---|---|---|
| Austria | 4434 | 1.00 | 172 |
| Bangladesh | 4405 | 0.96 | 315 |
| Sweden | 4096 | 1.01 | 179 |
| Jordan | 3928 | 1.06 | 99 |
| Czechoslovakia | 3860 | 1.00 | 155 |
| United Kingdom | 3857 | 1.05 | 134 |
| Romania | 3823 | 0.98 | 135 |
| Bulgaria | 3754 | 0.99 | 127 |
| Finland | 3694 | 0.95 | 272 |
| Cyprus | 3691 | 1.10 | 70 |
| Zimbabwe | 3656 | 1.18 | 67 |
| Rwanda | 3555 | 1.19 | 111 |
| Philippines | 3449 | 1.00 | 102 |
| Yugoslavia | 3355 | 0.97 | 151 |
| Greece | 3313 | 1.02 | 103 |
| El Salvadore | 3225 | 0.99 | 111 |
| Haiti | 3021 | 1.06 | 153 |
| Indonesia | 3002 | 1.02 | 120 |
| Portugal | 2892 | 0.93 | 125 |
| Spain | 2881 | 1.03 | 86 |
| Thailand | 2736 | 0.96 | 105 |
| Jamaica | 2712 | 1.01 | 86 |

| Country | Output per Hectare (kg. WEQ) (1) | Total Productivity Ratio (2) | Price Ratio Index (3) |
|---|---|---|---|
| Sri Lanka | 2678 | 0.91 | 167 |
| Burma | 2646 | 0.99 | 116 |
| Turkey | 2564 | 1.00 | 90 |
| Colombia | 2357 | 1.05 | 102 |
| Trinidad-Tob. | 2313 | 0.92 | 93 |
| Cuba | 2195 | 0.95 | 100 |
| China (PRC) | 2150 | 0.97 | 100 |
| Guatemala | 2133 | 0.97 | 92 |
| India | 2109 | 0.91 | 150 |
| Dominican Republic | 2075 | 1.02 | 69 |
| Gambia | 2068 | 1.05 | 114 |
| Pakistan | 2048 | 0.92 | 148 |
| Ireland | 2023 | 1.01 | 130 |
| Albania | 2022 | 0.85 | 160 |
| Ivory Coast | 1824 | 1.05 | 56 |
| Kenya | 1746 | 0.99 | 145 |
| Panama | 1738 | 0.96 | 67 |
| Costa Rica | 1682 | 0.95 | 169 |
| New Zealand | 1682 | 1.14 | 25 |
| Nepal | 1619 | 0.93 | 206 |
| Ecuador | 1586 | 0.98 | 61 |
| USA | 1554 | 1.04 | 111 |

| Country | Output per Hectare (kg. WEQ) (1) | Total Productivity Ratio (2) | Price Ratio Index (3) |
|---|---|---|---|
| Burundi | 1482 | 1.17 | 75 |
| Canada | 1269 | 1.05 | 72 |
| Malawi | 1229 | 1.08 | 67 |
| Ghana | 985 | 1.00 | 55 |
| Honduras | 969 | 0.99 | 48 |
| Uganda | 962 | 1.12 | 49 |
| Colombia | 948 | 1.00 | 47 |
| Syria | 921 | 1.04 | 37 |
| USSR | 920 | 1.00 | 51 |
| Iraq | 833 | 0.96 | 55 |
| Tunisia | 832 | 1.00 | 45 |
| Brazil | 809 | 0.95 | 47 |
| Guyana | 807 | 1.00 | 27 |
| Zaire | 773 | 1.04 | 61 |
| Mexico | 762 | 0.94 | 48 |
| Benin | 754 | 1.03 | 55 |
| Togo | 705 | 0.97 | 56 |
| Nigeria | 701 | 0.97 | 58 |
| Chile | 687 | 1.00 | 37 |
| Morocco | 611 | 0.97 | 47 |
| Swaziland | 594 | 0.94 | 48 |
| Venezuela | 577 | 0.91 | 42 |

| Country | Output per Hectare (kg. WEQ) (1) | Total Productivity Ratio (2) | Price Ratio Index (3) |
|---|---|---|---|
| Guinea | 572 | 0.99 | 56 |
| Iran | 548 | 0.99 | 38 |
| Argentina | 530 | 1.10 | 23 |
| Uruguay | 506 | 0.98 | 45 |
| Cameroon | 477 | 1.00 | 40 |
| Somalia | 458 | 1.00 | 37 |
| Nicaragua | 415 | 0.94 | 30 |
| Peru | 391 | 0.89 | 30 |
| Paraguay | 366 | 1.01 | 24 |
| Senegal | 358 | 0.99 | 36 |
| C.A.R. | 332 | 1.07 | 37 |
| South Africa | 315 | 0.94 | 27 |
| Tanzania | 314 | 0.99 | 42 |
| Niger | 265 | 1.20 | 42 |
| Afghanistan | 260 | 1.06 | 29 |
| Ethiopia | 252 | 0.98 | 50 |
| Madagascar | 214 | 0.96 | 28 |
| Algeria | 206 | 0.92 | 28 |
| Upper Volta | 178 | 1.06 | 35 |
| Sudan | 167 | 0.90 | 33 |
| Lesotho | 155 | 0.81 | 52 |
| Australia | 137 | 1.08 | 11 |

| Country | Output per Hectare (kg. WEQ) (1) | Total Productivity Ratio (2) | Price Ratio Index (3) |
| --- | --- | --- | --- |
| Bolivia | 134 | 0.96 | 19 |
| Gabon | 89 | 0.92 | 13 |
| Mali | 77 | 0.93 | 25 |
| Somalia | 76 | 0.96 | 30 |
| Angola | 75 | 0.85 | 17 |
| Congo | 71 | 1.00 | 6 |
| S. Arabia | 41 | 0.95 | 8 |
| Zambia | 41 | 0.78 | 13 |
| Chad | 35 | 1.00 | 13 |
| Mauritania | 11 | 0.72 | 6 |
| Botswana | 11 | 0.88 | 8 |