WPS 1827

POLICY RESEARCH WORKING PAPER 1827

The Determinants of Agricultural Production

A Cross-Country Analysis

Yair Mundlak
Don Larson
Ritz Butzer

Capital is important to agricultural production, so policies that improve access to agricultural capital will facilitate growth, if the capital is used efficiently.

The World Bank
Development Research Group
September 1997

Summary findings

In this analysis of capital's role in agricultural production, a new construction of data on capital allowed Mundlak, Larson, and Butzer to advance the cross-country study of production functions. The model reveals the relative importance of capital, a finding quite robust to modifications of the model and the disaggregation of capital to its two components. The model is also consistent with the view that lack of physical capital serves as a constraint on agricultural growth.

The shift to more productive techniques is associated with a decline in labor, reflecting labor-saving technical changes. This is not news, but it is emphasized here because it comes out of an integral view of the process which distinguishes between the core technology and the changes that took place over time and between countries.

Not only is capital important to agricultural production, and agricultural development dependent on the economic environment, but agriculture is more cost-capital-intensive than nonagriculture.

Capital is all the more important as a factor of production in that land (also important) varies little over time. The availability of agricultural capital determines whether the gap between available and applied technologies can be closed.

Prices have little direct, immediate impact on agricultural growth, beyond their impact through inputs and choice of technology. The legacy of past policies that distorted the relative returns to economic activity is enshrined in current stocks, which may respond slowly to policy reform.

The analysis assumes that the production technology is heterogeneous and the implemented technology is endogenous and determined jointly with the level of unconstrained inputs. Thus, a change in the state variables affects both the technology and the inputs, so the production function is not identified. To overcome that problem, changes in productivity are decomposed to three orthogonal components caused by the fundamentally different processes underlying panel data.

The statistical framework explains the unstable results observed in production functions derived from panel data. Statistically, the results depend on how the data are projected. Comparisons between units over time or of deviations from unit-means or time-means all describe different processes. This is based on theory but has an intuitive appeal as well.

In this case, the spread in productivity among countries is different from the spread in productivity for a country through time. The factors explaining the spread will differ. The modeling approach should explicitly recognize the fact that panel data measure a combination of economic phenomena.

This paper — a product of the Development Research Group — is part of a larger effort in the group to examine the determinants of growth in agriculture. The study was funded by the Bank's Research Support Budget under the research project "Determinants of Agricultural Growth" (RPO 679-03). Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Pauline Kokila, room N5-030, telephone 202-473-3716, fax 202-522-3564, Internet address pkokila@worldbank.org. September 1997. (40 pages)

THE DETERMINANTS OF AGRICULTURAL PRODUCTION: A CROSS-COUNTRY ANALYSIS

Yair Mundlak, Donald F. Larson, and Rita Butzer

Yair Mundlak is a professor in the Economics Department, University of Chicago; Donald F. Larson is an economist in the Commodity Policy and Analysis Unit at the World Bank; and Rita Butzer is a consultant at the World Bank. The authors would like to thank Al Crego for valuable research assistance. This research was conducted at the World Bank as part of a larger research effort on the determinants of agricultural growth (RPO 679-03).

Summary findings

This study is triggered by the desire to shed light on the role of capital in agricultural production, a neglected topic due to lack of appropriate data. The construction of the data on capital allowed us to advance the cross-country study of production functions in what turns out to be an important direction. The analysis is based on the premise that the production technology is heterogeneous and the implemented technology is endogenous and determined jointly with the level of the unconstrained inputs. Therefore, a change in the state variables affects both the technology and the inputs, and consequently the production function is not identified. To overcome this problem, we decompose the changes in productivity to three orthogonal components caused by the fundamentally different processes underlying panel data and thereby gain meaningful economic insight.

The statistical framework provides an explanation for the unstable results observed in production functions derived from panel data. Statistically, the results depend on how the data are projected. Underlying this is the fact that comparisons between units, over time or of deviations from unit-means or time-means all describe different processes. This is based on theory, but has an intuitive appeal as well. In the case at hand, the spread in productivity among countries is a different economic phenomenon or process from the spread in productivity for a country through time. In turn, the factors explaining the spread will differ. Panel data measures a combination of these economic phenomena—a fact which should be recognized explicitly in the modeling approach.

The most striking result is the relative importance of capital. This result is quite robust to various modifications of the model and to the disaggregation of capital to its two components. Our findings are also consistent with the view that physical capital serves as a constraint to agricultural growth. At the same time, the between-time regression shows that the shift to more productive techniques is associated with a decline in labor, which is an indication of the labor-saving technical change in agriculture. This is not news, but it is emphasized here because it comes out of an integral view of the process which separates between the core technology and the changes that took place over time and between countries. These results highlight the importance of capital in agricultural production, an attribute critical in the understanding of agricultural development and its dependence on the economic environment.

The introduction of the appropriate state variables to account for technology, prices and physical environment produced a production function that displays constant returns to scale and thus avoided the pitfalls of previous studies and the misguided conclusions that followed. The contribution of inputs to growth should be judged by their contribution to output under a constant technology, attributing the rest of the growth to technical change. Our results support the view that agriculture is cost-capital-intensive as compared to nonagriculture. We provide estimates of factors' productivity that can be compared to the factors' price. Comparing our results to the factor shares, it seems that on the whole there is a surprising agreement. We do find that the growth calculations are

sensitive to the weight of land, and this is where earlier results erred the most. Still, after all these years of intensive work on production functions, there is no hard evidence that estimated elasticities do a better job than the factor shares as were originally used by Solow (1957).

Finally, our results have important implications for policy. First, we can say that agricultural capital is directly an important determinant of agricultural production. This is especially significant, since land, another important determinant of production, varies little over time. Moreover, agricultural capital is also important in closing the gap between available and applied technologies. Therefore policies facilitating access to agricultural capital will facilitate growth, provided the capital is used efficiently. This implies that the overall economic environment must be conducive to the efficient use of capital. Second, we find that prices have little immediate and direct impact on agricultural growth, beyond their impact through inputs and the choice of technology. Consequently, past policies that distort the relative returns to economic activity leave a legacy enshrined in current stocks that may respond slowly to policy reforms.

CONTENTS

THE DETERMINANTS OF AGRICULTURAL PRODUCTION: A CROSS-COUNTRY ANALYSIS

Yair Mundlak, Donald F. Larson, and Rita Butzer

Introduction

Knowledge of the production structure, as reflected in the production elasticities, is essential in the discussion of several key topics such as:

1. The contribution of inputs to output and, in a dynamic context, to growth.
2. The existence of returns to scale.
3. The sensitivity of the cost of production to changes in factor prices.
4. The relationships between factor prices and their productivity.

The discussion in this paper and the results bear directly on the first three subjects and indirectly on the last one.

Empirical studies utilize data collected at various levels, from micro data at the firm level to macro data at the national level. Cross-country studies utilize national data, and their potential contribution comes from the large spread in inputs and other important variables which helps to increase the precision of estimates. However, cross-country studies have suffered from lack of sectoral capital data. To overcome this deficiency, data on agricultural capital were constructed and used here in the estimation (Crego, Larson, Butzer and Mundlak, 1997). The results are striking in that it becomes clear that capital plays a major role in agricultural production.

The practice in empirical studies has been to assume that technology is homogeneous and is represented by a production function applicable to all the observations in the sample. This assumption is not supported by the data. For instance, when panel data have been used, the results vary according to whether country or time dummies are introduced. Such dependence on the specification has been discussed in the literature within the framework of statistical properties under the assumption that all the versions provide information on the same function. We take here the alternative view which differentiates between functions estimated from observations within country and time and those obtained from variability across countries and over time. Again, the results are striking.

The recognition of the variability of the function relates to a more general view that technology is heterogeneous and the choice of the implemented technology is determined by the economic and physical environment. Earlier empirical applications of this approach utilize factor shares, which we do not have. We therefore settle for less and formulate the problem in a way that allows us to estimate the function.

The plan of the paper is as follows: we begin with a brief literature review of cross-country studies of the agricultural production function. This is followed by an outline of the model, a discussion of the statistical aspects, data description, presentation of the results, a discussion of the results and conclusions.

Cross-country studies[1]

Analysis of agricultural production functions began in 1944 with the work of Tintner(1944), Tintner and Brownlee (1944), followed by Heady (1944). These studies were based on farm data. Subsequent work was extended to cover aggregate data, and in 1955 Bhattacharjee presented the first analysis based on cross-country data. The underlying notion for these early studies was that all observations were generated from the same production function. In an effort to get a definitive statement on the agricultural production function, Heady and Dillon (1961, Chapter 17) compared the result of Bhattacharjee's study with numerous other studies and discovered that the notion of a homogenous technology was elusive. Thus they concluded "Still, the variations shown among the elasticities ... bears witness to the dangers associated with the use of any such global production function." (Op. cit., p.633).[2]

The use of cross-country data to estimate a global production function gained impetus with the work of Hayami (1969, 1970) and Hayami and Ruttan (1970) -- studies which sought to explore the causes of cross-country differences in agricultural productivity. Again, the assumption underlying these studies is that all countries use the same production function. This assumption does not stand, and we find considerable disparities between their results and those obtained in country studies.

Since Bhattacharjee's study, with the passage of time, it was possible to increase the sample size and thus estimate the functions for different periods and additional countries. Also researchers have introduced new subjects, including: checking the robustness of the estimates and the returns to scale, improving the specification by adding state variables and using different methods of estimation, and doing away with the assumption of constant technology.

Table 1 summarizes results obtained in a series of cross-country studies where the quantities (outputs and inputs) are expressed either as country totals or in per worker terms.[3] Studies using data for a single period provide estimates for the between-country regression for that particular year. This is also the case for studies which use panel data and introduce time dummies (within-time regressions) but not country dummies. Studies with panel data which contain country dummies (with or without time dummies) provide estimates for the within-country (or within-country and time) regression. We elaborate on this point below.

---

1 For a survey of agricultural production functions see Mundlak (1997).

2 Clark (1973) assembles many results of factor shares in a nonformal framework but with extensive international coverage. It is very clear that the estimates depend on the economic environment which is a major theme of the discussion.

3 We do not include studies where the quantities are expressed as averages per farm because this would raise issues unessential to our discussion

We will try to characterize some of the results. The study by Bhattacharjee does not include any measure of capital items nor shifters, technology or others, and therefore the results cannot be compared meaningfully with the other studies. The remaining studies have some shifters such as schooling, research and extension, infrastructure and the like. In a way of generalization, the table shows that the between-country estimates of land elasticity are low in absolute terms and relative to estimates obtained from the within regression (compare the two versions of the Evenson and Kislev study). Two measures of capital have been used in most studies, machinery and livestock. The elasticity of machinery varies around 0.1 (a little higher for the between-country regression) and that of livestock concentrates in the range of 0.2-0.3. The estimates for the labor elasticity are less stable. Of course, this is a very general evaluation but sufficient to provide a background for the discussion.

The model

The underlying premise is that producers at any time face more than one technique of production and their economic problem is to choose the techniques to be employed together with the choice of inputs and outputs. The outline of the approach follows Mundlak (1988, 1993). Let x be the vector of inputs and $F_j(x)$ be the production function associated with the jth technique, where F_j is concave and twice differentiable, and define the available technology, T, as the collection of all possible techniques, $T = \{F_j(x);\ j=1, \dots, J\}$. Firms choose the implemented techniques subject to their constraints and the environment. We distinguish between constrained (k) and unconstrained (v) inputs, $x = (v, k)$, and assume for simplicity, without a loss of generality, that the constrained inputs have no alternative cost. The optimization problem calls for a choice of the level of inputs to be assigned to technique j so as to maximize profits. To simplify the presentation, we deal with a comparative statics framework and therefore omit a time index for the variables. The extension to the intertemporal version is conceptually straightforward. The Lagrangian equation for this problem is:

$$L = \sum_j p_j F_j(v_j, k_j) - \sum_j w v_j - \lambda\left(\sum_j k_j - k_0\right), \qquad (1)$$

subject to $F_j(.) \in T;\ v_j \geq 0;\ k_j \geq 0$,

where p_j is the price of the product of technique j, w is the price vector of the unconstrained inputs and k is the available stock of the constrained inputs. The solution is characterized by the Kuhn-Tucker necessary conditions. Let $s=(k,p,w,T)$ be the vector of state variables of this problem and write the solution as: $v_j^*(s)$, $k_j^*(s)$, $\lambda^*(s)$, to emphasize the dependence of the solution on the state variables. The optimal allocation of inputs v_j^*, k_j^* determines the intensity of implementing the jth technique. To the extent that the implementation of a technique requires positive levels of some inputs, when the optimal levels of these inputs are zero, the technique is not implemented. The optimal output of technique j is: $y_j^* = F_j(v_j^*, k_j^*)$ and the implemented technology (IT) is defined by

$IT(s) = \{F_j(v_j,k_j);\ F_j(v_j^*,k_j^*) \neq 0,\ F_j \in T\}$.

The empirical analysis can provide estimates of the production function that corresponds to the implemented technology. The aggregate production function expresses the aggregate of outputs, produced by a set of micro production functions, as a function of aggregate inputs. This function is not uniquely defined because the set of micro functions actually implemented, and over which the aggregation is performed, depends on the state variables and as such is endogenous. Let the aggregate production function be written as:

$$\sum_j p_j y_j^*(s) \;\equiv\; F(x^*,s) \;\equiv\; \varphi(s). \tag{2}$$

This production function is defined conditional on s, but changes in s imply changes in x^* as well as in $F(x^*,s)$. It is therefore meaningless in this framework to think of changes in x, except by 'error', which are not instigated by changes in s. This means that it is impossible to reveal a stable production function from a sample of observations taken over points with changing available technology. Consequently, in general, the aggregate production function is not identifiable.

The empirical aggregate production function can be thought of as an approximation in a specific way. For (2) to be a production function in the usual sense, x should be disjoint from s. Such a separation requires a discrepancy between x and x^* that will allow us to write for the observed output:

$$\sum_j p_j y_j \;\cong\; F(x, s). \tag{3}$$

Strictly speaking, $F(x, s)$ is not necessarily a function since x can be allocated to the various techniques in an arbitrary way. It is only when we have an allocation rule leading to x^* that uniqueness can be achieved. With this caveat, we view $F(x, s)$ as a function of s, since s determines the techniques to which the inputs are allocated. A discrepancy, x-x^*, produces information on a given implemented technology, and such a discrepancy is also the source of information for identifying a given production function.

It has been shown (Mundlak, 1988) that $F(x, s)$ can be approximated by a function which looks like a Cobb-Douglas function, but where the elasticities are functions of the state variables and possibly of the inputs:

$$\ln y = \Gamma(s) + B(s,x)\ln x + u \tag{4}$$

where y is the value added per worker, $B(s,x)$ and $\Gamma(s)$ are the slope and intercept of the function respectively and u is a stochastic term.[4]

4 This expression can be given a more descriptive structure which leads to an approach in its estimation. However, we do not have the factor shares needed for this approach and therefore we do not go into it. For the utilization of factor shares, see Mundlak, Cavallo and Domenech (1989) and Coeymans and Mundlak (1993).

Variations in the state variables affect $\Gamma(s)$ and $B(s,x)$ directly as well as indirectly through their effect on inputs. The state variables may not be independent, a change in one state variable may be associated with a change of the others. This is illustrated by evaluating the elasticity of average labor productivity with respect to a given state variable (say s_i):

$$\partial \ln y / \partial s_i = \sum_h \{\partial \Gamma / \partial s_h + \ln x[\partial B(s) / \partial s_h] + B(s)(\partial \ln x / \partial s_h)\} \partial s_h / \partial s_i . \qquad (5)$$

The first two terms in the brackets show the response of the implemented technology to a change in the state variables, whereas the last term in the brackets shows the output response to a change in inputs under constant technology. The elasticities in (5) have a time index, which is suppressed here, indicating that they vary over the sample points. The innovation in this formulation lies in the response of the implemented technology to the state variables. To isolate this effect, we rewrite (5), assuming independence between the state variables, namely $\partial s_h / \partial s_i = 0$ for $h \neq i$, and holding x constant to yield the elasticities

$$E_i = \partial \Gamma(s) / \partial s_i + \ln x[\partial B(s) / \partial s_i]. \qquad (6)$$

The effect captured by (6) is part of the unexplained productivity residual in the standard productivity analysis under the assumption of constant technology.

When the available technology consists of more than one technique, a change in the state variables may cause a change in the composition of techniques in addition to a change of input used on a given technique. In this case, the empirical function is a mixture of functions and as such may violate the concavity property of a production function.

Statistical aspects

The dependence of the implemented technology on the state variables causes it to vary across countries and over time in any given country. Countries differ in their natural endowments such as weather and soil quality—differences which remain roughly constant over time. They also vary in their constraints and the economic environment. We should therefore expect different coefficients from cross-country and from time-series analyses. An examination of the empirical distribution of the various variables reveals that between-country variability is considerably larger than the variability over time. To gain insight, it is useful to review the various forms of analyses within a uniform framework. We label W, $B(i)$, $W(i)$, $B(t)$, $W(t)$ and $W(it)$ projection (symmetric and idempotent) matrices that generate residuals. They can be defined in terms of their operation on an arbitrary vector $x=\{x_{it}\}$ of order NT. Let $x_{i.}$ and $x_{.t}$ denote the averages of x_{it} over t and i respectively and the terms in parentheses contain the typical elements of the vectors in question:

$$Wx = (x_{it} - x_{..}),\ W(i)x = (x_{it} - x_{i.}),\ W(t)x = (x_{it} - x_{.t}),$$

$$W(it)x = (x_{it} - x_{i.} - x_{.t} + x_{..}),$$

$B(i)x = (x_{i.} - x_{..})$, and $B(t)x = (x_{.t} - x_{..})$, i=1,...,N, t=1,...,T.

The following identities can then be derived:

$$W = W(i) + B(i) \quad (7)$$

$$W = W(t) + B(t) \quad (8)$$

$$W = W(i) + W(t) - W(it) \quad (9)$$

$$W = B(i) + B(t) + W(it) \quad (10)$$

Let y be the vector of observations of the dependent variable and X be the matrix of observations of the explanatory variables. The regression coefficients of interest can be written in a generic form for a projection matrix P as:

$$b = (X'PX)^{-1}X'Py$$

where P can be any one of the projection matrices of interest listed above with rank not smaller than rank X. To introduce the notation for the regression coefficients, we present in the brackets the projection matrix and the corresponding vector of coefficients: Pooled: [W, b]; within-time and country: [$W(it)$, $w(it)$]; within-country: [$W(i)$, $w(i)$]; within-time: [$W(t)$, $w(t)$]; between-time: [$B(t)$, $b(t)$]; between-country: [$B(i)$, $b(i)$].

It is well-known (Maddala, 1971) that the pooled regression can be presented as a matrix-weighted average of within and between regressions. For instance, use (7) and simplify:

$$b = (X'WX)^{-1}X'Wy = Gw(i) + (I - G)b(i), \quad (11)$$

where $G = (X'WX)^{-1} X'W(i)X$.

When, G, the share of the within component of variance X, is relatively small, the coefficients of the pooled regression will reflect largely the between-regression coefficients.

The common practice in empirical analysis is to use dummy variables for time or country and to obtain b, $w(i)$, $w(t)$ and $w(it)$ from pooled data without dummies, with country dummies, with time dummies and with country and time dummies respectively. Referring to the identities presented above, it appears that data generated by $W(it)$ (using country and time dummies) is cleaned from the between-time and between-country variations in the data and as such should best represent a measure of the more stable technology, referred to as the core implemented technology. Data generated by $W(i)$ (using country dummies) are cleaned of the between-country variations but contain the variability over time. Similarly, data generated by $W(t)$ are cleaned of the time variability but contain the cross-country variability. This can be seen by rearranging the identities in (7)-(10):

$$W(i) = W(it) + B(t) \quad (12)$$

$$W(t) = W(it) + B(i) \quad (13)$$

To determine the empirical importance of this distinction, we estimate and present the three canonical regressions of this problem: $b(i)$, $b(t)$ and $w(it)$. There is however a practical problem with the estimation of the $b(t)$, as we have only 21 years, and as such the sample size is small for estimating the full model. However, we can obtain an approximation of the time-effect on the regression coefficients by comparing $w(it)$ and $w(i)$.

Data description

Output and inputs

We estimate a cross-country agricultural production function where agricultural output depends on inputs, agricultural technology and the state of the economy. Agricultural *output* is measured as agricultural GDP in 1990 US dollars. Inputs to agricultural production include land, capital, labor and fertilizers and pesticides.

Hectares of arable and permanent cropland, along with permanent pastures, are used for the measure of *land.* Agricultural *labor* is defined as the economically active population in agriculture. *Fertilizer* consumption is often viewed as a proxy for the whole range of chemical inputs and more.[5]

Data on agricultural *capital* have been scarce. Commonly, crude data on tractors or machinery have been used in cross-country analyses of agricultural production functions. To overcome this problem, Crego, Larson, Butzer and Mundlak (1997) constructed a series of capital in agriculture. National accounts data on investment were used to construct a measure of the stock of fixed capital, consisting primarily of *structures and equipment.* The fixed capital stock used here is measured in 1990 US dollars. FAO data were used to construct a series of capital in livestock and in trees. Livestock is measured in value terms by multiplying the quantities of livestock in a country by the regional trade prices. The value of an orchard in any period is assumed to be the discounted stream of future revenues that it will yield less production costs. We use data on the value of production and harvested land area for major tree crops. The net revenue associated with each acre of tree crops is imputed forward in time (with discounting) and aggregated to yield the value of capital in the form of trees.

Not only does fixed capital differ from capital of agricultural origin—livestock and orchards—in the method of construction, the two types of capital can also differ fundamentally in terms of markets and pricing. Capital of agricultural origin is produced largely by resources in agriculture and therefore its cost of production is largely independent of the markets for nonagricultural inputs, which are often imperfect. As such, farmers may face noncompetitive prices for their fixed investment inputs. Also, fixed investments depend more on outside finance and are frequently hindered by credit constraints.

5 "We first observe that the correlation between research and fertilizer variable is .95, reflecting the well-known association between agricultural research and the introduction of modern inputs." (Antle, 1983, p.613).

Environment

Agricultural production depends on the physical environment or natural conditions. As observed by Mundlak and Hellinghausen (1982), this feature is usually omitted in empirical analysis. In part, such an omission can be rationalized for time-series studies where the basic features of the environment are constant and changes over time, such as weather—distinguished from climate—are transitory in nature. However, this rationalization is invalid for cross-sectional analysis, and it is therefore important to try to capture the impact of the environment. In our analysis, we follow Mundlak and Hellinghausen (1982) by using two variables extracted from Buringh, van Heemst and Staring (1979). The variables are *potential dry matter (PDM)* and a *factor of water deficit (FWD)*.[6] The first variable is motivated by the desire "to compute theoretical potential production, that is the production of a healthy, green, closed, standard crop, well supplied with nutrients, oxygen, water and foothold and therefore only limited by the daily photosynthetic rate, that depends on the state of the sky, the latitude and the date." (Op. cit., p.8).

The production of dry matter requires moisture. Arid areas may have a large value for *PDM* but actual production is small due to water deficit. The relative water availability is measured by the ratio of actual transpiration to potential transpiration where the potential transpiration "depends only on the climate and is defined as the amount of water which will be lost from a surface completely covered with the vegetation if there is sufficient water in the soil in all times. On the other hand, the actual transpiration is also based on rain data and calculated by evaluation of monthly water balance, ... The difference between potential and actual evapotranspiration is moisture deficit during the growing season." (Op. cit., p.9). The variable, referred to as *FWD*, measures relative availability of moisture rather than deficit; the lower is the value of the *FWD* the larger is the deficit. Thus the variable is expected to be positively correlated with productivity.

Technology

As indicated above, the tacit assumption that all the observations are generated by the same technology is a very strong one and should be tested empirically. This can be done by introducing variables that will account for important differences in technology in the sample. To do this, we experimented with several variables.

The most common variable used in empirical studies as a carrier or representative of technology is some measure of human capital. The application of the concept of human capital in empirical analysis is quite problematic for a variety of reasons. In practice, it is mostly represented by a measure of *schooling*. The basic idea is that higher levels of education are conducive for technological progress. However, the causality could go in either direction in that economic progress generates a demand for schooling. Therefore, the interpretation of a schooling variable in empirical analysis is somewhat

6 Binswanger, Mundlak, Yang, and Bowers (1987) used the same source to construct somewhat different variables.

ambiguous. We include the mean school years of education of the total labor force as a proxy for the human capital stock for the overall economy.

In addition to schooling, we include several variables whose meaning are somewhat more specific and perhaps easier to interpret. In the case of agriculture, there is a natural variable to measure the level of technology for a given crop; this is the yield or output per unit of land. Extending this concept to aggregate output, we construct an aggregate *peak yield.* For each country and each commodity, the maximum of the past yields is computed. Country-specific Paasche indices (1990=1) are constructed of these peak commodity yields, weighted by land area. A Paasche index is used since changing the composition of output changes the relevance of existing technologies. This index is intended to capture country-specific variations in technology over time but, as measured, it is inadequate to represent variability across countries in technology in a given year. However, we can capture the cross-country variability in growth rates. To do this, we calculate the average rate of growth in the index over the period by regressing the log of the peak yield on time. This variable is used in the between-country analysis.

Countries do not always perform on the technology frontier. Deviation from the peak yield may be due to economic considerations or to natural disturbances. Be the reason what it may, the deviation may affect the productivity of the various inputs. To allow for such an effect, we measure the difference between the actual yield and the peak yield for each crop, obtain a land-weighted sum of these differences and divide by the peak yield. This ratio is calculated for each country in each year and referred to as the *yield gap.*

Agricultural productivity is likely to be affected by the overall technological level of the country. As economies develop generally, the physical, legal, regulatory infrastructure and institutions which support agriculture develop as well. We measure this influence with two variables. The state of *development* is measured by the per capita output in the country relative to that in the United States. The main variability of this measure is across countries, but it also varies over time. To supplement the variability of the overall technology over time in each country, we use the maximum past average labor productivity in non-agriculture in the country and refer to this variable as *na-peak.* It turns out that this variable was only of marginal importance and will not be discussed here.

Incentives

We introduce two measures of incentives to allow for the direct effect of incentives on productivity over and above their indirect effect that comes through resource allocation and accumulation. The measures are the terms of trade between the agricultural and manufacturing sectors obtained as the ratio of the sectoral prices, or the *relative price*, (agricultural GDP deflator to manufacturing GDP deflator, lagged one period) and its fluctuations, calculated as a moving standard deviation from the three previous periods. For the between-country analysis, we modify the measures, and use the average rate of growth in the relative price over the period, calculated by regressing the log of the price ratio on time. Also the standard deviation of the relative price over the entire period is used in place of the moving standard deviation. The *variability in agricultural prices* reflects the market risk faced by agricultural producers. In addition to the sector-specific risk, there is an economy-wide market risk, that of price volatility for the economy as a whole as measured by the rate of *inflation*. This is calculated as the rate of change in the total GDP deflator.

Expected improvement of future profitability encourages investment and thereby augments the capital stock which appears as a variable in the analysis. The regression coefficients of the incentive variables represent only the direct effect of prices that is not captured in input changes. To obtain the full impact of the incentives on productivity, it is necessary to add their indirect effect through investment, but this is not done here.

The data are more fully described in Annex I.

Sample description

The sample was determined by the data availability and the preference for a balanced data panel in order to simplify the analysis. It consists of annual data from 37 countries, listed in Annex I, for a 21-year period (1970-90). The information conveyed by the sample is summarized in Table 2. The first column presents the average annual growth rate of the variables over the sample period. Output grew at a rate of 3.82 percent. Capital has the highest growth rates among the inputs, 4.25 percent. This is a weighted average of its two components, where the growth rate of structures and equipment is 5.42 percent. On the other hand, the growth rate of schooling is 1.8 percent and that of the peak yield is 1.9 percent. The gap in the level of development compared to the US has widened over the period and the terms of trade of agriculture deteriorated at an average rate of 0.3 percent. There has been little change in land and less so in the labor force. It should be noted that these rates are for the sample as a whole and there are differences among countries as we can learn from the decomposition of the sum of squares.

The remaining columns of the table present a decomposition of the total sum of squares to its components that corresponds to equation (10) above. To standardize the results, we divide the components by the total sum of squares so that the numbers give the percentage of each component in the total sum of squares. The terms are

SS total = $SS(x_{it} - x_{..})$, $SSW(it) = SS(x_{it} - x_{i.} - x_{.t} + x_{..})$, $SSB(i) = SS(x_{i.} - x_{..})$,

$SSB(t) = SS(x_{.t} - x_{..})$, where, for any variable z, we use the notation: $SS(z) = \sum_i \sum_t z_{it}^2$.

The between-country differences account for most of the variability of the output and the inputs. Thus, just by allowing for a country effect, and without introducing any input to the regression, the R^2 is 0.9617 so that the unexplained residual from country averages accounts for only 3.83 percent of the total sum of squares of output. Similarly, the between-country variability accounts for 95 to 98 percent of the variability of capital and practically all of the variability in land and labor. The situation is similar when the output and inputs are measured per worker. The relative importance of the country and time components is different for the state variables; the between-country component is important in schooling and development and less important in the other variables. In part, this difference is due to the way the variables are measured. Schooling and development are measured in units that allow cross-country comparisons, and interestingly, the relative importance of the between-country component in the total sum of squares is similar to that of inputs. On the other hand, peak yield, prices and price fluctuations were measured differently for the variability over time and for that over countries as explained above. In short, peak yield varies largely over time. This variable is measured as an index for each country, so that the between-country variability reflects differences in the rate of growth of the peak yield rather than differences in the level. The yield gap is a derived measure from the peak yield, but here most of the variability is in the transitory component of within-country-time. This suggests that the deviations from the peak yields are affected considerably by local conditions, some of which are weather triggered and the others can be attributed to the economic environment. Be the case what it may, these variables show variability over time and also have a strong transitory component.

To sum up, the relative importance of the between-country component is dominant. This can lead to the erroneous conclusion that the within analysis has little to contribute. As a matter of principle, this conclusion is not well founded because the precision of the estimated coefficients depends not only on the spread in the regressors but also on the variance of the equation shock and this usually contains a component that is time invariant. Consequently, the variance of the within component is considerably smaller than the total variance.[7] Indeed, as we see below, the within estimates are meaningful empirically and informative substantively.

Empirical results

The estimates for a base model are given in Table 3 which, in line with the specification in equation (10), consists of three blocks. The first block presents the within-country-time estimates, $w(it)$, which summarize the changes that took place over time and over countries after allowing for country and time effects. As such, these estimates are based on observations taken from the more stable, or core technology. The second block presents the between-time estimates, $b(t)$, obtained from a short time-series of the sample means for each year. This represents the time-series component, common to all countries and as such it captures the impact of changes in the available technology. The last block presents the between-country estimates, $b(i)$, based on the between-country variations which constitute the major component of the total sum of squares. It summarizes the locus of points that go across the different techniques implemented by the countries, all operating under the same available technology.

The within estimates are obtained under the constraint of constant returns to scale[8], whereas both between regressions are unrestricted. Variables that remain constant over time, such as the environment, are not included in the first two blocks. By

7 This point was taken into account in the comparison of the within and the dual estimators in Mundlak (1996).

8 We tested and were not able to reject the constant-returns-to-scale hypothesis. See Table 4.

construction, variables in different blocks are orthogonal to each other and therefore the estimates in one block are unaffected by the omission or addition of variables in the other blocks.

The first question is whether we can do away with any of the three aforementioned regressions. The answer to this question is given in Table 4 which presents results for several F-tests. The null-hypotheses that blocks can be omitted are rejected and therefore we should interpret the information embedded in all of the blocks. The second question is whether the coefficients of the variables common to the various equations are the same. Casual inspection indicates that they are quite different, confirming the basic initial hypothesis that the regressions summarize the combined effect of changes in inputs and technology and therefore the within and between regressions summarize different processes. We now turn to interpret the results.

Inputs

The results are striking in several respects. Perhaps the most interesting result is the magnitude of the elasticity of capital, 0.37 in the within regression, 0.34 in the between-country and 1.03 in the between-time regression. Thus, it is high and significant in all three blocks, which is not the case with the other inputs. The between-time estimate is particularly high, and it indicates that the implementation of changes in the available technology, which can not be observed directly, were strongly affected by investment in agriculture.

The effect of capital becomes even stronger when capital is disaggregated to the two components as seen in Table 5. The within coefficient is 0.29 for structures and equipment and 0.13 for livestock and orchards, a sum of 0.42. The relative importance of the two components is almost the same in the between-time regression, and their sum is similar to that of the elasticity of total capital. The relative importance takes on a different form in the between-country regression, where livestock and orchards is the dominant component.

The land elasticity in the within regression is 0.47 for the aggregate capital (Table 3) and 0.44 for the disaggregated capital (Table 5). Thus we find no empirical support for the idea, originally expressed by Schultz (1953) and echoed by others (see for instance Kawagoe and Hayami, 1985, p.91), that land has lost importance in modern agriculture. Indeed, the land coefficient is negative, though small, in the between-country regression. This indicates that the techniques used by the more productive countries were land saving.[9] However, with a given technology, the marginal productivity of land is positive,

9 To illustrate possible consequences of imperfect knowledge of the production process we bring an example from a study of cross-country differences in agricultural productivity. "Depending on the weight to be applied to land, the total productivity of new continental countries becomes higher or lower than other DCs." (Kawagoe and Hayami, 1985, p.91). They use three alternative weight systems in their productivity exercise, where land weights (elasticities) are 0.1 (obtained from cross-country production function), 0.3 (less developed countries "in which factor shares are high for land and low for modern inputs such as fertilizers and machinery") and 0.05 (the "situation in the highly advanced stage of economic development" relying on Schultz that at this stage the importance of land declined). (Kawagoe and

or else there would be no cultivation. Finally, land is not included as a variable in the between-time regression in view of the low variability of land over time as indicated in Table 2.

The coefficient of fertilizers is particularly high in the between-country regression and much lower in the other two. A value of 0.08 obtained in the within regression for the elasticity of fertilizers may seem to be low, but this is not the case. A point estimate of 0.08 means that about 8 percent of the within changes in agricultural output are to be attributed to fertilizers. It is to be noted that this result is obtained for the aggregate agricultural output whereas fertilizers are used only on plant products. It is likely that a production function for plant products alone would show a larger elasticity for fertilizers. Thus, a value of 0.08 for aggregate output may even be a bit high. One possibility is that fertilizers capture the impact of other chemicals and more generally, the modern inputs, as indicated above. As such, it is possible that the variable also captures some inter-technology effects. Another possibility is that the elasticity reflects a high shadow price of fertilizers, which is a signal for constraints that prevent optimal use.

The striking result is the high value of the fertilizers elasticity obtained from the between-country regressions. This means that the locus of country means represents a changing technology package where the improvement in the implemented technology is fertilizer using. At the same time it is also capital using but land saving

Referring to Table 3, the elasticity of labor, obtained in the within regression by imposing the assumption of constant returns to scale, is relatively low, 0.08, and it is 0.26 for the between-country regression. The corresponding results for Table 5 are 0.10 and 0.22 respectively. Thus, the variations of output in each country are largely accounted for by variations in capital and land and less by labor.

The within regressions were obtained under the constraint of constant returns to scale. The constraint was tested empirically and it is not rejected, as can be seen from the results in Table 4. The between regressions are unconstrained, and it is interesting that the sum of the elasticities of the inputs of the between-country regressions is practically one in Tables 3 and 5. This is in contrast to the results of those cross-country studies which show increasing returns to scale (for instance, Kawagoe, Hayami and Ruttan, 1985, p.120). This indicates that our specification succeeds in capturing the impact of cross-country differences in technology and thus eliminates the spurious result of increasing returns to scale.[10]

Hayami, 1985, p.88). There is no theoretical basis for this classification, but we bring this reference to indicate that the higher value is close to that obtained in the within analysis and the low value is not far from that obtained from the between-country analysis. There is a similar ambiguity with respect to the other weights. Therefore, without gaining a clearer view with respect to the appropriate weights, the whole exercise does not convey any clear message.

10 The finding of increasing returns to scale in cross-country analysis found justification of similar finding by Griliches (1963b) in cross-regions analysis for the US. For more evidence, see Kislev and Peterson (1996).

Technology

The technology variables play a dual role in the analysis. First they serve as technology shifters and as such reduce, or eliminate completely, the bias of the estimated input coefficients that is caused by the correlation of inputs and technology. Second, we can examine empirically how well they describe the data and thereby guide us in the search for appropriate technology indicators. The test of the null hypothesis that the technology block can be omitted is rejected, as reported in Table 4.

Turning to the individual components, the estimated elasticities in Tables 3 and 5 give the same message. The peak yield serves well as a shifter of the agricultural productivity, as measured by the core technology, with an elasticity of about 0.83. The level of development of the country relative to the US is also an important explanatory variable of agricultural productivity. Note that the contribution of this variable is over and above that of the peak yield which shows that the yield level is not the only indicator; first, the yield variable does not represent the productivity in livestock production which accounts for about one third of output and second, there is a scope for improving efficiency under a given technology by coming closer to the frontier, as represented by the performance of the US.

The between-time regression shows that, for the sample as a whole, none of the technology variables was important in accounting for the changes in agricultural productivity over time. The work is done by physical capital. The implication is that even though schooling and peak yields increased with time (Table 2), we get no evidence that they contributed to the benefits harvested from improvements in the available technology. It is the changes in the available technology that caused the increase in these variables, at least in peak yield and perhaps in schooling. But it was capital availability that was crucial for the countries to take full advantage of the available technology. This sheds light on the importance of physical capital in accounting for the changes in agricultural productivity in the study period.

The results are different for individual countries, as seen from the between-country regression, where the level of development is important in accounting for the productivity variations. This is a statement of the importance of the various attributes of the overall level of development of a country in determining the level of agricultural productivity. This may also be the reason that schooling appears to be irrelevant. To the extent that schooling matters, it may have an indirect effect through the development variable. However, to what extent schooling matters and how it can be measured using aggregate data is still an open question and was recently highlighted by Pritchett (1996).

The peak yield is a measure of the frontier of the implemented technology, but countries do not always operate at the frontier. We thus introduced the yield gap variable described above, whose average for the sample as a whole is 9 percent of the peak yield. As seen in Table 2, this variable varies considerably within country and time. We add this variable to the regression and report the results in Table 6. The variable has a negative effect on output in the within regression. This is of no surprise, operating off the frontier has a negative effect on productivity. The reason for introducing the variable is to allow for a shift of the function to account for the unfavorable environment and thereby relieve the inputs from accounting for this outcome. Interestingly, the effect on the input elasticities is minor, except for labor, as can be seen by comparing Tables 6 and 3. It thus leads to the conclusion that the within-country-time yield gap was caused by transitory effects that could not be anticipated or were anticipated to be transitory and therefore there was no reason to make major changes in the inputs. The main change in the within analysis is in the peak yield coefficient, which increases from 0.83 (Table 3) to 0.93 (Table 6). The latter number is obtained by freeing the variable from the noise of the transitory conditions and thus is thought to be more reliable.

The results are different for the between-country regression where the coefficient of the yield gap is positive, significant and sizable, 1.24, higher than the coefficient of peak yield in the within regression. To understand this result, we have to go back to the definition of the variables. In the between-country regression, we use the average growth rate of the peak yield in place of the peak yield index and therefore we do not control for the level of technology as we have done in the within analysis. Thus, the gap captures some of this effect. An increase in the gap occurs either by an increase in the peak yield, which is of a permanent nature, or by a transitory decline in the performance in a given year. In the between-country regression the relative gap is measured as the country average gap over the 21 year of the study period and as such it summarizes permanent effects, rather than the transitory ones which dominated the within variations. Therefore, a larger permanent increase in the gap seems to reflect larger peak yields and this explains the positive regression coefficient of this variable in the between-country regression. What countries find it difficult to stay closer to their own frontier? The answer can be found by examining the correlation coefficients of the gap and the other variables given in the appendix. The correlation coefficients are close to zero for the within deviations, which is consistent with the interpretation that these deviations in the yield gap were transitory. On the other hand, they are significantly negative for the country averages, particularly with capital and fertilizers, and to a lesser degree with schooling and development. It is the poorer countries that had on average a larger yield gap.

Prices

The test of the null hypothesis that the price block can be omitted from the analysis is rejected. It appears however that the allocation of the effect to the individual components is problematic. On the whole, the signs of the coefficients are in line with expectations but the precision is low. The coefficient of relative prices is positive and that of its variability is negative. The magnitude of the price elasticity is small, 0.04 in the within regression. This indicates a small quantitative effect on agricultural productivity, but note that this effect is obtained conditional on given inputs and on technology. Thus, there is little scope for additional price effects. The fact that this effect is at all detected is of prime importance. The channels for the price effect are the level of inputs and the choice of technology, and these are represented by explanatory variables. Therefore, when evaluating policies that alter the relative returns to economic activity, it is important to realize that the legacy of past policies become enshrined in current stocks.

Two measures of market-risk, inflation and relative price volatility, dampen agricultural production (as seen by the within estimates); however both effects are quantitatively small. The coefficient of the measure of price volatility is negative, but it is significantly different from zero only in the between-country regressions. The effect of inflation is ambiguous in that it is negative and insignificant in the within regression, and it is positive and significant in the between-country analysis.

Environment

The two environment variables introduced to the between-country regression, have a positive and significant effect in the analysis with aggregate capital but the effect of potential dry matter becomes unimportant when capital is disaggregated. This may suggest that this measure is not sufficiently robust.

Interactions

As indicated by equation (4), for the aggregate production function to serve as an appropriate second order approximation of technology, the coefficients of the inputs should be made functions of the state variables. To estimate the coefficients, it is useful to have data on factor shares which are used for estimating the dependence of the shares on the state variables. (Mundlak, Cavallo and Domenech, 1989 for Argentina and Coeymans and Mundlak, 1993 for Chile). However, we do not have data on factor shares, which by itself is a serious deficiency of the international data sets related to agriculture. Therefore, this approach is not feasible here. In principle, as an alternative, we can add cross products of the variables to the regression. However, such variables, by construction, are highly correlated with the variables which are already in the regression. Moreover, even without such cross products, the degree of the explanation of the regressions is rather high. Consequently, the scope for such an extension is limited, restricting the number of variables that can be added. We report here the cross products of peak yield with schooling, capital and labor (Table 7). Three coefficients of the cross products are significant at an acceptable level—schooling in the within regression, capital and labor in the between-country regressions. The mean elasticities differed only slightly from the elasticities of the base regression but, nevertheless, the results are suggestive. The negative coefficient on the schooling cross product indicates that an increase in peak yield, or more generally in the level of technology, is schooling saving in the within regression. Similarly in the between-country regression, an increase in peak yield is capital saving and labor using. These results are reasonable, but we do not elaborate on them further because of the limitations mentioned above. The main message from this experiment is that there is a scope for investigating the nature of the dependence of the elasticities on the state variables, but for this we need data on factor shares.

Robustness

In the tables we presented all the regression coefficients without eliminating those coefficients which are insignificantly different from zero (no pretesting). Recall that in the present model, the inputs and technology are determined jointly by the state variables, so that the data reflect such joint changes. Thus, instead of eliminating individual variables, we impose zero restrictions on linear combinations of the coefficients using the method of principal components (PC) in Mundlak (1981). The results in Table 8 are the PC versions of Table 3, with an imposition of constant returns to scale in the within regression. The last line in the table shows the maximum number of zero restrictions that could be imposed jointly at the 5 percent level of significance. For example, 4 such restrictions could be imposed on the 10 coefficients of the within regression.[11] Thus, the within and between-time regressions are being affected more than the between-country regression where only two restrictions are imposed. In this block, the main effect is on the coefficients in the price block.

In spite of the imposed restrictions, the main results of the analysis are maintained. As before, there is a considerable difference between the within and between regressions. The capital elasticity declined slightly in the within and between-time regressions, but it is still high. In the within regression, the decline in the capital elasticity is offset by an increase in the elasticities of labor, fertilizer, peak yield and development. In the between-time regression, the important change occurs in the coefficients of schooling and peak yields which become positive and significant. Also, the labor coefficient is now larger but with a negative sign. This pattern reflects the changes that took place over time in these variables (Table 2), a growth of schooling and peak yield, and a decline of labor. It is thus consistent with the view that the between-time regression traces the locus of production plans across technologies. However, this result differs from that of the OLS regression and makes tentative our conclusion on the role of schooling in the implementation of changes in the available technology. The reason for this difference in results can be found in the high values of the correlation coefficients of the between-time changes in capital, schooling, peak yield, and fertilizer (Appendix table, last block). The OLS estimates placed the explanation with capital whereas the PC procedure sorted it out and allocated some of the explanation to the other variables as well.

However, the PC version of the disaggregated capital did not confirm the results obtained for the aggregate capital as can be seen by comparing Tables 9 and 5. The PC estimates in this case increased the importance of capital at the expense of the other components.

To conclude, the most robust results are the relative importance of physical capital and land in the within-country-time regression, capital in the between-time regression and the irrelevance of land, the importance of capital and fertilizer in the between-country regression.

11 The restrictions are imposed on the coefficients of the principal components rather than on the coefficients of the original regressions.

Comparing to conventional analysis

Often, regressions are presented with either time or country dummies, which amounts to running a within-time or within-country regression. The relationships between such regressions and ours is established by combining equations (12) and (13) with one similar to (11). This will show that *w(i)* is a matrix-weighted combination of *w(it)*, and *b(t)*, and similarly, *w(t)* is a matrix-weighted combination of *w(it)* and *b(i)*. The implication is that allowing for only one effect results in regression coefficients which reflect some between effects. The importance of the between component is determined by its relative weight in the total sum of squares (see Table 2). Thus, the regression coefficients obtained with time dummies reflect largely the between-country regression because the relative weight of the between-country sum of squares is dominant. Similarly, the regression coefficients obtained with country dummies reflect the between-time regression, but not to the extent of the previous case because the variations in the variables over time are much smaller than those across countries as can be seen from Table 2. In any case, the mere fact that a regression is done with some dummies does not guarantee that it identifies a stable function.

Table 10 presents within regressions for the specifications in Tables 3 and 5 respectively. Comparing the within-country regression in the second column in Table 10 to that of the within-country-time regression in Table 3, we see the impact of the between-time regression. In a way of generalization, the between-time sum of squares of output and input is of the order of magnitude of twice as much as that of the within-time-country. The coefficient of capital increases from 0.37 to 0.53, and many of the coefficients of the within-country regression are insignificantly different from zero reflecting the influence of the between-time coefficients. This comparison provides a framework for interpreting empirical results obtained under different specifications of effects.

With this interpretation we can now compare our results to those presented in Table 1. In this we ignore the first study by Bhattacharjee because it has no measure of capital nor of state variables; thus it is not very comparable to the other studies. Most of the studies are strictly cross-country and as such are comparable to the between-country results. The similarity is in the low land elasticity, and also the sum of the elasticities of machines and livestock is close in most cases to the value of 0.4 we obtained for the sum of structures and equipment and livestock and orchards in the between-country regression. This similarity is consistent with our interpretation that these studies describe only the between-country changes; hence they provide a limited and incomplete picture of the production process. In any case, they do not provide coefficients of a stable production function and as such, do not provide the appropriate weights for growth accounting, as they were intended to do.

It is always useful to check the results against all available information. The Global Trade Analysis Project (GTAP) reported factor shares of land and labor in agriculture for 1992 for 24 regions (Hertel, 1997). The data needed to compute factor shares are not available for all countries. The more available data are on labor costs, and these were used as a pivot to generate the other shares relying on "other sources" where available (op. cit., p.113). Applying the appropriate regional data to the 37 countries in our study, we summarize this information in Figure 1 in terms of the empirical distributions. The median values are 0.24 for land, 0.39 for labor and 0.39 for capital.[12] Another source of information is the OECD which reports "compensation of employees" by sectors. Computing labor shares from these series for 19 countries for the period 1970-90 (for 7 countries the period is somewhat shorter) yields a median value of 0.19. The labor share in these statistics is higher than the estimated elasticity from the within regression, but nevertheless, these values are conveniently close to the within estimates and are conspicuously far away from the between-country estimates. This seems to provide independent support for our interpretation.

Summary and conclusions

This study is triggered by the desire to shed light on the role of capital in agricultural production, a neglected topic due to lack of appropriate data. The construction of the data on capital allowed us to advance the cross-country study of production functions in what turns out to be an important direction. The analysis is based on the premise that the production technology is heterogeneous and the implemented technology is endogenous and determined jointly with the level of the unconstrained inputs. Therefore, a change in the state variables affects both the technology and the inputs, and consequently the production function is not identified. To overcome this problem, we decompose the changes in productivity to three orthogonal components caused by the fundamentally different processes underlying panel data and thereby gain meaningful economic insight. The between-time process captures changes that are induced by changes in the available technology (technical change). The between-country process captures the changes that take place when the available technology is held constant but other state variables differ across countries and account for their differences in the implemented technology. Finally, the within-country-time process represents the changes in outputs, inputs and state variables when the available technology is held constant as well as the fundamental changes across countries and as such comes closest to a production function. This framework also allows us to reinterpret results from earlier studies of cross-country productivity in a new way.

The most striking result is the relative importance of capital. This result is quite robust to various modifications of the model and to the disaggregation of capital to its two components. Capital seems to account for about 40 percent of total output in the core technology. This indicates that agricultural technology is cost-capital intensive compared to non-agriculture.[13] This result is further reinforced by the magnitude of the land elasticity in the core technology and is at variance with the view that land is not an important factor of production in modern agriculture. This view is based on an incorrect

12 The median values obtained using the unweighted regional data were similar (0.25 for land, 0.31 for labor and 0.42 for capital).

13 We say that a technology is cost-capital intensive with respect to a reference technology if the factor share of capital is larger than that of the reference technology.

reading of the data where no distinction is made between changes in technology and a movement along a given production function. The sum of capital and land elasticities is around 0.8 in various formulations, making it clear that agriculture should be more sensitive than nonagriculture to changes in the cost of capital, and less to that of labor (Mundlak, Cavallo and Domenech, 1989). The value we obtained for the sum is a bit high compared to the literature. Consistent with our view of heterogeneous technology, it is possible that a different choice of countries and time periods would lead to somewhat different results. However, a sum of 0.8 for land and capital elasticities leaves a lot of room for the conclusion on the importance of capital to remain intact.

The capital elasticity in the between-time regression is much higher than in the within regression and this is consistent with the view that physical capital serves as a constraint to agricultural growth. This is well illustrated by McGuirk and Mundlak (1992) in the context of the Green Revolution. At the same time, the between-time regression shows that the shift to more productive techniques is associated with a decline in labor, which is an indication of the labor-saving technical change in agriculture. This is consistent with the observed slight decline of labor over time (Table 2) while output grew at a brisk pace. This is not news; but it is emphasized here because it comes out of an integral view of the process which separates between the core technology and the changes that took place over time and between countries. These results highlight the importance of capital in agricultural production, an attribute critical in the understanding of agricultural development and its dependence on the economic environment.

The introduction of the appropriate state variables to account for technology, prices and physical environment produced a production function that displays constant returns to scale and thus avoided the pitfalls of previous studies and the misguided conclusions that followed.

The statistical framework provides an explanation for the unstable results observed in production functions derived from panel data. Statistically, the results depend on how the data are projected. Underlying this is the fact that comparisons between units, over time or of deviations from unit-means or time-means all describe different processes. This is based on theory, but has an intuitive appeal as well. In the case at hand, the spread in productivity among countries is a different economic phenomenon or process from the spread in productivity for a country through time. In turn, the factors explaining the spread will differ. Panel data measures a combination of these economic phenomena—a fact which should be recognized explicitly in the modeling approach.

While we are specifically dealing with these issues in the context of agricultural production, the arguments probably extend to other applications as well. The decomposition of the sum of squares to their canonical components most likely will tell the importance of the various processes. It is however important to emphasize that even if one of the components carries only a small weight in the sum of squares, it can still convey a great deal of meaningful information, as we have demonstrated in the case of the within-country-time regression.

To sum up, we can now return to the key topics listed at the beginning of the paper. The contribution of inputs to growth should be judged by their contribution to output under a constant technology, attributing the rest of the growth to technical change. After all these years of intensive work on production functions, there is no hard evidence that estimated elasticities do a better job than the factor shares as were originally used by Solow (1957). In terms of our work here, the within estimates come closest to the little evidence we have on factor shares. Also, it is clear that the weights obtained from between regressions by Hayami and Ruttan (1970, 1985), and earlier by Griliches (1963a, 1963b), give a distorted picture. We have pointed above to the sensitivity of the growth calculations to the weight of land, and this is where the between results erred the most. Not independently, our results indicate no evidence of increasing returns to scale. The increasing returns to scale inflated the contribution of the inputs and reduced the role of the residual technical change in the growth calculations ala Griliches, Hayami and Ruttan.

Our results support the view that agriculture is cost-capital-intensive as compared to nonagriculture. We provide estimates of factors' productivity that can be compared to the factors' price. Comparing our results to the factor shares, it seems that on the whole there is a surprising agreement.

Finally, our results have important implications for policy. First, we can say that agricultural capital is directly an important determinant of agricultural production. This is especially significant, since land, another important determinant of production, varies little over time. Moreover, agricultural capital is also important in closing the gap between available and applied technologies. Therefore policies facilitating access to agricultural capital will facilitate growth, provided the capital is used efficiently. This implies that the overall economic environment must be conducive to the efficient use of capital. Second, we find that prices have little immediate and direct impact on agricultural growth, beyond their impact through inputs and the choice of technology. Consequently, past policies that distort the relative returns to economic activity leave a legacy enshrined in current stocks that may respond slowly to policy reforms.

Annex I: Description of Variables

Output – agricultural GDP in 1990 US dollars. Original source of the GDP data: National Accounts of the World Bank, the UN and the OECD, the International Financial Statistics of the IMF and various country sources.

Structures and equipment – stock of fixed agricultural capital (structures and equipment) in 1990 US dollars. The mapping from fixed investment to fixed capital follows the methodology of Ball, Bureau, Butault and Witzke (1993). The capital stock is represented as a weighted sum of past investments where the sequence of relative efficiencies of capital of different ages serves as the weights. The following function of physical depreciation is chosen to describe the relationship between the efficiency of an asset and its age:

$$S_t = \frac{(L-t)}{(L-\beta t)}, \quad 0 \le t < L,$$

$$S_t = 0, \quad t \ge L,$$

where S is the relative efficiency of an asset with a lifetime of L at age t. β is the decay parameter. If $0<\beta<1$, the function is concave, that is, it exhibits gradual losses in efficiency in the early life of the asset and more rapid losses as it ages (accelerating physical depreciation). A truncated normal distribution of service lives of capital around a mean is assumed. For the construction of the agricultural capital stocks, the mean lifetime of an asset was assumed to be 20 years with a standard deviation of 8. The decay parameter was set at 0.7. The capital stock in any given year is the sum of the relative efficiency for that year of all past investments. This method requires a certain amount of extrapolation of the investment data. The series (in logs) of GDP and the ratio of investment to GDP are backcasted to 1913 using OLS regressions of the data series against time. The extrapolated investment series is calculated from these. Original source of investment data: National Accounts of the UN, the World Bank and the OECD and various country sources.

Livestock and orchards – livestock and orchards in 1990 US dollars. Livestock: Data on trade volume and trade quantities of livestock are readily available at the regional level. By dividing volume by quantity, regional trade prices were obtained. Quantities of livestock in each country are valued at the corresponding trade prices for the region. Orchards: Using data on the value of production and harvested land area for major tree crops, an indirect measure of the value of orchards is constructed. The value of a tree in any period is the discounted stream of future revenues that it will yield through production, less production costs. The net revenue associated with each acre of tree crops is imputed forward in time (with discounting) and, when aggregated, taken as the value of capital in the form of trees. To obtain net revenue, profits are assumed to be 20% of revenues. Additionally, the simplifying assumption is made that at any point in time the average tree is halfway through with its assumed lifetime. Original source of production data: FAO Production data set. Original source of trade data: FAO Trade data set.

Capital – total stock of agricultural capital in 1990 US dollars. Total agricultural capital is the sum of the fixed capital stock, livestock and orchards. (Capital = Structures and equipment + livestock and orchards). Original source of investment data: National Accounts of the UN, the World Bank and the OECD and various country sources.

Land – agricultural area (arable and permanent cropland and permanent pastures) in hectares. Original source: FAO Fertilizer data set.

Labor – agricultural labor force. Labor is defined as the economically active population. The data are reported for various sectors as well as for the overall economy for every ten years (1950-90). The data for other years are estimated by using straight-line interpolations of the total labor series and the ratio of agricultural labor to total labor, and calculating agricultural labor from these. Original source: ILO data set.

Fertilizer – total fertilizer (nitrogenous, phosphate and potash) consumption in metric tons. Original source: FAO Fertilizer data set.

Schooling – economy-wide human capital proxied by the mean school years of education of the total labor force. This data series was constructed by Nehru, Swanson and Dubey (1993) from enrollment data using the perpetual inventory method. "The average education stock measures the mean school years of education of the working age population (defined as the population between the ages of 15 and 64), and is the sum of primary, secondary, and post-secondary average education stock...The series are built from enrollment data using the perpetual inventory method, adjusted for mortality. Estimates are corrected for grade repetition among school-goers and country-specific dropout rates for primary and secondary students." (Op. cit., p.8). This data series is available up to 1987. The data for 1988-90 are forecast by fitting the data using an OLS regression of human capital on time. Original source: Nehru, Swanson and Dubey (1993).

Peak yield – country-specific index of peak yield to measure available agricultural technology. Compute yields of each commodity for each country in each year by dividing the production of the commodity in metric tons by the hectares of land used in the commodity. Find the maximum of past yields of each commodity for each country in each year. Construct Paasche indices of the peak yields for each country in each year by multiplying the peak commodity yields by the area of land used in the commodity and then summing over the commodities, and dividing by the peak commodity yields in the base year (1990) multiplied by this year's area of land in the commodity, summed over all the commodities. Original source on commodity production and land usage: FAO Production data set.

NA-peak – peak of nonagricultural productivity to measure available general technology. Calculated as the maximum of past ratios of nonagricultural GDP in 1990 US dollars to the nonagricultural labor force. Nonagricultural GDP is the difference between total GDP and agricultural GDP, nonagricultural labor is the difference between total labor force and agricultural labor. Original source of the GDP data: National Accounts of the UN, the World Bank and the OECD, the International Financial Statistics of the IMF and various country sources.

Development – development indicator. Calculated as the ratio of the country's total GDP per capita in US dollars to total US GDP per capita. Original source of the GDP data: National Accounts of the UN, the World Bank and the OECD, the International Financial Statistics of the IMF and various country sources.

Yield gap – relative gap between available and implemented technology. Calculate the difference between the peak commodity yield (maximum of past commodity yields) and the actual commodity yield of each commodity for each country in each year. Construct an index of the gap for each country in each year by multiplying the gap for each commodity by the area of land used in the commodity and then summing over the commodities, and dividing by the peak commodity yields multiplied by the area of land in the commodity, summed over all the commodities. Original source on commodity production and land usage: FAO Production data set.

Relative prices – relative sectoral prices. Calculated as the ratio of the agricultural GDP deflator to the manufacturing GDP deflator, lagged one period. Original source of the GDP data: National Accounts of the UN, the World Bank and the OECD, the International Financial Statistics of the IMF and various country sources.

Variability in prices – fluctuations in the relative sectoral prices. Calculated as a moving standard deviation of the ratio of the agricultural GDP deflator to the manufacturing GDP deflator from the three previous periods. Original source of the GDP data: National Accounts of the UN, the World Bank and the OECD, the International Financial Statistics of the IMF and various country sources.

Inflation – inflation (or deflation). Calculated as the rate of change in the total GDP deflator. Original source of the GDP data: National Accounts of the UN, the World Bank and the OECD, the International Financial Statistics of the IMF and various country sources.

PDM – potential dry matter production. Output in kilograms per hectare per year in roots, stems, leaves, flowers and fruits that can be achieved if precipitation and soil conditions are optimal. Original source: Buringh, van Heemst, and Staring (1979).

FWD – factor of water deficit. Measured by the ratio of actual transpiration to potential transpiration. Original source: Buringh, van Heemst, and Staring (1979).

The following variables are expressed in natural logs: output, capital, structures and equipment, livestock and orchards, land, labor, fertilizer, schooling and NA-peak.

The following variables were converted from nominal local currencies to nominal US dollars using exchange rates obtained from the International Financial Statistics of the IMF: output, capital, structures and equipment, livestock and orchards, NA-peak and development.

The following countries are included in the sample: Australia, Austria, Canada, Chile, Colombia, Costa Rica, Cyprus, Denmark, Egypt, Finland, France, Great Britain, Greece, Honduras, Indonesia, India, Italy, Jamaica, Japan, Kenya, Korea, Sri Lanka, Morocco, Mauritius, Malawi, Netherlands, Norway, Pakistan, Peru, Philippines, El Salvador, Sweden, Tunisia, Turkey, Tanzania, Uruguay and the United States.

Bibliography

Antle, J. M. 1983. "Infrastructure and Aggregate Agricultural Productivity: International Evidence." *Economic Development and Cultural Change* 31(3):609-19.

Ball, V. E., J. Bureau, J. Butault, and H. Witzke. 1993. "The Stock of Capital in European Community Agriculture." *European Review of Agricultural Economics* 20:437-50.

Bhattacharjee, J. P. 1955. "Resource Use and Productivity in World Agriculture." *Journal of Farm Economics* 37(1):57-71.

Binswanger, H., Y. Mundlak, M-C. Yang, and A. Bowers. 1987. "On the Determinants of Cross-Country Aggregate Agricultural Supply." *Journal of Econometrics* 36:111-31.

Buringh, P., H. D. J. van Heemst, and G. J. Staring. 1979. "Computation of the Absolute Maximum Food Production of the World." Wageningen: Netherlands Department of Tropical Soil Science, 1975; also published in *Moira Model of International Relations in Agriculture,* ed. H. Linneman et. al. Amsterdam: North-Holland Publishing Co.

Clark, C. 1973. *The Condition of Economic Progress.* London: Macmillan & Co.

Coeymans, J. E., and Y. Mundlak. 1993. "Sectoral Growth in Chile: 1962-82." Research Report 95. Washington, D.C.: International Food Policy Research Institute.

Crego, A., D. Larson, R. Butzer, and Y. Mundlak. 1997. "A New Database on Investment and Capital for Agriculture and Manufacturing." *World Bank Working Paper Series*, forthcoming. Washington, D.C.: World Bank.

Evenson, R. E., and Y. Kislev. 1975. *Agricultural Research and Productivity.* New Haven: Yale University Press.

Griliches, Z. 1963a. "The Sources of Measured Productivity Growth: United States Agriculture, 1940-1960." *Journal of Political Economy* 71(4):331-46.

Griliches, Z. 1963b. "Estimates of the Aggregate Agricultural Production Function from Cross-Sectional Data." *Journal of Farm Economics* 45:419-28.

Hayami, Y. 1969. "Sources of Agricultural Productivity Gap among Selected Countries." *American Journal of Agricultural Economics* 51:564-75.

Hayami, Y. 1970. "On the Use of the Cobb-Douglas Production Function on the Cross-Country Analysis of Agricultural Production." *American Journal of Agricultural Economics* 52:327-9.

Hayami, Y., and V. W. Ruttan. 1970. "Agricultural Productivity Differences Among Countries." *American Economic Review* 60 (5):895-911.

Hayami, Y., and V. W. Ruttan. 1985. *Agricultural Development, An International Perspective*. Baltimore: The Johns Hopkins University Press.

Heady, E. O. 1944. "Production Functions from a Random Sample of Farms." *Journal of Farm Economics* 26:989-1004.

Heady, E. O., and J. D. Dillon. 1961. *Agricultural Production Functions*. Ames: Iowa University Press.

Hertel, T. 1997. *Global Trade Analysis.* Cambridge: Cambridge University Press.

Kawagoe, T., and Y. Hayami. 1985. "An Intercountry Comparison of Agricultural Production Efficiency." *American Journal of Agricultural Economics* 67:87-92.

Kawagoe, T., Y. Hayami and V. W. Ruttan. 1985. "The Intercountry Agricultural Production Function and Productivity Differences among Countries." *Journal of Development Economics* 19:113-32.

Kislev, Y., and W. Peterson. 1996. "Economies of Scale in Agriculture: A Reexamination of Evidence." In *The Economics of Agriculture: Papers in Honor of D. Gale Johnson, Volume 2.* J. M. Antle and D. A. Sumner, eds. pp. 156-170. The University of Chicago Press.

Maddala, G. S. 1971. "The Use of Variance Components Models in Pooling Cross Section and Time series Data." *Econometrica* 39:341-58.

McGuirk, A., and Y. Mundlak. 1992. "The Transition of Punjab Agriculture: A Choice of Technique Approach." *American Journal of Agricultural Economics* 74(1):132-43.

Mundlak, Y. 1981. "On the Concept of Non-Significant Functions and its Implications for Regression Analysis." *Journal of Econometrics* 16(1):139-49.

Mundlak, Y. 1988. "Endogenous Technology and the Measurement of Productivity." In *Agricultural Productivity: Measurement and Explanation,* S.M. Capalbo and J.M. Antle, eds. Washington, D.C.: Resources for the Future.

Mundlak, Y. 1993. "On the Empirical Aspects of Economic Growth Theory." *American Economic Review* 83(2):415-20.

Mundlak, Y. 1996. "Production Function Estimation: A Revival of the Primal." *Econometrica* 64(2):431-8.

Mundlak, Y. 1997. "Agricultural Production Functions: A Critical Survey." Working Paper #9702, Rehovot, Israel: The Center for Agricultural Economic Research.

Mundlak, Y., and R. Hellinghausen. 1982. "The Intercountry Agricultural Production Function: Another View." *American Journal of Agricultural Economics* 64(4):664-72.

Mundlak, Y., D. Cavallo and R. Domenech. 1989. "Agriculture and Economic Growth in Argentina, 1913-84." Research Report 76. Washington, D.C.: International Food Policy Research Institute.

Nehru, V., E. Swanson and A. Dubey. 1993. "A New Database on Human Capital Stock: Sources, Methodology, and Results." Policy Research Working Paper 1124. Washington, D.C.: The World Bank.

Nguyen, D. 1979. "On Agricultural Productivity Differences among Countries." *American Journal of Agricultural Economics* 61(3):565-70.

Pritchett, L. 1996. "Where Has All the Education Gone?" Policy Research Working Paper 1581. Washington, D.C.: The World Bank.

Schultz, T. W. 1953. *Economic Organization of Agriculture.* New York: McGraw Hill.

Solow, R. M. 1957. "Technical Change and the Aggregate Production Function." *Review of Economics and Statistics* 39(3):312-20.

Tintner, G. 1944. "A Note on the Derivation of Production Functions from Farm Records." *Econometrica* 12:26-34.

Tintner, G., and O. H. Brownlee. 1944. "Production Functions Derived from Farm Records." *Journal of Farm Economics* 26:566-71 (a correction in *JFE,* February 1953, p.123).

Yamada, S., and V. W. Ruttan. 1980. "International Comparisons of Productivity in Agriculture." In *New Developments in Productivity Measurement and Analysis*, J. W. Kendrick and B. N. Vaccara, eds. Chicago: The University of Chicago Press.

TABLE 1 -- COMPARISON OF RESULTS

	Bhattacharjee	Hayami & Ruttan	Evenson & Kislev	Yamada & Ruttan	Antle	Hayami & Ruttan	Nguyen	Evenson & Kislev	Mundlak & Hellinghausen
Date of study	1955	1970	1975	1980	1983	1970	1979	1975	1982
Sample:									
Number of countries	22	37	36	41	43	36	40*	36	58
Time period	1949	1960	1955, 60, 65, 68	1970	1965	1955, 60, 65	1955, 60, 65 70, 75	1955, 60, 65, 68	1960, 65, 70, 75
Estimation method	OLS	OLS	OLS	OLS	PCR	OLS	OLS	OLS	PCR
Data specification	S; N	M; N	M; N	M; N	S; N	M; PW	M; N	M; N	M; N
Fixed effects included						year	year	country	country#
Elasticities									
Structures & equipment/Machinery/Tractors		0.12	0.10	0.11		0.11	0.14	0.06	0.07
Livestock & orchards/Livestock		0.23	0.30	0.23	0.14**	0.28	0.33	0.35	0.19
Land	0.42	0.08**	0.04**	0.02**	0.16	0.07	0.02**	0.14	0.16
Labor	0.28	0.41	0.23	0.33	0.38	0.40	0.39	0.03**	0.46
Fertilizer	0.29	0.12	0.10	0.24	0.07**	0.14	0.10	0.09	0.11
Irrigation									0.01
Schooling/General education		0.32**		0.08**	0.25**	0.24	0.10**		
Technical education		0.14	0.04	0.14		0.12	0.17	0.00**	
Research and extension			0.14		0.17			0.07	
Infrastructure					0.21				
Policy variable									
Peak yield index									
Development									
sum of input elasticities	0.99	0.96	0.77	0.93	0.75	1.00***	0.98	0.67	1.00***

* sample is not balanced, n=183 for Nguyen study
** not significant at P=.05 for one-tailed test
*** homogeneity constraint imposed
# Country effects on slopes and intercept
OLS and PCR are ordinary least squares and principal components regressions.
S and M represent single year observations and multi-year averages.
PW represents per-worker averages of national aggregated data, N represents national aggregates.

TABLE 2 -- GROWTH RATES AND THE DECOMPOSITION OF THE SUM OF SQUARES

Variable	Average Annual Growth Rate (%)	Decomposition of the Sum of Squares (expressed as a percentage of total) SSB(t)	SSB(i)	SSW(it)
Output:				
GDP	3.82	2.49	96.17	1.34
Inputs:				
Capital	4.25	2.67	95.77	1.56
Structures & equipment	5.42	3.00	95.24	1.76
Livestock & orchards	2.17	0.96	97.83	1.21
Land	0.12	0.00	99.95	0.05
Labor	-0.04	0.01	99.35	0.64
Fertilizer	3.04	1.14	96.76	2.09
Technology:				
Schooling	1.80	4.14	93.48	2.38
Peak yield	1.90	58.10	24.64	17.27
Development	-0.29	1.41	94.18	4.41
Yield gap		8.97	30.91	60.12
Prices:				
Relative prices	-0.30	3.01	41.98	55.00
Price variability		2.48	15.78	81.75
Inflation		2.38	10.65	86.97
Per Labor Output and Inputs:				
GDP		2.67	95.00	2.33
Capital		2.14	95.46	2.40
Structures & equipment		2.17	95.86	1.98
Livestock & orchards		1.14	96.78	2.07
Land		0.01	99.41	0.58
Fertilizer		0.98	97.78	1.24

TABLE 3 -- BASE MODEL

Variable	Within time and country		Between time		Between country	
	Estimate	t-score	Estimate	t-score	Estimate	t-score
Inputs:						
Capital	0.37	6.90	1.03	6.01	0.34	13.13
Land	0.47	3.78			-0.03	-2.82
Labor	0.08		-0.16	-0.16	0.26	13.67
Fertilizer	0.08	1.53	0.14	0.33	0.43	21.91
Technology:						
Schooling	0.09	0.55	-0.28	-0.06	0.02	0.52
Peak yield	0.83	3.80	-0.32	-0.07	0.06	4.19
Development	0.52	3.36	-0.21	-0.33	0.31	2.97
Prices:						
Relative prices	0.04	1.78	0.02	0.09	0.01	1.95
Price variability	-0.03	-0.97	-0.07	-0.26	-0.08	-2.82
Inflation	-0.00	-0.75	0.04	0.71	0.07	4.25
Environmental:						
Potential dry matter					0.16	2.68
Water availability					0.44	7.96

Note: R-square for 777 obs. = .9696

TABLE 4 -- STATISTICAL TESTS

Tests of significance of blocks of variables

	R-square	k	h	F-statistic	5% critical value	outcome
Full regression	0.9696	31				
Null hypothesis is that the following block is not significant.						
within time & country	0.9643	22	9	14.45	1.89	reject
between time	0.9448	22	9	67.62	1.89	reject
between country	0.0302	19	12	1921.03	1.77	reject
technology block	0.9676	22	9	5.45	1.89	reject
price block	0.9685	22	9	3.00	1.89	reject
environmental block	0.9670	29	2	31.90	3.01	reject

Number of observations, n, is 777.

k represents the number of parameters estimated.

h represents the number of constraints imposed by omission of a block of variables.

Test of constant returns to scale for within-time and country analysis

Input	Estimate
Capital	0.36
Land	0.42
Labor	0.08
Fertilizer	0.08
Sum	0.94
F-statistic	0.04
5% critical value	3.84

The null hypothesis of constant returns to scale is not rejected.

TABLE 5 -- ALTERNATIVE MODEL, DISAGGREGATED CAPITAL

Variable	Within time and country		Between time		Between country	
	Estimate	t-score	Estimate	t-score	Estimate	t-score
Inputs:						
Structures & equipment	0.29	6.51	0.58	2.95	0.11	5.62
Livestock & orchards	0.13	2.09	0.44	1.81	0.29	9.04
Land	0.44	3.62			-0.06	-4.35
Labor	0.10		-0.58	-0.55	0.22	11.05
Fertilizer	0.04	0.79	0.09	0.22	0.42	20.41
Technology:						
Schooling	-0.07	-0.43	1.08	0.26	0.05	1.07
Peak yield	0.78	3.60	-1.64	-0.33	0.01	0.69
Development	0.46	3.01	-0.02	-0.02	0.28	2.73
Prices:						
Relative prices	0.04	1.78	0.01	0.03	0.05	5.91
Price variability	-0.02	-0.76	-0.12	-0.42	-0.15	-4.87
Inflation	-0.00	-0.84	0.01	0.22	0.11	6.15
Environmental:						
Potential dry matter					-0.03	-0.49
Water availability					0.55	9.41

Note: R-square for 777 obs. = .9703

TABLE 6 -- ALTERNATIVE MODEL, INCLUDES YIELD GAP

Variable	Within time and country		Between time		Between country	
	Estimate	t-score	Estimate	t-score	Estimate	t-score
Inputs:						
Capital	0.37	7.13	1.03	6.02	0.39	14.04
Land	0.44	3.55			-0.05	-3.85
Labor	0.12		-0.18	-0.18	0.24	12.52
Fertilizer	0.07	1.44	0.17	0.38	0.44	22.66
Technology:						
Schooling	0.11	0.65	0.06	0.01	0.02	0.57
Peak yield	0.93	4.24	-0.82	-0.15	0.07	4.91
Development	0.54	3.55	-0.29	-0.39	0.20	1.95
Yield gap	-0.42	-2.90	0.17	0.20	1.24	4.39
Prices:						
Relative prices	0.04	1.68	0.02	0.12	0.01	2.24
Price variability	-0.02	-0.74	-0.05	-0.20	-0.05	-1.92
Inflation	-0.00	-0.63	0.05	0.73	0.06	4.04
Environmental:						
Potential dry matter					0.18	3.09
Water availability					0.46	8.45

Note: R-square for 777 obs. = .9707

TABLE 7 -- ALTERNATIVE MODEL, INCLUDES CROSS PRODUCTS

Variable	Within time and country Estimate	t-score	Between time Estimate	t-score	Between country Estimate	t-score
Inputs:						
Capital	0.32	3.54	0.24	0.12	0.42	11.25
Land	0.51	3.81			-0.03	-2.38
Labor	0.09		-2.87	-0.54	0.19	5.99
Fertilizer	0.08	1.62	-0.07	-0.12	0.45	15.46
Technology:						
Schooling	0.36	1.61	6.39	0.39	-0.05	-0.52
Peak yield	1.18	1.61	4.92	0.08	0.65	2.38
Development	0.49	3.16	-0.36	-0.36	0.21	1.63
Peak yield*schooling	-0.56	-2.10	-6.64	-0.44	0.04	1.05
Peak yield*capital	0.06	0.63	0.84	0.37	-0.05	-3.82
Peak yield*labor	-0.06		-0.98	-0.24	0.04	2.31
Prices:						
Relative prices	0.04	1.71	0.05	0.23	0.01	0.99
Price variability	-0.03	-0.92	-0.12	-0.41	-0.09	-3.18
Inflation	-0.00	-0.64	-0.01	-0.06	0.06	3.82
Environmental:						
Potential dry matter					0.16	2.39
Water availability					0.46	7.25
Note: R-square for 777 obs. = .9704						
Mean Elasticities						
Capital	0.37		0.96		0.32	
Labor	0.04		-3.72		0.26	
Schooling	-0.12		0.66		0.03	
Peak yield	0.73		-1.24		0.02	

TABLE 8 -- PRINCIPAL COMPONENTS ANALYSIS OF BASE MODEL

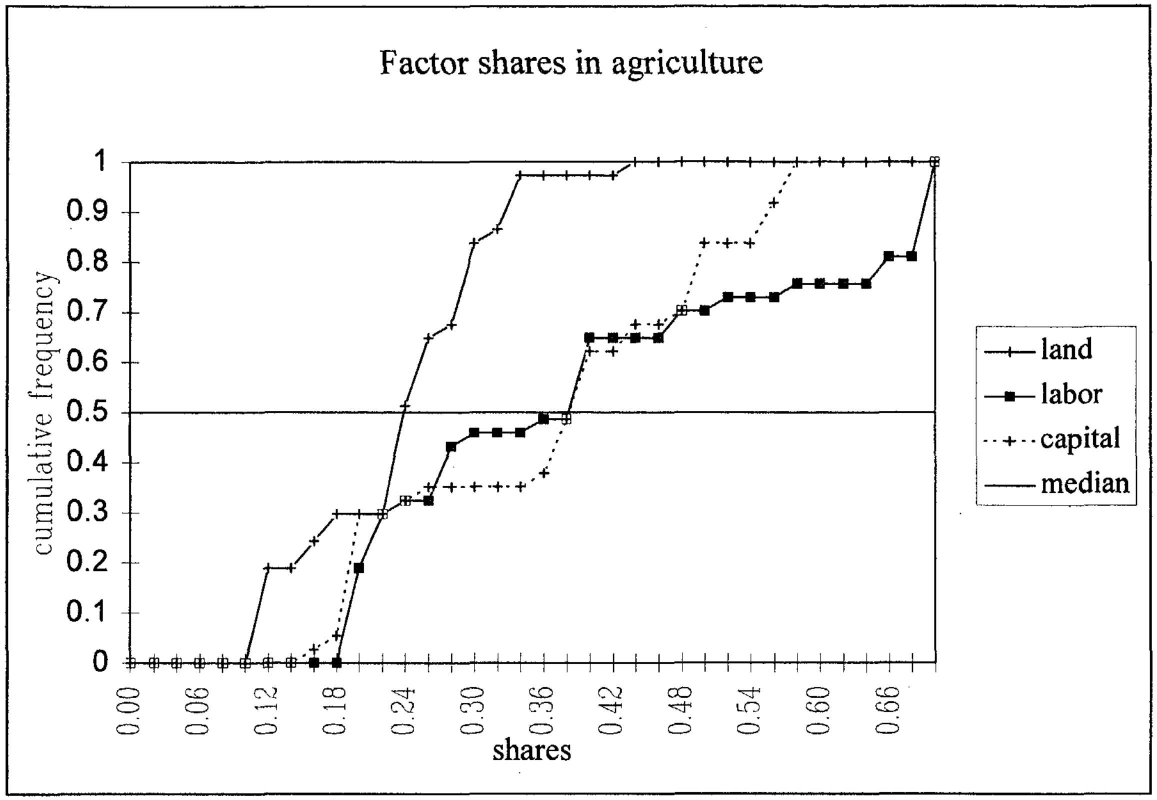
	Within time and country		Between time		Between country	
Variable	**Estimate**	**t-score**	**Estimate**	**t-score**	**Estimate**	**t-score**
Inputs:						
Capital	0.26	17.25	0.87	8.10	0.34	29.54
Land	0.46	15.85			-0.03	-2.94
Labor	0.16		-0.70	-1.71	0.26	20.59
Fertilizer	0.12	2.54	-0.33	-3.26	0.43	22.74
Technology:						
Schooling	-0.08	-1.27	0.32	8.83	0.02	0.52
Peak yield	0.99	6.38	0.36	8.05	0.06	5.55
Development	0.87	16.10	-0.02	-0.07	0.31	4.91
Prices:						
Relative prices	0.03	2.34	-0.01	-0.07	0.01	2.45
Price variability	-0.01	-0.40	0.03	0.13	-0.08	-3.28
Inflation	-0.00	-0.92	-0.01	-0.36	0.06	4.05
Environmental:						
Potential dry matter					0.15	2.59
Water availability					0.44	8.44
Number of restrictions	4		4		2	

TABLE 9 -- PRINCIPAL COMPONENTS ANALYSIS OF DISAGGREGATED CAPITAL MODEL

Variable	Within time and country		Between time		Between country	
	Estimate	t-score	Estimate	t-score	Estimate	t-score
Inputs:						
Structures & equipment	0.25	8.56	0.25	10.43	0.12	6.60
Livestock & orchards	0.19	4.79	0.73	7.20	0.24	25.89
Land	0.47	9.28			-0.05	-3.93
Labor	0.05		-1.75	-4.27	0.25	17.35
Fertilizer	0.04	0.84	0.00	0.03	0.42	20.73
Technology:						
Schooling	0.07	0.75	0.26	7.87	0.04	0.94
Peak yield	0.61	3.67	0.32	8.81	0.03	2.83
Development	0.51	7.49	-0.68	-4.01	0.37	4.15
Prices:						
Relative prices	0.02	1.38	0.08	0.55	0.04	7.12
Price variability	0.00	0.11	-0.03	-0.12	-0.12	-4.55
Inflation	-0.01	-8.05	0.04	2.45	0.10	5.93
Environmental:						
Potential dry matter					0.02	0.34
Water availability					0.53	9.12
Number of restrictions	5		6		1	

TABLE 10 -- WITHIN-TIME AND WITHIN-COUNTRY ANALYSES

	Aggregate Capital				Disaggregated Capital			
	Within time		Within country		Within time		Within country	
Variable	Estimate	t-score	Estimate	t-score	Estimate	t-score	Estimate	t-score
Inputs:								
Capital	0.44	19.04	0.53	11.51				
Structures & equipment					0.18	10.82	0.38	9.21
Livestock & orchards					0.23	10.48	0.21	3.50
Land	-0.04	-4.08	0.51	1.81	-0.06	-4.81	0.57	2.06
Labor	0.31	19.37	0.13	1.16	0.35	21.11	0.08	0.76
Fertilizer	0.29	16.70	0.03	0.68	0.28	14.65	0.00	0.07
Technology:								
Schooling	0.15	3.83	0.07	0.42	0.15	3.68	-0.10	-0.58
Peak yield	0.37	2.42	0.82	4.24	0.32	1.94	0.84	4.41
Development	0.34	4.45	0.21	1.60	0.66	8.80	0.22	1.69
Prices:								
Relative prices	0.06	2.71	0.03	1.05	0.04	1.80	0.02	1.01
Price variability	-0.05	-1.71	-0.01	-0.50	-0.05	-1.47	-0.01	-0.36
Inflation	-0.01	-1.30	-0.00	-1.07	-0.00	-0.96	-0.00	-0.98


Factor shares in agriculture
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
cumulative frequency
0.00
0.06
0.12
0.18
0.24
0.30
0.36
0.42
0.48
0.54
0.60
0.66
shares
land
labor
capital
median

APPENDIX – CORRELATION MATRICES OF VARIABLES

Within-time and country variables

	Capital	S&E	L&O	Land	Labor	Fert	School	Peak	Dev	Gap	Price	Var	Inf
Capital	1.0000	0.7645	0.6685	-0.2508	-0.3368	-0.0225	-0.1091	0.0183	0.4650	0.0340	0.1360	-0.0100	-0.0051
Structures and equipment		1.0000	0.3153	-0.2194	-0.2493	0.0790	0.0727	0.0968	0.4187	0.0607	0.1086	-0.0444	0.0301
Livestock & orchards			1.0000	0.0508	0.1458	0.2369	0.1160	0.0820	0.1172	0.0799	0.1478	0.0278	-0.0949
Land				1.0000	0.4811	0.3184	0.2852	0.0445	-0.2464	0.0958	0.0640	0.1247	-0.0078
Labor					1.0000	0.5475	0.6058	0.0780	-0.4282	0.1370	0.0322	0.0260	0.0746
Fertilizer						1.0000	0.4224	0.0791	-0.1957	0.0468	0.1203	-0.0057	-0.0213
Schooling							1.0000	0.3847	-0.2472	0.1483	0.0771	0.0185	0.0490
Peak yield								1.0000	-0.0436	0.1736	0.1362	0.0447	-0.0921
Development									1.0000	0.0057	0.0275	-0.0207	-0.0575
Yield gap										1.0000	0.0167	0.0767	0.0573
Relative prices											1.0000	0.5050	-0.1696
Price variability												1.0000	0.0556
Inflation													1.0000

Between-country variables

	Capital	S&E	L&O	Land	Labor	Fert	School	Peak	Dev	Gap	Price	Var	Inf	PDM	FWD
Capital	1.0000	0.9478	0.8776	0.6892	0.4252	0.9295	0.2629	-0.0748	0.5687	-0.5241	-0.0311	-0.1920	-0.0921	-0.4006	0.1300
Structures and equipment		1.0000	0.6998	0.5113	0.2340	0.9075	0.4382	-0.1904	0.6977	-0.5353	-0.0406	-0.2096	-0.0736	-0.5573	0.1667
Livestock & orchards			1.0000	0.8588	0.6404	0.8001	-0.0622	0.0852	0.2229	-0.4211	-0.0716	-0.0946	-0.0524	-0.0040	-0.0801
Land				1.0000	0.5777	0.6049	-0.2126	0.0290	0.1107	-0.1901	-0.0605	-0.0891	0.1345	0.1484	-0.2284
Labor					1.0000	0.4207	-0.5609	0.1434	-0.4083	-0.1180	0.3384	-0.2066	0.0294	0.3917	-0.3126
Fertilizer						1.0000	0.3016	-0.2128	0.5433	-0.4949	-0.0326	-0.1952	-0.1303	-0.3876	0.1028
Schooling							1.0000	-0.2815	0.7290	-0.2788	-0.3559	0.0693	-0.0103	-0.6327	0.5629
Peak yield								1.0000	-0.3339	-0.1620	0.3774	-0.0295	-0.1991	0.1934	-0.0610
Development									1.0000	-0.2695	-0.2785	-0.1345	-0.1721	-0.8191	0.4957
Yield gap										1.0000	-0.0707	-0.1254	0.1648	0.2261	-0.1611
Relative prices											1.0000	-0.1122	-0.3581	0.1794	-0.2631
Price variability												1.0000	0.2480	0.1943	0.0576
Inflation													1.0000	0.1646	-0.1156
PDM														1.0000	-0.5812
FWD															1.0000

APPENDIX -- CORRELATION MATRICES OF VARIABLES (*Continued*)

Between-time variables	Capital	S&E	L&O	Labor	Fert	School	Peak	Dev	Gap	Price	Var	Inf
Capital	1.0000	0.9950	0.9694	-0.0117	0.8797	0.9328	0.9343	0.3586	0.7104	-0.4599	0.1404	0.3356
Structures and equipment		1.0000	0.9460	-0.0265	0.8787	0.9333	0.9363	0.3337	0.6902	-0.4584	0.1443	0.3490
Livestock & orchards			1.0000	0.0901	0.7925	0.8512	0.8525	0.3305	0.6862	-0.4232	0.1882	0.2460
Labor				1.0000	-0.0648	-0.0847	-0.0809	0.0837	0.2056	0.4814	0.4866	-0.5916
Fertilizer					1.0000	0.9803	0.9796	0.4538	0.7869	-0.4501	-0.0408	0.3765
Schooling						1.0000	0.9992	0.4344	0.7804	-0.4878	-0.0270	0.4416
Peak yield							1.0000	0.4064	0.7844	-0.4969	-0.0335	0.4254
Development								1.0000	0.3980	0.2995	0.3867	0.4636
Yield gap									1.0000	-0.2585	-0.0143	0.0787
Relative prices										1.0000	0.5881	-0.2840
Price variability											1.0000	-0.1308
Inflation												1.0000

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS1801	Regional Integration as Diplomacy	Maurice Schiff L. Alan Winters	August 1997	J. Ngaine 37947
WPS1802	Are There Synergies Between World Bank Partial Credit Guarantees and Private Lending?	Harry Huizinga	August 1997	P. Sintim-Aboagye 38526
WPS1803	Fiscal Adjustments in Transition Economies: Social Transfers and the Efficiency of Public Spending: A Comparison with OECD Countries	Barbara Fakin Alain de Crombrugghe	August 1997	M. Jandu 33103
WPS1804	Financial Sector Adjustment Lending: A Mid-Course Analysis	Robert J. Cull	August 1997	P. Sintim-Aboagye 37644
WPS1805	Regional Economic Integration and Agricultural Trade	Junichi Goto	August 1997	G. Ilogon 33732
WPS1806	An International Statistical Survey of Government Employment and Wages	Salvatore Schiavo-Campo Giulio de Tommaso Amitabah Mukherjee	August 1997	M. Guevara 32959
WPS1807	The Ghosts of Financing Gap: How the Harrod-Domar Growth Model Still Haunts Development Economics	William Easterly	August 1997	K. Labrie 31001
WPS1808	Economic Transition and the Distributions of Income and Wealth	Francisco H. G. Ferreira	August 1997	M. Geller 31393
WPS1809	Institutions in Transition: Reliability of Rules and Economic Performance in Former Socialist Countries	Aymo Brunetti Gregory Kisunko Beatrice Weder	August 1997	M. Geller 31393
WPS1810	Inspections and Emissions in India: Puzzling Survey Evidence about	Sheoli Pargal Muthukumara Mani Mainul Huq	August 1997	E. Krapf 80513
WPS1811	Agricultural Development: Issues, Evidence, and Consequences	Yair Mundlak Donald F. Larson Al Crego	August 1997	P. Kokila 33716
WPS1812	Managing Guarantee programs in Support of Infrastructure Investment	Michael Klein	August 1997	S. Vivas 82809
WPS1813	Tackling Health Transition in China	Shaikh I. Hossain	August 1997	C. Anbiah 81275
WPS1814	Making Education in China Equitable and Efficient	Shaikh I. Hossain	August 1997	C. Anbiah 81275

Policy Research Working Paper Series

	Title	Author	Date	Contact for paper
WPS1815	Unfair Trade? Empirical Evidence in World Commodity Markets Over the Past 25 Years	Jacques Morisset	August 1997	N. Busjeet 33997
WPS1816	Returns to Regionalism: An Evaluation of Nontraditional Gains from Regional Trade Agreements	Raquel Fernandez	August 1997	J. Ngaine 37947
WPS1817	Should Core Labor Standards Be Imposed through International Trade Policy?	Keith E. Maskus	August 1997	J. Ngaine 37947
WPS1818	What Affects the Russian Regional Governments' Propensity to Subsidize?	Lev Freinkman Michael Haney	August 1997	N. Campos 38541
WPS1819	The Argentine Pension Reform and Its Relevance for Eastern Europe	Dimitri Vittas	August 1997	P. Infante 37642
WPS1820	Private Pension Funds in Argentina's New Integrated Pension System	Dimitri Vittas	August 1997	P. Infante 37642
WPS1821	The "IPO-Plus": A New Approach to Privatization	Itzhak Goldberg Gregory Jedrzejczak Michael Fuchs	August 1997	I. Goldberg 36289
WPS1822	Intergovernmental Fiscal Transfers in Nine Countries: Lessons for Developing Countries	Jun Ma	September 1997	C. Ima 35856
WPS1823	Antidumping in Law and Practice	Raj Krishna	September 1997	A. Bobbio 81518
WPS1824	Winners and Losers from Utility Privatization in Argentina: Lessons from a General Equilibrium Model	Omar Chisari Antonio Estache Carlos Romero	September 1997	T. Malone 37198
WPS1825	Current Accounts in Debtor and Creditor Countries	Aart Kraay Jaume Ventura	September 1997	R. Martin 39026
WPS1826	Standards and Conformity Assessment as Nontariff Barriers to Trade	Sherry M. Stephenson	September 1997	M. Pateña 39515