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Do Country Idiosyncracies Matter in Estimating a Production Function for World Agriculture?

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An alternative five-input (labor, land, livestock, fertilizer and machinery) meta-production function for agriculture is estimated with the cross-section data for 43 countries and 3 years (1960, 1970 and 1980) that were assembled and used by Kawagoe, Hayami and Ruttan and Hayami and Ruttan in their studies. First, by allowing for country-specific efficiency factors while maintaining the assumption of a Cobb-Douglas production function, strikingly different results from those of Kawagoe, Hayami and Ruttan are obtained. Second, it is found that even with the introduction of the country-specific efficiency factors, the Cobb-Douglas production function does not provide an adequate representation of the agricultural technology. When it is replaced by a more flexible functional form — the transcendental logarithmic production function — it is found that the elasticities of output with respect to labor, land, livestock and fertilizer are 0.40, 0.40, 0.14 and 0.06 respectively (as opposed to 0.55, 0.03, 0.30 and 0.15); the elasticity of output with respect to machinery is variable and increases with the

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usage of machinery; the degree of returns to scale is not fixed and the local returns to scale increases with the usage of machinery; the elasticity of output with respect to the number of agricultural graduates at the post-secondary level is approximately 0.1; and technical progress (not accounted for by changes in inputs and technical education) averaged less than 1 percent per annum for developed countries and less than 1/2 of 1 percent for less developed countries during the decades of the 1960's and 1970's. Besides these specific results, the study has implications for empirical analyses involving international cross-sections in that it demonstrates how the common problems of underlying inter-country differences — whether in the definition, measurement and quality of data or in unmeasurable country-specific environmental factors (country idiosyncracies, in short) — may be successfully handled and that failure to account for these differences can lead to biased results.

I. Introduction

An important cornerstone of the academic discipline of development economics is the implicit assumption that the process of development is characterized by regularities which transcend national boundaries. Intercountry studies of various aspects of development — structural change, the morphology of growth, or the process of production, to mention a few — have flourished.[1] The practice of pooling data from different countries is empirically attractive because it has the potential of increasing the reliability of the estimates. However, it also presents new problems. The first problem is the non-comparability of data, caused by inter-country differences in definitions, measurements and qualities. But even if it were possible to standardize the definitions, measurements and qualities of variables across countries completely, the actual efficiencies of the variables may still differ across countries because of the second problem — the existence of inter-country differences in the basic economic environment, including differences in climate, topography and infrastructure, broadly defined, that are not reflected in the measured variables, however standardized. There may, in the

[1] For examples of analyses based on inter-country data see Chenery (1960, 1979), Chenery, Robinson and Syrquin, Hayami and Ruttan (1970, 1985), and Nugent and Yotopoulos.

context of production, also be differences in the levels of technical efficiency, that is, the ability of producing outputs from given quantities of inputs. These country-specific differences may be referred to as country effects or "idiosyncracies." The third problem is the extensiveness of the domain over which a given function is expected to apply. Thus, when the ranges of variation of the quantities of inputs are large, a production function such as the Cobb-Douglas is not likely to represent the input-output relationship over the entire ranges satisfactorily.

In this paper we shall show how estimation biases introduced as a result of the problems mentioned above may be avoided or reduced through first-differencing and using a flexible functional form.

II. A Meta-Production Function for World Agriculture

One of the most intriguing uses of pooled inter-country data is due to Hayami and Ruttan (1970, 1985)[2] who gave currency to the concept of an agricultural meta-production function, based on the simple but attractive hypothesis that all countries have access to the same technology but each may operate on a different part of it depending on specific circumstances. Kawagoe, Hayami and Ruttan (1985) (hereafter KHR) estimated an agricultural production function on a per farm basis using inter-country data for 3 years — 1960, 1970 and 1980. Outputs (Y) are measured as gross outputs net of agricultural intermediate products and expressed in terms of wheat-equivalents or wheat units. Five conventional inputs, labor (X_1), land (X_2), livestock (X_3), fertilizer (X_4) and machinery (X_5), and two nonconventional inputs, general and technical education (X_6 and X_7), are distinguished. The sample of 43 countries is divided into two mutually exclusive and exhaustive subsamples: 22 LDC's and 21 DC's, with LDC's defined as those with a 1980 per capita GNP below US$4,000 and DC's defined as those above.[3]

2 Other parallel references are Kawagoe and Hayami (1983, 1985) and Kawagoe, Hayami and Ruttan. There are many other studies of agricultural production using inter-country data. See the references listed in Kawagoe, Hayami and Ruttan and Lau and Yotopoulos.

3 Except Libya, which is included in the LDC subsample despite a 1980 per capita GNP in excess of US$8,000.

The production function is assumed to have the Cobb-Douglas form:

$$(2.1)\quad \ln Y_{it} = \beta_0 + \Sigma_{j=1}^{7}\ \beta_j \ln X_{ijt} + \beta_8 DLDC_{it} + \beta_9 D1970_{it} + \beta_{10} D1980_{it} + \varepsilon_{it}$$

$$i = 1, \ldots, 43;\ t = 1960,\ 1970,\ 1980.$$

where X_{i6t} is represented by the literacy ratio;[4] $DLDC_{it}$ is a dummy variable for an LDC; $D1970_{it}$ and $D1980_{it}$ are year dummy variables for 1970 and 1980 respectively; and ε_{it} is a stochastic disturbance term with the usual properties. There are thus no country-specific effects other than the LDC effect. The results of estimating (2.1) by ordinary least squares are presented in Table 1 under the headings "no country effects."[5]

Despite a generally good fit, the estimates of several of the coefficients do not seem plausible. The estimated coefficients for land (0.04 for all countries, -0.05 for LDC's and 0.07 for DC's) appear too low; the estimated coefficients for the literacy ratio appear either too high (LDC's) or have the wrong sign (DC's); and the estimated coefficients for the year dummy variables suggest that agricultural technology for the LDC's has retrogressed by 15% between 1960 and 1970 and by 30% between 1960 and 1980. Can these implausible estimates be the results of biases due to misspecification?

An examination of the data[6] reveals considerable inter-country variations in the quantities of inputs per farm. The ratio of the maximum to the minimum value of the quantity of input per farm observed across countries ranges from a low of 84 for labor to a high of 41,900 for machinery. The wide inter-country ranges suggest that measured variables such as "number of male workers," "hectares of land," and "machinery horsepower" may not be efficiency-equivalent across countries and thus an alternative specification which takes into account inter-country differences in the measured variables may be more appropriate.

4 Kawagoe, Hayami and Ruttan also employ as an alternative general education variable the school enrollment ratio. However, the estimation results do not seem sensitive to the choice of the general education variable.

5 These are essentially the KHR estimates.

6 Hayami and Ruttan (1985), Appendix A: Inter-country Cross-Section Data.

III. A Cobb-Douglas Model with Country-Specific Effects

Two types of country-specific effects are accommodated in the alternative meta-production function. First, neutral differences in the levels of technical efficiency are allowed across countries. Second, the factors of production, including both the physical inputs and the education variables, are not assumed to be directly comparable or efficiency-equivalent across countries, even with the standardizations, as measured. Instead, they are assumed to be comparable across countries only after the multiplication by constant country and factor-specific scalar conversion factors, A_{ij}'s, called augmentation factors. Thus for each country the quantity of each efficiency-equivalent input, X^*_{ijt} is given by:

$$(3.1)\quad X^*_{ijt} = A_{ij}X_{ijt},\ i=1,\ldots,43;\ j=1,\ldots,7;\quad t=1960,\ 1970,\ 1980;$$

where the X_{ijt}'s are the measured quantities of the variables.

The Cobb-Douglas production function is assumed to be identical across countries in terms of the quantities of the efficiency-equivalent inputs up to a multiplicative technical efficiency factor, A_{i0}. This,

$$(3.2)\quad \ln Y_{it} = \beta_0 + \ln A_{i0} + \Sigma_{j=1}^{7}\beta_j \ln X^*_{ijt} + \beta_8 DLDC_{it} + \beta_9 D1970_{it} + \beta_{10} D1980_{it} + \varepsilon_{it},\ i=1,\ldots,43;\quad t=1960,\ 1970,\ 1980.$$

By using (3.1), (3.2) may be rewritten as:

$$(3.3)\quad \ln Y_{it} = \ln A^*_i + \Sigma_{j=1}^{7}\beta_j \ln X_{ijt} + \beta_9 D1970_{it} + \beta_{10} D1980_{it} + \varepsilon_{it},\ i=1,\ldots,43;\ t=1960,\ 1970,\ 1980.$$

Note that there is now a constant term, $\ln A^*_i$, which varies across countries. (3.3) can be estimated directly. Instead, it is estimated in first-differenced form:

$$(3.4)\quad \ln Y_{it} - \ln Y_{i(t-1)} = \Sigma_{j=1}^{7}\ \beta_j(\ln X_{ijt} - \ln X_{ij(t-1)}) + \beta_9(D1970_{it} - D1970_{i(t-1)}) + \beta_{10}(D1980_{it} - D1980_{i(t-1)})$$

Table 1

Estimates of Intercountry Production Function

Regression	All Countries (43)			LDCs (22)			DCs (21)		
	No Country Effects (with literacy)	With Country Effects (1) (w.lit.)	With Country Effects (2) (w/out lit.)	No Country Effects (with literacy)	With Country Effects (1) (w.lit.)	With Country Effects (2) (w/out lit.)	No Country Effects (with literacy)	With Country Effects (1) (w.lit.)	With Country Effects (2) (w/out lit.)
Constant	1.905 (4.788)	---	---	1.113 (2.276)	---	---	9.592 (2.768)	---	---
Labor (X_1)	0.560 (7.988)	0.162 (2.314)	0.325 (4.333)	0.672 (6.068)	0.268 (2.469)	0.349 (3.247)	0.660 (7.995)	0.229 (2.022)	0.322 (2.827)
Land (X_2)	0.035 (1.011)	0.938 (9.164)	0.668 (5.793)	-0.051 (0.821)	0.891 (5.741)	0.796 (5.062)	0.069 (2.116)	0.383 (2.057)	0.217 (1.170)
Livestock (X_3)	0.293 (6.302)	0.133 (2.162)	0.134 (2.249)	0.264 (3.033)	0.053 (0.638)	0.088 (1.038)	0.186 (2.865)	0.326 (3.495)	0.255 (2.693)
Fertilizer (X_4)	0.154 (4.010)	0.023 (0.840)	0.057 (2.173)	0.081 (1.461)	0.042 (1.307)	0.058 (1.796)	0.192 (2.481)	0.100 (1.342)	0.154 (2.014)
Machinery (X_5)	0.070 (1.998)	0.058 (2.555)	0.061 (2.751)	0.141 (2.761)	0.044 (1.631)	0.042 (1.505)	0.215 (3.838)	0.041 (0.798)	0.127 (3.204)
Literacy Ratio (X_6)	0.123 (1.379)	0.187 (1.683)	---	0.268 (2.498)	0.282 (2.230)	---	-1.600 (2.090)	2.756 (2.423)	---
Technical Educ. (X_7)	0.181 (6.025)	0.059 (2.281)	0.095 (3.816)	0.177 (4.507)	0.071 (2.222)	0.094 (2.941)	0.134 (3.907)	0.047 (0.839)	0.120 (2.370)
LDC Dummy	-0.461 (4.224)	---	---	---	---	---	---	---	---
Time Dummy 1970	-0.002 (0.023)	0.120 (3.206)	0.170 (3.948)	-0.157 (1.550)	0.071 (1.422)	0.090 (1.765)	0.044 (0.639)	0.143 (1.755)	0.056 (0.715)
Time Dummy 1980	-0.041 (0.512)	0.193 (3.215)	0.270 (4.164)	-0.328 (2.762)	0.125 (1.600)	0.144 (1.760)	0.095 (1.086)	0.243 (1.772)	0.096 (0.729)
LDC* 1970 Dummy	---	---	-0.103 (2.261)	---	---	---	---	---	---
LDC* 1980 Dummy	---	---	-0.175 (2.768)	---	---	---	---	---	---
$\bar{R}^2$	0.946	0.829	0.837	0.919	0.834	0.816	0.965	0.816	0.789
S	0.287	0.124	0.121	0.307	0.129	0.136	0.178	0.091	0.098

Note: Numbers of parentheses are t-ratios.

$$+ \varepsilon_{it} - \varepsilon_{i(t-1)}, \; i = 1, \ldots, 43; \; t = 1970, \; 1980.$$

The unknown $\ln A_i^*$'s are thus eliminated. To allow the possibility that the rate of technological change may differ systematically across LDC's and DC's, two terms, β_9^* $DLDC_{it}*(D1970_{it} - D1970_{i(t-1)})$ and β_{10}^* $DLDC_{it}*(D1980_{it} - D1980_{i(t-1)})$ are added to (3.4).[7]

The results of estimation (3.4) are presented under the heading "with country effects" in Table 1. The differences between these and the "no country effects" results are most striking. The estimated coefficients for land become much larger and statistically significant (although probably too large for all countries and for the LDC's). The estimated coefficients of the year dummy variables now have the expected signs. However, the estimated coefficients for the literacy ratio still appear unreasonably large. Since the variable as defined and measured applies to the whole and not just the agricultural population, it is unsatisfactory for our purposes. We therefore dropped the literacy ratio and obtained the estimates in the second "with country effects" columns of Table 1. These estimates seem reasonable and consistent with a priori expectations.

By estimating both (2.1) and (3.3) for all observations we obtain the sums of squared residuals which are used to test the hypothesis of non-existence of the country-specific effects other than the LDC effect. In other words, the null hypothesis is:

$$\ln A_i^* = \begin{cases} \ln A_L^*, & \text{if the } i\text{th country is an LDC} \\ \ln A_D^*, & \text{if the } i\text{th country is a DC} \end{cases}$$

This hypothesis is decisively rejected by the estimated test statistic.[8]

Next, we consider returns to scale. KHR found evidence in favor of constant returns to scale for the LDC's and increasing

[7] While first-differencing removes the fixed country-specific effects, it introduces heteroscedasticity even if it is absent prior to first-differencing. Hence, the first-differenced equations must be further transformed to obtain a specification that has homoscedastic stochastic disturbance terms. For details, see Lau and Yotopoulos.

[8] The F-statistic for the null hypothesis of no country-specific effects is $F(41,77) = 29.1$ (critical value at $5\% = 1.54$).

returns to scale for the DC's. However, when the model with country effects is used, the conclusions are exactly reversed. With the literacy ratio omitted, the hypothesis of constant returns to scale is rejected for both the LDC's and the DC's at the 5 percent level of significance. These results are summarized in Table 2.

IV. A Transcendental Logarithmic Model with Country-Specific Effects

We next investigate whether the Cobb-Douglas production function with country effects is sufficiently flexible to represent the meta-production function over these wide inter-country ranges of data. We assume that the meta-production function has the transcendental logarithmic form introduced by Christensen, Jorgenson and Lau (1973).[9] In terms of the quantities of efficiency-equivalent inputs, the transcendental logarithmic production function may be written as:

$$(4.1)\quad \ln Y_{it} = \beta_0 + \ln A_{i0} + \Sigma_{j=1}^{5} \beta_j \ln X^*_{ijt} + \beta_7 \ln X^*_{ijt} + 1/2\ \Sigma_{j=1}^{5} \Sigma_{k=1}^{5} \delta_{jk} \ln X_{ijt} \ln X^*_{ikt} + \beta_8 DLDC_{it} + \beta_9 D1970_{it} + \beta_{10} D1980_{it} + \varepsilon_{it}{}^{10}$$

where $[\delta_{jk}]$ may without loss of generality be taken to be symmetric. In terms of the quantities of measured inputs and other factors, (4.1) may be rewritten as:

$$(4.2)\quad \ln Y_{it} = \ln A^*_i + \Sigma_{j=1}^{5} \beta_j \ln X_{ijt} + \beta_7 \ln X_{i7t} + 1/2\ \Sigma_{j=1}^{5} \Sigma_{k=1}^{5} \delta_{jk} \ln X_{ijt} \ln X_{ikt} + \beta_9 D1970_{it} + \beta_{10} D1980_{it} + \Sigma_{j=1}^{5} \beta^*_{ij} \ln X_{ijt} + \varepsilon_{it}$$

where A^*_i and β^*_{ij} for each i are unknown constants that are functions of the β_j's, δ_{jk}'s, A_{i0} and A_{ij}'s. As there are only 3 observations per country, it is not possible to identify the individual

9 KHR also attempted to estimate a transcendental logarithmic production function, but without country effects, and did not obtain satisfactory results.

10 As the literacy ratio variable is unsatisfactory, it is omitted from further empirical analyses.

Table 2

ESTIMATES OF THE DEGREE OF RETURNS TO SCALE

Regression	No Country Effect (with literacy)	With Country Effects (with literacy)	(without literacy)
All Countries	1.112	1.314	1.245
	(2.246)	(3.898)	(2.966)
	[1.980]	[1.994]	[1.994]
Less Developed Countries	1.107	1.298	1.333
	(1.714)	(2.749)	(2.985)
	[2.005]	[2.032]	[2.029]
Developed Countries	1.322	1.079	1.075
	(4.603)	(0.663)	(2.239)
	[2.010]	[2.036]	[2.033]

Notes: Numbers in parentheses are t-ratios for the null hypothesis of constant returns to scale. Numbers in square brackets are the critical values of the t-statistics at the 5 percent level of significance.

Table 3

TESTS OF THE TRANSCENDENTAL LOGARITHMIC SPECIFICATION

Hypothesis	Degree of Freedom	F-Value	Critical Value at 5%
1. Zero Second-Order Parameters (Cobb-Douglas Specification)	15,55	2.35	1.86
2. Identical First-Order LDC & DC Parameters	6,55	2.02	2.27
3. Additivity	10,55	1.81	2.00

β^*_{ij}'s without additional assumptions. We assume that

$$\beta^*_{ij} = \begin{cases} \beta^*_j, & \text{if the } i\text{th country is an LDC} \\ 0, & \text{if the } i\text{th country is a DC} \end{cases}$$

and further allow β_7, β_9 and β_{10} to differ between the LDC's and DC's, so that:

$$(4.3)\ \ln Y_{it} = \ln A_i^* + \Sigma_{j=1}^{5} \beta_j \ln X_{ijt} + \Sigma_{j=1}^{5} \beta_j^* (DLDC_{it} * \ln X_{ijt}) + \beta_7 \ln X_{i7t} + \beta_7^* (DLDC_{it} * \ln X_{i7t}) + 1/2\ \Sigma_{j=1}^{5} \Sigma_{k=1}^{5} \delta_{jk} \ln X_{ijt} \ln X_{ikt} + \beta_9 D1970_{it} + \beta_9^* (DLDC_{it} * D1970_{it}) + \beta_{10} D1980_{it} + \beta_{10}^* (DLDC_{it} * D1980_{it}) + \varepsilon_{it},\ i = 1, \ldots, 43;\ t = 1960, 1970, 1980.$$

As before, by taking first differences of (4.3) for each country, we eliminate the $\ln A_i^*$'s. We also further transform the first-differenced equation to achieve homoscedasticity.

We first test whether the Cobb-Douglas specification is adequate, that is, whether all the second-order coefficients, δ_{jk}'s, are zero. This hypothesis is rejected at the 5 percent level of significance. We next test whether the first-order coefficients, β_j's, are identical between the LDC's and the DC's, that is, whether β^*_j's are zero. This hypothesis cannot be rejected at the 5 percent level of significance. We next test whether the transcendental logarithmic function is additive in the inputs, that is, has all second-order cross coefficients, δ_{jk}'s, $j \neq k$, equal to zero. This hypothesis cannot be rejected at the 5 percent level of significance. The results are summarized in Table 3.

Finally we test the hypothesis that second-order own coefficient, δ_{jj}, is equal to zero for each input. The only such hypothesis that can be rejected is that for machinery. We therefore estimated a final summary specification imposing this restriction for all inputs other than machinery. The results of the estimation of the transcedental logarithmic function are reported in Table 4.

The final summary specification is quite interesting. It implies that the degree of (local) returns to scale, μ, varies monotonically with the quantity of machinery input:

$$(4.4)\quad \mu = \Sigma_{j=1}^{5} \beta_j + \delta_{55} * \ln X_5 = 1.112 + 0.026 * \ln X_5$$

We observe that the elasticities of output with respect to labor, land, livestock and fertilizer are 0.40, 0.40, 0.14 and 0.06 respectively; the elasticity of output with respect to technical education, proxied by the number of agricultural graduates at the post-secondary level is approximately 0.1; and technical progress

Table 4

ESTIMATES OF THE INTER-COUNTRY PRODUCTION FUNCTION FROM TRANSFORMED FIRST-DIFFERENCED DATA – TRANSCENDENTAL LOGARITHMIC SPECIFICATIONS (All 43 Countries)

Variables	Additivity	Final Summary
Labor (X_1)	0.420	0.396
	(5.022)	(5.638)
Land (X_2)	0.335	0.403
	(1.610)	(3.282)
Livestock (X_3)	0.162	0.143
	(1.947)	(2.634)
Fertilizer (X_4)	0.029	0.058
	(0.452)	(2.455)
Machinery (X_5)	0.112	0.109
	(4.377)	(4.683)
Technical Education (X_7)	0.114	0.108
	(4.352)	(4.714)
ln X_1-Squared	-0.005	–
	(0.168)	
ln X_2-Squared	0.017	–
	(0.538)	
ln X_3-Squared	-0.009	–
	(0.405)	
ln X_4-Squared	-0.004	–
	(0.472)	
ln X_5-Squared	0.015	0.013
	(3.235)	(4.137)
Time Dummy 1970	0.114	0.098
	(2.246)	(2.307)
Time Dummy 1980	0.171	0.154
	(2.291)	(2.358)
LDC* 1970 Dummy	-0.063	-0.056
	(1.361)	(1.303)
LDC* 1980 Dummy	-0.140	-0.132
	(2.251)	(2.260)
$\bar{R}^2$	0.859	0.866
S	0.112	0.110
SUM OF SQUARED RESIDUALS	0.896	0.901

Note: Numbers in parentheses are t-ratios.

averaged less than 1 percent per annum for DC's and less than 1/2 of 1 percent for LDC's during the decades of the 1960's and 1970's.[11]

V. Conclusions

What have we learned from this study? We do not claim that we have found the definitive meta-production function for world agriculture. However, we find that it is important when estimating a production function (or for that matter any other kind of function) from inter country data to take into account the possible existence of inter-country differences and to use a sufficiently flexible functional form. This finding may also have implications on other empirical studies based on inter-country data.

11 Note that these estimates are different again from the estimates under the heading "with country effects" in Table 1.

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