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AGRICULTURAL PRODUCTIVITY AND ECONOMIC POLICIES: CONCEPTS AND MEASUREMENTS

by

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RÉSUMÉ

Le dispositif conceptuel développé dans ce document montre de quelle manière l'évolution de l'environnement économique modifie la productivité des facteurs. L'accent est mis sur la technologie utilisée dans la production — technologie installée — plutôt que sur la création de nouvelles technolgies. Sa mise en oeuvre reflète les caractéristiques des incitations et des contraintes liées aux conditions économiques et auxquelles sont confrontés les producteurs lorsqu'ils doivent faire des choix technologiques.

Le document constitue une base originale, formelle et théorique à la proposition courante mais pas véritablement explicitée, selon laquelle la productivité et son taux de croissance dépendent de la conception structurelle des politiques.

SUMMARY

This study develops a conceptual framework for analysing the ways in which changes in the economic environment modify factor productivity. It focuses on the technology actually used in production — implemented technology — rather than the generation of technology. Implementation reflects the pattern of incentives and constraints deriving from the underlying economic conditions with which producers are faced in making technology choices.

The study provides an original, formal theoretical underpinning to the popular but essentially unsubstantiated proposition that productivity and the rate of growth of productivity depend on the policy framework.

ACKNOWLEDGEMENTS

PREFACE

This study is one of several which constitute different components of a research project on "Technological Change in Developing Country Agriculture: Implications of the Changing Public/Private Sector Balance". The project has been undertaken in the context of the Development Centre's 1990-1992 research programme on "Developing Country Agriculture and International Economic Trends".

Its principal objective is to determine whether the structural adjustment and liberalisation process — and, by implication, changes in the public/private sector balance — is enhancing or impairing the economic and institutional conditions conducive to technological innovation and greater productivity. In order to examine this hitherto unresearched issue, an eclectic approach has been adopted and a number of different types of study commissioned. These include: a conceptual study of the interaction between changes in economic policies and agricultural productivity; two commodity studies — rice and cocoa; a study of biotechnology research developments with respect to those two commodities; a case study of agricultural research institutions in Brazil; a study of seeds supply and diffusion in three African countries. These provide different perspectives and angles on the relation between economic reform and technological change in agriculture.

Yair Mundlak has contributed this conceptual study which develops a framework for examining ways of measuring the impact of changes in economic policies on agricultural productivity. In contrast to some of the other studies included in the project which are concerned with the generation of technology, the study concentrates on the theoretical determinants of the implementation of technology.

In Mundlak's approach technological change is seen as a shift between production functions and implemented technology reflects the economic environment. Implementation reflects the pattern of incentives and constraints deriving from the underlying economic conditions with which producers are faced in making technology choices.

The major conclusions and policy implications to be drawn from the project will be published by the OECD in its Development Centre Studies series in a synthesis volume edited by Carliene Brenner.

Louis Emmerij
President of the Development Centre
May 1992

I. INTRODUCTION

Policies aimed at structural adjustments intend to change the economic environment and thereby they affect productivity. In this paper we examine in some detail the process through which changes in the economic environment change factor productivity. The underlying premise of our analysis is that the technology actually used in production, referred to as the implemented technology, is not necessarily the most advanced technology, or frontier of the available technology. The gap between this frontier and the implemented technology reflects the economic environment. Our task then is to unfold this complex relation in such a way that will facilitate an empirical evaluation of policies on productivity. We begin with a review of some elementary and known concepts as a background for introducing the new aspects of the analysis.

Agricultural productivity is a short name for the productivity of resources in agricultural production. Aside of the general interest in the working of the economy, there are several important reasons for our interest in agricultural productivity: food supply, growth aspects, competitive position of agriculture in the factor markets, off-farm labour migration, intersectoral flow of savings, farmers' income and more.

The concept of productivity, regardless of the actual method used in computing productivity, calls for a comparison of changes in outputs and inputs. In that, it is implicitly assumed that regularity in the relationship between inputs and outputs prevails over time or across producers so that the results of one comparison are valuable in predicting the response of output to input changes in another experiment. It is this repetitious property that justifies the study of such input output relationships, usefully summarized in terms of the production function. Some writers or analysts avoid the use of the concept of a production function and some even object to it. However, the assumption of regularity in production gives rise to such a concept and we make no apologies for using it as a reference point. There are, nonetheless, as we shall see below, some delicate issues related to the aggregate production function that have to be addressed.

When the output obtained from a given set of inputs increases, we say that there is an improvement in productivity or more commonly, technical change. Such a comparison of two points with inputs held constant is a conceptual exercise because in reality inputs do not necessarily remain constant and while output grows, both outputs and inputs vary over time or among producers. Thus, in order to evaluate changes in productivity empirically it is necessary to determine the change in inputs and outputs. The various inputs do not ordinarily change at the same rate over the sample, so they have to be aggregated in order to yield a measure of total input change. Such an aggregation requires assigning weights to the contribution of the various inputs to output. The weights can be obtained by assuming that the observed factor shares provide an appropriate measure of the importance of the inputs in production. Such a procedure is based on some assumptions with respect to factor market behaviour which should not be taken at face value in empirical analysis. Thus, weights are obtained from empirical analysis using the available historical information. This procedure calls for the estimation of the production function. Issues related to this approach are discussed in detail below. Similar considerations apply in principle to the aggregation of outputs.

Much of the discussion of productivity in the literature deals with technology and its change over time. However, technology is an abstract concept and not an observable quantity easily measured. We can identify specific techniques, such as a crop variety in a given region or a given type of computer, but once we want to generalize the concept to deal with a technology which consists of more than one technique the problem becomes more complex. The inference about the technology is indirect and it is made by comparing changes in output and inputs. As such, the inference is drawn from the **implemented** rather than on the **available** technology, but implementation reflects the underlying economic conditions namely, the incentives, input and other constraints, as well as the available knowledge or technology.

As economic policies affect the incentives as well as the factor supply, they also affect productivity. The effect of policies depends to a large extent on the nature of factor supply, and particularly on the response of factor supply to changes in the economic environment. This is an important aspect of our analysis and it is therefore included in the discussion.

Technology is not merely an esoteric research topic for economists. It takes centre stage in the public discussion of agriculture. There are several reasons for the public interest in agricultural technology but to a large extent it is rooted in the desire to prevent food shortage. Thus, there are public experimental stations in each country, and there is a global network of experimental stations under the umbrella of the CGIAR. In addition to the public effort there is also private research in areas — such as in the development of chemicals or more recently in the area of genetic engineering — where the benefits of research and development can be captured.

The invention of new methods of production, to be referred to as **techniques** — such as plant and seed varieties, insecticides, and methods of irrigation — makes it possible to increase food production from a given cultivated area and thereby to increase the food supply. This is the only way to increase the **capacity** of food production (leaving this concept vague for the time being). However, actual production, being less than capacity production, as well as productivity in general, can be increased considerably without a change in capacity.

This distinction between actual and capacity production helps to concentrate our attention on important sources of growth which are pertinent to the discussion of structural adjustments. First, not all output is produced by the most productive techniques. This gap between availability and implementation of technology is often attributed to lack of information, uncertainty and inability to comprehend the new techniques which can be related to inadequate human capital.[1] More important, it is related to economic considerations. For instance, McGuirk and Mundlak (1991) show that the pace of adoption of the modern wheat and rice varieties in the Punjab was largely related to the pace of expansion in the irrigation facilities, infrastructure and fertilizers all of which require resources and as such the pace of adoption is related to the scarcity or availability of capital.

Second, there are considerable differences in the efficiency of production between farmers. A regime which allows for perfect and complete markets as well as free entry and exit is likely to lead to redistribution of scarce resources, particularly land and water, in such a way that the more productive farmers will operate the available resources. This point is particularly important in the light of two factors:
1. On a net basis, the numbers of farmers and farms decline in the process of economic growth. This implies a redistribution of land. 2. Farming is by and large a family operation and therefore it is subject to life cycles. In the process of intergenerational transfer, the decision of the incoming generation on whether or not to stay in agriculture depends on their opportunities. This element exists even if the farm population remains constant. Such a shift of resources requires the appropriate economic environment which will provide a correct evaluation of the various opportunities.

Third, a similar consideration is applied to the global distribution of agricultural production. This possibility is related to economic policies which countries follow. In a free-trade environment with no subsidies or taxes on agriculture or trade, more production will be forthcoming from areas where food production requires fewer resources or simply from countries with comparative advantage in agriculture.

While much of the research on technical change in agriculture is focused on the development of new technology, we will concentrate on the issues related to the implementation of this technology and its relation to economic policy. The term policy is general in the sense that it also covers policies which are not directed specifically toward agriculture. Our task is then to place all these considerations within a uniform and quantifiable framework. This framework can also be used in the discussion of the development of new technology. The core of the discussion is technical. As the framework is not widely used, the discussion will be based largely on our own

research, and that done with colleagues, for supplementing the conceptual discussion and for providing empirical evidence on various applications. In addition, using this framework as a background, we survey some of the general literature for both conceptual and empirical evidence.

The plan of the paper is as follows: We begin with a heuristic discussion of some central issues that arise with the appearance of a new technique, using the Green Revolution as an example. This presentation is then generalized for the analysis of the structure of production. The choice of production techniques is endogenized and the composition of techniques and their level of intensity, as measured by the inputs allocated to the various techniques, are determined simultaneously. This formulation allows for the evaluation of the direct effect of policies on productivity.

The empirical aspects of the analysis consist of algebraic presentation of the technology, the scope for and role of dual estimation and the implications of the fact that inputs are endogenous. These are the main topics of the literature on the econometrics of production functions.

The supply of inputs to agriculture and their effect on productivity offers the indirect channel through which policies affect productivity. The last section summarizes some of the findings in order to evaluate the possible effects of some major policy measures.

II. ISSUES ARISING WITH THE APPEARANCE OF A NEW TECHNIQUE: THE GREEN REVOLUTION AS AN EXAMPLE

In general, the analysis of production assumes, implicitly or explicitly, that the technology consists of a single technique, characterized by a production function. In this framework, when there is a change in technology, producers replace the old technique with the new one. However, this assumption is inconsistent with the data which show that the process of transition from old to new techniques takes time — and generally a long time — and in the process different techniques coexist. Therefore the removal of this assumption has important consequences for our understanding of producers behaviour, in general and more specifically, in their implementation of new techniques.

In this discussion we draw on the experience of the introduction of modern cereal varieties, known as the green revolution, which began in the mid-1960s. A recent empirical study of food grains growth in India based on district data provides empirical evidence for some of the propositions developed here, (Bhalla *et al.*). In comparing production changes from the period 1962-65 (pre-green revolution) to 1970-73, a period when the new technology in Punjab agriculture was well established, the study concludes that the introduction of modern varieties:

1.   represents technical change in that yields are increased and the productivity of all inputs is increased, including that of labour whose factor share declines,

2.   has required capital inputs,

3.   is capital intensive in the sense that it increases the share of capital inputs in total output,

4.   most important, has taken a long time to implement and after twenty years is far from being completed. Thus, the transition period is characterized by co-existence of traditional and modern techniques.[2]

Points 1-3 are consistent with labour-saving technical change generated by factor augmentation to yield under given prices higher capital-labour ratios. To illustrate some important implications of factor augmenting technical change we turn to Figure 1 where f_1 and f_2 describe the production functions of the traditional and modern varieties respectively. For the purpose of illustration, and without a loss of generality, let the horizontal axis represent the ratio of fertilizer to land, denoted by k, ignoring other inputs for the time being. The vertical axis represents the output per unit of land produced by technique j, f_j. When the technology consists of only the traditional variety, producers produce at point A, with fertilizer-land ratio k_0 and a marginal productivity of fertilizer $r_0 = f_1'(k_1)$. The introduction of the modern variety (technique), f_2, opens up new possibilities. When the supply of fertilizer is perfectly elastic at the price r_0, producers should be moving to point M determined by $f_2'(k_2) = r_0$. At this point the return to land is higher than at A and there is no scope for co-existence of the traditional and modern varieties.

If co-existence is observed, there must be reasons not taken into account in our analysis. Often, the reason given for the co-existence is that producers do not have perfect knowledge about the new technique. This explanation is reasonable but it can not by itself account for the length of time that it has required to introduce the modern varieties and for the geographical variations in the pattern of their use. The green revolution is considered here as an example, indeed a very important one. Another example is the motorization of agriculture which has also taken a long time to be implemented. The explanation given here for the delayed response is the scarcity of inputs, such as fertilizers and irrigation facilities, needed for a full implementation of the modern technique. Fertilizer was used here as an example, though it was an important constraint in the case of the green revolution. At this point we can generalize the discussion and replace the fertilizer in the illustration by capital to represent the aggregate input which restricts the expansion of the modern technique.

To show the effect of scarcity in this case, assume that the initial capital-land ratio is k_0. With k_0 given, the traditional variety dominates the modern one because it produces a higher yield. This is illustrated in Figure 1 by comparing points A and B. However, point A is not optimal because there is a better possibility than that of specializing in the production of the traditional variety; to allocate the scarce resource to the two varieties. Such an allocation should result in equal marginal productivity of capital for the two varieties, otherwise some producers could gain by an arbitrage. The optimal combination is shown in Figure 1 by the line tangent to the two production functions at the points A and M. The slope of the tangent line is $\tilde{\rho}$ = $\phi_1(\kappa_1)$ = $\phi_2(\kappa_2)$ where κ_φ are the corresponding capital-land ratios to be referred to as threshold values. The average yield is now given by N which dominates the yield at point A.

Once point N is chosen, the crop composition can change only by changing the available capital-land ratio. As capital per unit of land increases, point N will move to the right indicating an increase in the shares of land and capital allocated to the modern variety. If capital could be acquired in unlimited quantities, within the relevant range, at the price r_0, there would be no reason to grow the traditional variety. But as long as there is insufficient supply to allow all farmers who want to grow the modern variety to produce at point M, some of the available supply will be allocated to the traditional variety. It is in this sense that the pace of the transition is related to the scarcity of capital.

The essence of this example is that the modern variety is more capital intensive and if the supply of capital is limited, the two techniques will co-exist. It is important to note that the mere appearance of a new technique, which is more capital-intensive than the existing one, increases the demand for capital and its rate of return increases from r_0 to $\tilde{\rho}$. Thereby capital is likely to be attracted from other uses.

The foregoing analysis is somewhat simplified in order to enable graphical illustration. Nevertheless, it brings up the important points for our subsequent discussion. We begin the discussion by reviewing some supplemental empirical evidence which will help us to place the discussion within an appropriate perspective. This is then followed by constructing the choice of technique framework which considers the choice to be endogenous within the economic system. The discussion generates a direct link between capital accumulation and technical change which is of prime importance for the evaluation of the growth process. Underlying the choice of the implemented technology is the available technology, which changes with the appearance of new techniques. The new techniques are not entered into the economy exogenously. Some agents invest resources in the production of new techniques. Thus, economic considerations must also have an effect on the flow of new techniques. Hence, both the supply and the demand of new techniques are endogenous and in this sense the technology is endogenous.

The application of this framework to the Indian Punjab agriculture was studied by McGuirk and Mundlak (1991) and their results are pertinent for the present discussion. The study deals with the determination of the level and pace of the implementation of the modern wheat and rice varieties, as well as new varieties of cotton and maize introduced in Punjab during 1960-79. The implementation of these new varieties resulted in a dramatic growth in crop production. The data are district-level data. The techniques that are included in the analysis are the most important crops, accounting for about 70 per cent of the sown area in the period under consideration. A distinction is made according to seasons (*rabi, kharif*), irrigation and varieties (traditional, modern). The analysis deals with three levels of decisions, area allocation, yield determination and finally, investment-type decision to be explained below. We turn immediately to the results, providing only necessary details as we go along, and postponing the explicit formulation to subsequent discussion.

At each stage, the variables affecting the decision are grouped into three groups: incentives, constraints and environment. Our immediate interest is in the role of the constraints. Table 1 reports the results for the empirical equations determining the area allocation to the wheat and rice varieties, which are the most important crops. The constraints consist of area irrigated from private sources, mainly tube wells, and from government sources, mainly canals, the quantity of fertilizers expected to be available for the planting season and roads. The results show that an increase in the irrigation, mainly private, fertilizers and roads was associated with an increase in the share of the modern varieties of wheat in the total area and at the same time in a decrease in the area of the traditional irrigated wheat. Turning to rice, it is seen that fertilizers and roads increased the share of the modern varieties in total acreage, but irrigation was associated with a decline in their share. This is consistent with the view that the irrigation favoured wheat and therefore the share of rice declined. However, it should be noted that the table reports **shares** and not **total** area. Total area sown in modern variety of rice increased. Without going into further details at this stage, the results indicate that with prices — or more generally, the level of incentives — held constant, the transition to the modern variety was associated with an increase in the level of these capital inputs.

The results for the yield equation are reported in Table 2. The dependent variable in this equation is the average crop yield, which can be written as $y = (1-S)y_1 + Sy_2$, where S is the share of the modern variety in the total area and y_j is the yield of variety j. The incentives were empirically irrelevant and therefore are not included in the equations. The most striking result is that the fertilizer variable is not significantly different from zero.[3] Thus, the only variable that matters in the yield equation is the proportion of the modern variety in total area, or simply S. The coefficient of this variable indicates the yield difference of the traditional and modern varieties.[4] The empirical results confirm the response to a change in the constraint as shown in Figure 1; it changes the proportion of the modern variety in total area, while each technique is implemented at a constant level of the input ratio so as to equate the shadow price of the constraint over techniques. In simple words, this result indicates that each variety has its optimal level of fertilizer and when the availability of fertilizer increases, it is used to increase the area sown to the modern variety rather than to increase the quantity applied to a given unit of land of either variety. Individual farmers may be very heterogenous in other respects but this need not affect their behaviour in the utilization of fertilizers.

The results indeed indicate that the pace and level of the transition to the modern variety were determined by the availability of the capital, or quasi-fixed, inputs. The expansion of their supply required resources and those had to be taken from other productive uses. Thus it all goes back to the fact that resources are finite and if the implementation of a new technique requires resources, it cannot move faster than the necessary change in the supply of the needed inputs, but the pace of the change in input supply depends on the rate of return to the scarce resources. As shown in Figure 1, the rate of return increases with the appearance of the new technique from r_0 to $\bar{r}$. This explains the dramatic increase in the supply of fertilizers, tubewells electricity and roads as well as other variables which provide the infrastructure conducive for the adoption of the modern varieties. Some of these variables are plotted in Figure 2. Some of these variables are public inputs which are determined in a somewhat different framework than that of the private inputs. Nevertheless, this does not imply that the government is immune to opportunities offered by the new technology.

With this background we can turn now to formulate the process which we just described. This discussion is based on Mundlak (1988).

III. ANALYSIS OF THE STRUCTURE OF STRUCTURE

Formulation

The production of a given commodity or service can be decomposed into a set of elementary activities or techniques. A technique is described by a production function. The degree of disaggregation, or refinement of the definition of a technique, depends on the purpose of the analysis. To simplify the analysis, we begin with a single period optimization and single output production functions. Let x be the vector of inputs and $F_j(x)$ be the production function associated with the jth technique and define:

Definition: The *available technology*, T, is the collection of all possible techniques:

$$T = \{F_j(x)\} \tag{1}$$

The *implemented technology* is a subset of T, determined by the firms subject to their constraints and the economic environment.

The choice of techniques is made at the firm level. We distinguish between fixed (k) and variable (v) inputs, x = (v,k), and assume for simplicity that the fixed inputs have no alternative cost. The corresponding optimization problem calls for a choice of the variable (v_j) and the fixed (k_j) inputs to be assigned to technique j so as to maximize profits. The Lagragian equation for this problem is:

$$L = \Sigma_j p_j F_j(v_j, k_j) - \Sigma_j w v_j + \lambda(k - \Sigma_j k_j) \tag{2}$$

subject to $F_j(.)\_T$; $v_j \geq 0$; $k_j \geq 0$.

where p_j is the price of the product of technique j, w is the price vector of the variable inputs and k is the available stock of fixed inputs. The Kuhn Tucker necessary conditions for a solution are:

$$L_{vj} = p_j F_{vj} - w \leq 0 \tag{3}$$

$$L_{kj} = p_j F_{kj} - \lambda \leq 0 \tag{4}$$

$$\Sigma_j (L_{vj} v_j + L_{kj} k_j) = 0 \tag{5}$$

$$v_j \geq 0; \quad k_j \geq 0 \tag{6}$$

$$L_\lambda = k - \Sigma_j k_j \geq 0 \tag{7}$$

$$\lambda L_\lambda = 0 \tag{8}$$

where L_{vj}, L_{kj}, F_{vj}, F_{kj} and L_λ are vectors of the first partial derivatives. Let s=(k,p,w,T) be the vector of state variables and write the solution as: $v^*_j(s)$, $k^*_j(s)$, $\lambda^*(s)$ so as to emphasize the dependence of the solution on the available technology, on the constraints, and on prices. The optimal allocation of inputs v^*_j, k^*_j determines the

intensity of implementing the jth technique. This also include the decision not to use the technique, as can be seen by rearranging (3)-(5):

$$0 = \Sigma_j(p_j F_{v_j} - w)v_j + \Sigma(p_j F_{k_j} - \lambda)k_j$$

When (3) or (4) are negative, then v^*_j or k^*_j, respectively, are equal to zero. To the extent that the implementation of a technique requires positive inputs, then when the optimal levels of these inputs are zero, the technique is not implemented. The implemented technology (IT) is defined by:

$$IT(s) = \{F_j(v_j, k_j) \mid F_j(v^*_j, k^*_j) \neq 0, F_j \_ T\}$$

The optimal output of technique j is: $y^*_j = F_j(v^*_j, k^*_j)$.

Definition: (intensity) The input-output ratio associated with technique j is a measure of input intensity of technique j.

Proposition 1: The implemented technology is determined simultaneously with level of intensity at which the inputs are used.

Given the usual regularity conditions for F_j, a restricted profit function can be derived:

$$(9) \qquad \pi(s) = \Sigma p_j F_j(v, k) - \Sigma w_j v.$$

The various theorems dealing with the duality between the profit and production function hold true conditional on s. Specifically, the frontier of IT(s) is dual to $\pi(s)$ and vice versa. The exploitation of this property in empirical analysis is restricted by the fact that s varies over the sample. Thus, strictly speaking, each point in the sample comes from a different profit function, which in turn describes a different implemented technology. Using Hotelling's lemma, one can obtain the factor demands aggregated over techniques, $\Sigma v = -\partial \pi(s)/\partial w$. Similarly, the supply of output from technique j is given by $y = \partial \pi(s)/\partial p_j$. However, if there is more than one technique for producing a given crop, then $\partial \pi(s)/\partial p_i = \Sigma_j y_i = y$, where y_i is the output produced by the jth technique used to produce the ith crop and y is the total (optimal) output of crop i.

Efficiency Frontier Production Functions

The dependence of the implemented technology on the state variables (k,p,w,T), has important repercussions for empirical analysis. The concept of physical efficiency is based on a comparison of a particular production plan with the efficiency frontier. Thus, in terms of Figure 1, point A is efficient when the available technology consists of only the traditional technique, but once the modern variety is introduced, point A becomes inefficient because it is dominated by point N which requires the same inputs but represents a higher output. What is changing here is the frontier. Under the old technology the frontier is given by f_1. With the introduction of f_2, the frontier is identical with f_1 for $K - \bar{K}_1$, identical with f_2 for $K - \bar{K}_2$, and given by the tangent line A, M for $\bar{K}_1 - K - \bar{K}_2$. Thus, the efficiency of point A depends on whether or not f_2 is available or, in other words, a correct evaluation of efficiency requires the identification of the available technology and the resource constraint.

Efficiency-frontier production functions are fitted to connect the points with largest output for given inputs, but as we have just seen, efficient points under the initial technology may be ruled as inefficient in a sample of mixed technologies. The problem of identifying the technology and the constraints is crucial for the efficiency frontier approach, but it is also important to all empirical analyses and will be discussed later.

A related concept which has been discussed in relation to agricultural production is that of the metaproduction function introduced by Hayami and Ruttan. In their words,

"The metaproduction function can be regarded as the envelope of commonly conceived neoclassical production functions. In the *short run*, in which substitution among inputs is circumscribed by the rigidity of existing capital and equipment, production relationships can best be described with an activity with fixed factor-factor and factor-product ratios. In the *long run*, in which the constraints exercised by existing capital disappear and are replaced by the fund of available knowledge, including all feasible factor-factor and factor-product combinations, production relationships can be adequately described by the neoclassical production function. In the *secular* period of production, in which the constraints given by the available fund of technical knowledge are further relaxed to admit all potentially discoverable possibilities, production relationships can be described by a metaproduction function which describes all conceivable technical alternatives that might be discovered." (Hayami and Ruttan, 1985, pp. 134-5).

This definition has two components, first it distinguishes between the short and long run production functions. Issues related to the dependence of the frontier on fixed inputs had been discussed in the literature on interfirm and intrafirm production functions and related issues, Reder (1943), Bronfenbrenner (1944), Smith (1945), and more recently formulated for empirical analysis in the form of the Putty-Clay production functions (Fuss 1977). Second, there is the secular component which describes all

conceivable technical knowledge. The implication of this component for empirical analysis is somewhat different from the first one. In principle, we can infer empirically only from techniques which are implemented and not from techniques which have not yet been developed. It appears that Hayami and Ruttan's interest in the last component is related to decisions with respect to new innovations:

"Thus defined, the metaproduction may appear to be the same as the innovation possibility curve advanced in Figure 4-2 in the previous chapter. In fact, we consider the metaproduction function an operational definition of the innovation possibility curve-operational in the sense that it can be measured empirically from observable production data. The metaproduction surface drawn in Figure 5-6 is the envelope of the most efficient production points available in the world. It is our basic assumption that such an envelope approximates the innovation possibility curve for the LDCs." (Op. cit., p. 135).

It is not sufficiently clear from this description what is known and what is to be innovated. One possibility of eliminating this ambiguity is to assume that techniques known in the advanced countries can be adopted in the LDCs with some cost of research. It is in this sense that the metaproduction function can be thought of as a representation of what is known and of innovation surface at the same time. This interpretation is also consistent with their notion of induced innovation.

"Our more general hypothesis is that the relatively low production efficiency of LDC agriculture is explained mainly by the limited capacity of LDC agriculture research systems to develop a new technology in response to changes in relative factor prices and of farmers' capacity to adopt it.", (Ibid).

Nonetheless, it is clear that the "most efficient production point" is a vague concept which requires more structure to be made operational. This is particularly the case when it is stated "that it can be measured empirically from observable production data." This concept is not operational without a supporting structure.

The situation becomes more complex when prices are introduced. To illustrate the effect of product prices, consider the two production functions in Figure 1 as representing two different products the outputs of which are measured in money terms, say dollars. The change in a product price causes a movement of the curve representing the production function of this product and the optimal points change accordingly. This of course changes the envelope, or the efficiency frontier. To illustrate the effect of factor prices, we consider the curves in Figure 1 as representing the value added, revenue net of the cost of variable inputs, produced by each technique. The prices of the quasi-fixed inputs, or shadow prices, are endogenous and therefore do not affect the decision on the optimal production. A change in input prices changes the value added according to the intensity of the technique in the use of that input and the curve, and with it the frontier, will change accordingly. For instance, a change in fertilizer price will affect the value added of the modern variety which is intensive in fertilizer more than that of the traditional variety. Thus, any application of the concept of frontiers should recognize the role of prices.

In order to take account of the complexity of the economic environment, we return to our framework and show its empirical implications. The essence is the dependence of the composition of techniques on the state variables. In general, data classified by techniques are not readily available and it is therefore impossible to estimate the production functions associated with individual techniques. Most empirical analyses use data which are aggregates over techniques. We therefore turn now to examine the properties of the aggregate production function.

Aggregation of Techniques

The aggregate production function, as commonly used, is perceived as an aggregation of outputs produced by a *given* set of micro production functions that are actually used. In the present framework such an aggregate is not uniquely defined because the set of functions which are actually implemented and over which the aggregation is performed is endogenous. The dependence of the implemented technology on the state variables implies that changing either the constraints or the available technology, while holding prices constant, will cause a change in the product mix. The same set of prices leads to a different choice of techniques when the available technology or the constraints change. For the same reason, prices are insufficient statistics for identifying the implemented technology. The results of time series analysis of production that do not take this endogenous aggregation into account will depend on the combination of prices, constraints and available technology that exist at each point in time.

To explore the implication of this framework for the estimation of a production function using aggregate data, we write the aggregate production function:

$$\Re_{\varphi} \pi_{\varphi} \psi_{\varphi}^{*}(\sigma) \quad \Phi(\xi^{*},\sigma) \quad \varphi(\sigma) \tag{9}$$

where x is the vector of inputs and $x^{*}=x(s)$ is its optimum level. The production function in (9) is defined conditional on s and changes in s imply changes in x^{*} as well as in $F(x^{*},s)$. In this framework it is meaningless to think of changes in x, except by error, which are not instigated by changes in s and therefore it is impossible to trace a stable production function. We have thus argued:

Proposition 2: In general, the aggregate production function is not identifiable.

The empirical aggregate production function can be thought of as an approximation to (9) in a specific way. For (9) to be a production function in the usual sense, x should be disconnected from s. Such a separation requires a discrepancy between x and x* which will allow the observed output to be written as:

$$\Re_{\varphi} \pi_{\varphi} \psi_{\varphi} \cong \Phi(\xi,\sigma) \tag{10}$$

Strictly speaking, F(x, s) is not necessarily a function since x can be allocated to the various techniques in an arbitrary way. Different allocations will result in

different outputs. 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. Then, a discrepancy x-x* produces information on a given implemented technology.

The problem is how to make this concept operational. The simple solution is to approximate this function with a set of functions, a procedure used by Fuss, McFadden and Mundlak (for details, see Mundlak, 1988). Using a weak assumption, F(x, s) can be approximated by a set of functions:

$$\Phi(\xi,\sigma) \cong \Re \alpha_\iota \eta_\iota = \gamma(\xi,\sigma) \tag{11}$$

where g(x,s) is the approximating function, the a_i are parameters, the h_i are known functions. F(x,s) is expanded around x* and terms higher than second degree are omitted. Ignoring technical details, the result is:

$$\ln y \quad = \Gamma(.) + B(.)\ln x \tag{12}$$

$$B(\cdot) \quad = S - (1/2)\pi_x \ln x \tag{13}$$

$$S \quad = \pi_{01} + \pi_{11}s + \pi_{x1}\ln x + u_x \tag{14}$$

$$\Gamma(.) \quad = \pi_{00} + \pi_{10}s + s\pi_{20}s + u_0 \tag{15}$$

where, y is the value added per worker, S is the vector of factor shares, B(.) and Γ(.) are the slope and intercept of the function respectively, s is the vector of state variables, π's are the coefficients to be estimated and u_x,u_0 are the stochastic terms. The use of the factor share in this approximation is, strictly speaking, appropriate for the competitive industries where the zero-profit condition is maintained through entry and exit. The system can be adjusted to account for situations where this condition is not met.

Variations in the state variables affect Γ(.) and B(.) directly as well as indirectly, through their effect on inputs. This, to be sure, is a description of reality under the present framework. If this reality is estimated with a constant coefficient function, the outcome will be unexplained variations in productivity, measured by any conventional method. Those variations are considered to be random to the researcher who takes no account of the state variables which determine the implemented technology.

Equations (13)-(15) indicate that the coefficients can vary either due to variations in the state variables, or in inputs. The literature on production functions deals with the latter. For instance, the translog production function (Christensen, Jorgenson and Lau, 1971) can be considered as a special case obtained by setting s=0. As such, the use of this function is based on the implicit assumption that the observations are generated by a well defined production function.   When this assumption is violated in that the observations are generated by more than one function, the empirical function may violate the concavity property of a production function. This is suggested as the explanation for the frequent failure in empirical

analysis to obtain concavity at some sample points. Such a failure is rather serious when the first order conditions are used in the estimation procedure, as indeed is the case in such studies. One direction of research aimed to correct the situation has been to introduce higher degree polynomials to approximate the production function, (Gallant). It is true that sufficiently high degree polynomials will approximate any function to a desired degree of accuracy. The question raised here is what is the meaning of the estimated function. The function that this method intends to estimate does not exist. In principle, there may be as many functions as there are sample points. Thus the key to estimation is to take this fact into account.

To emphasize some of the salient properties of this formulation, we write the production elasticity:

$$\partial \ln y / \partial \ln x = B(.) + (\partial B(.) / \partial \ln x) \ln x$$

$$= B(.) + (\pi_{x1} - \pi_x / 2) \ln x \tag{16}$$

Substituting (13) in (16) we note that in this formulation, the discrepancy between the factor share and the production elasticity depends on the difference $\pi_{x1} - \pi_x$. Given the model, when this difference is zero, the production elasticity is equal to the factor share. A discrepancy between the two is an indication of a distortion in the factor market. In the present formulation, such a distortion is attached to the inputs and its relevance can be tested empirically by restricting the values of the coefficients to be the same. Other forms of a discrepancy between the factor shares and the production elasticities can be introduced. This, however, is not a mechanical question, it is a substantive one but further elaboration of this point is beyond the scope of this paper.

Turning to the factor share, it is noted that it is allowed to be a function of the input, lnx, as is the case with the translog function. However, the major difference from the translog model is that in our model, the factor share depends also on the state variables.[5] To emphasize, in the translog model the variations in the factor shares are caused only by variations in the input combinations, whereas in our case the factor shares can vary as a result of variations in the state variables which lead to changes in the composition of techniques. This difference has very important consequences for the empirical estimates.

STATE VARIABLES

The empirical application of this framework requires a selection of the state variables. As a way of organizing the thinking about the state variables, they are classified into four groups: constraints, incentives, available technology and environment. We turn to a brief discussion of the variables in each of these groups.

Constraints to the implementation of the available technology are represented by the vector k in (2). The main constraints are the level and composition of the

capital stock. The overall level of the capital stock matters when the new techniques are more capital intensive than the existing ones. Other things equal, an increase in the capital-labour ratio is expected to result in more capital-intensive techniques. That is, the pace of implementation of new techniques is affected by **net** investment. The **composition** of the capital stock matters when the new techniques require a different mixture of capital items than the existing ones. An example is the heterogeneity of capital goods suggested by Solow's embodiment hypothesis. In a once and for all change in technology, the composition of the current capital stock is important only in the short-run, and with time it converges to the desired one through **gross** investment. However, in a situation of continuing changes, the composition may have to change accordingly and as such may remain a continuous constraint. The foregoing considerations pertain to all forms of capital, including human capital where the continuous change in the composition of skills is rather important. A good example is the demand for new skills generated by the development of the computer industry.

The discussion suggests that investment is expected to affect the **rate of change,** rather than the **level**, of output. However, the role of investment in an empirical analysis is somewhat more complex in that it represents other effects as well. The cost-of-adjustment argument (Lucas, 1967; Gould, 1968) implies a negative effect of investment on productivity. Another consideration is related to the information about the market conditions embedded in investment. Loosely speaking, the better the market prospects, the higher the investment. Thus, investment can be viewed as a measure, subject to error, of incentives. As the measure is imperfect, it does not replace the more direct measures discussed below. To conclude, on a net balance, the theory does not predict the sign of the effect of investment on productivity. It is an empirical question.

Incentives determine the relative profitability, as well as the risk, of the various techniques and thereby the degree of their implementation. In an empirical analysis of firm (farm) data, or more generally price-taker units, the natural variables to measure incentives, under constant technology, are prices. When prices are the only state variables, and the quadratic input terms are omitted from the production function, the empirical equations (12)-(15) are similar to those derived from a production model based on the profit function. However, there is a fundamental difference in interpretation. The analysis based on duality assumes that there is a given production function to be estimated, or identified, using prices. As we have seen above, when producers can chose and change the techniques of production in response to the economic environment, the profit function depends on all the state variables that affect this choice, including prices. As such different prices may yield different combinations of functions depending on the available technology and other constraints.

This is not a minor esoteric point and it has important empirical implications. It is often found in empirical analyses based on duality that the second order derivatives of the profit function have the wrong sign and this implies convex, rather than concave, production functions. This result points at a contradiction because the profit function is derived under the assumption of a concave production function. Therefore such a result should actually invalidate that analysis. On the other hand, this result is admissible under our model. This possibility is illustrated in Figure 3 which shows two

production functions, f_1 and f_2 and the clusters of observations on each function, C_1 and C_2 respectively. The observations on f_1, obtained prior to the introduction of f_2, also represent lower real product prices than the observations in C_2. The higher product prices might have been conducive to the introduction of the new technique f_2 through the encouragement of the investment necessary for the introduction of the new technique. However this causality is not a necessary condition for the distortion of the estimated production function. It is the association rather than the causality that matters here. The causality, however, is likely to increases the probability of this to happen.

With small samples, it is not feasible to include all the pertinent prices in the empirical equation and the less pertinent prices are omitted. Alternatively it is possible to use a summary measure such as the rate of return, measured roughly as the ratio of non-wage income to the value of the capital stock. This rate has a permanent and a transitory component. The permanent component is more relevant to the choice of techniques which require investment, whereas the transitory component, to the extent that it can be forecasted by the producers, affects largely the current variable inputs.

When dealing with an important sector of the economy, the prices should be replaced with product demand and factors' supply. To do this would require a detailed structure which is often convenient to avoid. A short cut would be to use the rate of return, as mentioned above, and a measure of the external shocks. The latter measure is important for open economies which are affected by external shocks, such as in the prices of the main traded products or in the external interest rates. An improvement in the foreign terms of trade causes an expansion in the aggregate demand which in turn affects sectoral demand. Indirectly, a similar effect, in the case of a borrowing country, is generated by a decline in the international rate of interest in that it reduces the burden of servicing the debt.

The response of sectoral demand to external shocks depends on the sector's degree of tradability and on its income, or absorption, elasticity. An expansion in sectoral demand causes an increase in **net** import of tradables, whereas the augmented demand for non-tradable goods can be met only by an increase in domestic production and therefore in their prices. The degree of the price change is inversely related to the degree of tradability of the particular sector. The degree of tradability of agriculture is relatively high and it is therefore sensitive to variations in the terms of trade. This subject is discussed in Mundlak Cavallo and Domenech (1989, 1990) where also the effect of changes in the trade and macro environment on sectoral incentives is discussed.

The foregoing discussion dealt only with the level of the incentives and not with their variability. The larger is the variability of a technique, other things being equal, the less it is likely to be employed.

Available technology. Conceptually, this is the most difficult group to measure because technology is an abstract concept rather than an observable quantity. We can speak of consequences of major inventions such as high yielding crop varieties, electricity, radio, transistors and so on. However, all this talk does not give us a compact or a unique representation of the technology. Empirical analysis

usually deals with changes in technology and such changes are often represented by time trend. Time trend is an associative variable which summarizes quantitatively changes over time but contains no other information. Also, it cannot be used to represent differences in technology in the cross section.

Another medium for representing technology is human capital variables such as schooling or expenditures on research and development. The term human capital refers to knowledge embodied in people, as well as disembodied knowledge generated by people, (Lucas 1988, Romer 1990). Conceptually, we can measure directly the inputs of variables such as schooling which reflect the component embodied in people. What we can not measure directly is the disembodied component which includes the accumulated knowledge found in libraries and which, most significantly, determines the path of new research. This knowledge component is internationally available and countries have access to it, in one form or another, perhaps with some delay, even without investing in its development. As we do not have a direct measure of the disembodied human capital, its contribution to production in any particular setting has to be derived indirectly from the production function after allowing for the contribution of the various inputs which can be measured, including measures of education. This is similar in spirit, but not in details, to the Solow residual and as such it is subject to similar limitations. We return to this below.

As an empirical proposition it can be said that investing in research and development increases knowledge and improves the available technology. It is beyond the scope or the ability of economics to say fundamentally much about the productivity of this process except to assume that the monotone relationship between investment in the production of knowledge and output of knowledge will continue and will improve the available technology. Whether the production function of knowledge is concave or convex we do not know, although this type of information would be very valuable. The reason is that the relationship between investment in research and its output lacks the property of regularity and therefore it is not repetitious. The relationship between inputs used in the growth of a crop in a given physical settings, say corn in the Corn Belt of the United States are regular and will be revealed in repeated experiments. This is not the case between time spent in basic research and its output. We do not discover more laws of thermodynamics by doubling the time spent on research in this area. Knowledge of the laws of thermodynamics affected subsequent research, and not much could be said on theoretical ground on the future outcome of such research. Apparently, as a practical matter, we manage without it, by projecting past relationships into the future. Sometimes empirical rules are sufficient and useful provided we keep our expectations in line.

New knowledge is translated to new techniques which appear, on the whole, to be more capital intensive. This again is an empirical observation which, however, can also be argued on the basis of general principles. The increase in capital intensity makes it possible to preserve the rate of return on capital as the capital labour-ratio increases.

A similar argument can be applied to the embodied human capital, but not without some complications. New techniques generate demand for new skills. For instance, the development of the computer created new subjects such as programming. Those who acquired the skill early realized good returns on their investment and this in turn attracted more workers and talent to this field. At the same time, new techniques may decrease the demand for other skills. Skills, like machines, may become obsolete, but unlike machines, people with obsolete skills are retained. The upshot of this is that the demand for skills, as well as for all inputs, is determined jointly with the implemented technology, and as such it depends on the same state variables.

With this background we turn to present a way of incorporating a measure of technology into the analysis. The essence of the foregoing discussion is that the technology at the aggregate level is an unobservable quantity and the evidence on it is strictly circumstantial, in that we observe that output increases faster than inputs. We do not have the convenience that we have at the micro level, such as in our example of the green revolution, where we can distinguish between the modern and traditional varieties. Therefore, the key is to use indirect methods of measurement which follow our discussion of technical change. This suggests introducing an indirect measure of technology into the empirical function. Mundlak and Hellinghausen (1982), relate technology to an aggregate measure of comprehensive, physical and human, capital. Following and extending this approach, the aggregate production function is written as: $y_t = F(k_t, h_t, z_t, u_t)$, where, y is the average labour productivity, k is the vector of ratios of physical capital goods to labour, h is a similar vector for human capital, z is vector of other state variables and u is a random disturbance. The variables are expressed per worker, indicating that constant returns to scale is imposed. The assumption is that increasing returns to scale that some studies report are due to changes in techniques of production that take place with changes in the available technology or removal of constraints. This can be illustrated by a slight modification of Figure 3 by drawing clusters of observations $\{C_j\}$ of the different techniques of production to represent the same prices. The observations then trace a convex locus which appears as a convex production function. The horizontal axis will be the aggregate input, which grows with time.

For the purpose of the discussion we interpret h as the unobserved component of capital. Given k, z and u, y is monotone increasing in h so that we can write h = H(k,y,z,u), $\frac{\partial \eta}{\partial \psi} \succ 0.$ As knowledge does not fluctuate much over short time periods, we can use past values to substitute for its current value. The past values of h can be extracted from the past values of output, after allowing for the effects of the other variables in the production function. Let x = (k,y,z,u) be the argument FH, and x_τ be some function of lagged values of x to be defined below, then $h_\tau = H(x_\tau)$. The idea is to substitute h_τ for h_t in the production function to get $y_t = F(k_t, h_\tau, z_t, u_t)$.

The value of h_τ depends on u_τ, z_τ and k_τ and as such it is subject to error which has to be eliminated. The fluctuations in u are by far larger than those in the capital

stock and they can be reduced by taking a moving average for y and assume away the effect of this term. The effect of k_τ and z_τ can be eliminated by introducing these variables explicitly into the analysis. In this, we build on the fact that a regression coefficient represents the effect of a variable, **net** of the (linear) effects of the other explanatory variables in the equation. We can then write, in a generic form, an empirical version that replaces equation (10):

$$y_t = F(y_\tau, k_\tau, z_\tau, k_t, z_t, u_t) \tag{15}$$

The high correlation between k_τ and k_t, means that the former will have little to contribute and therefore it is likely to be omitted in empirical analysis. A similar argument follows for z_τ but here the correlation is not as strong. Particularly, the incentives are subject to secular variations. In times of low profitability output declines, but this is not a reflection of a decline of h. To take this into account, we use the historical peak of y defined as:

$$y_\tau = \max (y_{t-1}), \ i<t,$$

and label y as peak. The peak coefficient represents the net effects of the various forms of human capital, institutions and organization which are referred to as technology and can not be measured directly. Indeed, the captured technology effect is lagged, rather than current, but this is inevitable in this approach and it constitutes a small price to pay. This is particularly so in the case of cross-country analysis.

The function that is actually estimated, in its general form is:

$$y_t = F(y_\tau, k_t, z_t, u_t) \tag{16}$$

The effect of z_τ on y_τ is asymmetric in that it can only cause the peak to increase. Therefore, a decline in y_t is attributed to state variables other than the peak and these are random in nature with possible cyclical components. In order to reduce the effects of such variations on the peak, in the empirical analysis we use per capita output instead of average labour productivity.

To sum up, we use an indirect measure of productivity and in this sense the measure is similar to Solow's residual. The difference is in that first, the effect of this measure on productivity is estimated jointly with the production function and second, the measure affects not only the intercept but also the slope of the function and as such it allows for a shift in factor intensity.

Environment - Physical. Agricultural productivity is affected by the physical environment. Variables such as average rainfall, temperatures, length of growing seasons, type of soils are of permanent nature and as such affect the decisions with respect to the crops to be grown and the methods of production and should be included in analyses based on cross-section data. The effect of the permanent component of the environment can be evaluated by allowing for "unit effect". For instance, in cross-country analysis, we can introduce a country effect (country dummies) to allow for the permanent component of the environment. The problem is

that such a country effect represents other variables as well. Thus, as a general principle, it is desirable to include the more important variables explicitly. In a cross-country analysis of agricultural productivity, Mundlak and Hellinghaussen used measures of the potential production of a region based on agrotechnical evaluation. Deviations from the average values of these variables affect the transitory variations of output and inputs and should be included in time-series analysis.

Environment - institutional. Less tangible, but sometimes more important, is the political and institutional environment. With the collapse of the economies of Eastern Europe it does not require much imagination today to realize the importance of this element. An interesting case which illustrates the effect that a change in institution can have on agricultural output is the shift to the household responsibility system (HRS) in China beginning in 1979. To place this development in a historical perspective we quote some results from Wen (1989). In the precommune period of 1952-57, referred to as the "golden age of Chinese agriculture", output (agricultural gross value added) increased at an average annual rate of 4.5 per cent. This rate declined drastically to 2.34 per cent during the commune period of 1958-78. The introduction of the HRS in 1979 brought about a dramatic change in output and during 1979-84 the rate jumped to 8.3 per cent. The transformation to the HRS was completed by 1984 and the rate of growth in the period 1985-88 declined to 4.0 per cent.[6] Thus, the output in 1988 was higher by 89 per cent than that of 1978. It is interesting to note that the cultivated area in this last period was somewhat smaller than during the commune period. The question is whether all the output growth is the result of the HRS.

Lin (1986) emphasized the dramatic impact of the HRS on the change in farmers' effort that came about when they stopped working for the commune. Capturing this effect directly in terms of an empirical production function requires adjusting the measure of labour input for effort or quality, reflecting the attitude toward the regime, on which there are no direct observations. What can be done in empirical analysis is to include a variable that measures the institutional change. This variable can also appear as a product with labour, or other variables for that matter, to show the interaction, or partial effect, with the productivity of labour. We have no results using this approach, but there are pertinent results from the estimation of the supply function by Wen which serve the purpose.

The HRS was not the only change that took place during the period beginning in 1979. The institutional change was accompanied by a considerable increase in agricultural prices which also contributed to the output growth. To obtain the role of prices Wen estimates an aggregate supply function, where output (y) is regressed on the price received by farmers (P_A), rural consumer price index as a proxy of the overall price index (P_c), the retail price of the industrial products sold in rural areas (P_I), the proportion of farms transformed to the HRS system (R) and a variable representing the effect of weather on the size of the harvested area. The equation is estimated, using data for 1953-87, with prices and output as first differences in logarithms except for R which appears as defined. The fit is very good (R^2=.973), the coefficients of P_A and P_c are 1.42 and -1.39 respectively and significantly different form zero. The coefficient of P_I is highly non significant. The coefficient of R is .31. It thus appears

that the relevant price ratio for output changes is P_A/P_c, to be labelled here as p.

The average annual rate of change of p, in per cent, for the sub periods mentioned above are: 2.1 for 1952-57, 0.86 for 1957-78, 4.2 for 1978-84 and 1.64 for 1988-84.[7] It is interesting that throughout the sample period China had to increase the real price of agriculture in order to obtain higher output from roughly constant amount of cultivated land. These data on prices indicate that the departure from the commune system was accompanied by a substantial change in the price level compared with the historical level. It is also interesting that once the increase of output in 1979-84 was realized, the subsequent price increase in the period 1984-88 was much more modest. This can be interpreted to reveal that there is a perception of a supply response on the part of the price fixers.

To calculate the contribution of prices and the HRS to the output growth during 1979-84, we use a coefficient of 1.4 for the price effect, and with an annual increase of 4.2 per cent in p, we get an output growth of 5.9 per cent which constitutes 71 per cent of the 8.3 per cent rate of growth of output in this period. The contribution of R to output is 3.1 per cent, or 37 per cent of the total. The contribution of the other variables is negative and accounts for the difference between the contribution of p and R and 100 per cent. The significant point here is that as much as the HRS was important, its contribution to the output growth amounts to only one half of that of prices. Wen reaches a somewhat different number, as he attributes to the HRS about 50 per cent of the increase in output over that period. He also discusses the calculations by Lin (1986) and McMillan *et al.* (1989) who obtain different results but this does not substantially affect our discussion. In any event, the institutional change due to the HRS was extremely important. The slowdown in the growth in the period beginning in 1985, when the transformation to the HRS was completed, is explained by Wen in terms of the land tenure system which discourages investment in land. Two other possible explanations may be added. First is the decline in p. Second, the change of regime in terms of the HRS represents a shift of the supply function and this has been largely played out. These are questions that require more data to answer.

Another example of land reform that was analyzed using the choice of technique framework appears in Coeymans and Mundlak (1991) in their study of the Chilean experience, where land reform was implemented during the 1960s and early 1970s. Two measures of land reform were used as state variables. It is interesting that the effect on productivity was initially positive but turned negative during the Allende government when the reform was pursued in an irresponsible way. In any case, the positive effect at the beginning of the period was not dramatic. Although there is a considerable difference between the Chilean and the Chinese cases, it should be pointed out that if one expects more effort from farmers who are self-employed, this was not observed in the Chilean case. At the same time the land reform in Chile was not accompanied with the improvement of the agricultural terms of trade as was the case in China. This comparison of two land reforms under very different situations suggests that a comparison of the effects of policy reforms, of which land reforms is a special case, need to take account of the accompanying changes in the economic environment. Concentrating on one variable may mislead the conclusions.

There are various studies which incorporate the effects of the political and

institutional environment on the economic performance using various methodologies and approaches including Adelman and Morris (1967), and McMillan, Rausser and Johnson (1991).

The Impact of the State Variables

There is no easy way to summarize the impact of the state variables empirically because the variables appear in two equations, one for the slope and one for the intercept. Also, and more importantly, the state variables may not be independent. A change in one state variable may affect the values of the others as well as the value of the capital-labour ratio. All this should be taken into account in evaluating the impact of the state variables on output. This is illustrated by evaluating the elasticity of average labour productivity with respect to a given state variable (say z_i):

$$\partial \ln y / \partial z_i = \sum_h \{\partial \Gamma / \partial z_h + \ln k [\partial \beta / \partial z_h] + \beta (\partial \ln k / \partial z_h)\} \partial z_h / \partial z_i \qquad (17)$$

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 (17) have a time index, which is suppressed here, indicating that they vary over the sample points. The innovation in the present formulation lies in the response of the implemented technology. This is evaluated here under the assumption that $\partial z_h / \partial z_i$ is equal to zero for $h \neq i$, yielding the elasticities:

$$E_i = \partial \Gamma(z) / \partial z_i + \ln k [\partial \beta(z) / \partial z_i]. \qquad (18)$$

The effect that is captured by (18) is part of the unexplained productivity residual in the standard productivity analysis under the assumption of constant technology.

The effect of z on factor bias is indicated by the sign of $\partial \beta(z) / \partial z_i$. It is capital (labour) saving when the this derivative is negative (positive).

IV. EMPIRICAL EVIDENCE

Variations of this system were estimated for Argentina by Cavallo and Mundlak (1982), Mundlak, Cavallo and Domenech (1989, 1990), for US agriculture by McMillan (1990) and for Punjab agriculture by McGuirk and Mundlak (1991). These studies differ in the state variables used, but on the whole, support the importance of the constraints, incentives, technology and environment on productivity.

DYNAMIC ASPECTS

The Framework

The foregoing analysis was conducted conditional on the quasi-fixed inputs which can be changed in the long run. The analysis is now extended to cover the choice of the quasi-fixed inputs. The underlying optimization problem calls for choosing the time path of inputs so as to maximize the present value of income. To simplify, we assume that the supply of v is perfectly elastic with prices w, and the supply price of capital is q. At the industry level q is assumed to depend on the level of investment, q=q(I,t). All the variables are functions of time. The net cash flow of a competitive firm at time t is:

(19) $R(t) = \Sigma_j p_j(t) F_j[v_j(t), k_j(t), e(t)] - \Sigma_j w(t) v_j(t)$

$$-q(t)[\dot{k}(t) + \delta k(t) + c(\dot{k})]$$

such that $F_j() \varepsilon T$ and where $\dot{k} = dk/dt$, $c(\dot{k})$ is the internal cost of adjustment and δ is the depreciation rate. Simplifying the problem of uncertainty that arises with respect to future values of the state variables, certainty equivalence is invoked. Thus, the problem calls for selecting a time path of inputs so as to maximize:

(20) $$\underset{(K(\tau), \varpi(\tau), \kappa(\tau))}{\text{Maximize}} \ E_0 \left[\int_0^\infty \varepsilon^{-\rho\tau} P(\tau) \delta\tau \right]$$

subject to $k(t) = \Sigma_j k_j(t)$, the initial condition $k(0) = k_0$, the definition of investment, $I = \dot{k} + \delta k$, the transversality condition $\lim_{\tau \to \infty} [\varepsilon^{-\rho\tau} P(\tau)] = 0,$ and where $E_0(X)$ is the expected value of X conditional on the information set at t=0.

The first order conditions are:

(21)
$$\frac{\partial P(\tau)}{\partial \varpi} = 0, \text{ιμπλψινγ } \frac{\partial \Phi}{\partial \varpi} = \omega/\pi$$

and the Euler equation

(22)
$$\frac{\partial P(\tau)}{\partial \kappa} - \frac{\delta}{\delta\tau}[\partial P(\tau)/\partial \dot{\kappa}(\tau)] = 0.$$

The condition in (21) is extremely important for empirical analysis and it is therefore stated as a proposition.

Proposition 3: Along the optimal path, the use of the inputs which do not affect revenue or cost in subsequent periods is determined by equating their marginal productivity to their real prices in each period.

This leads to a recursive system. First, we determine for each period the optimal levels of the variable inputs as functions of the state variables of that period, including k(t). The outcome is the restricted or short-run solution as obtained above, in a single period framework and summarized by the profit function in (9). For the present discussion this function can be condensed on k(t), π[k(t), s(t)]. Second, we determine k(t) so as to maximize

(23) $\quad$ L(k(t), $\dot{\kappa}$) = $\displaystyle\int_0^{\text{ινφινιτψ}}$ e^{-rt}\{π[k(t), s(t)] - q(t)[$\dot{\kappa}$ (t) + δk(t) + c($\dot{\kappa}$)]\}dt

subject to the conditions in (20).

The solution of this problem provides the optimal time path of k(t):

(24) $\qquad$ k*(q,q,δ,r,c,w,p,T),

Where q is the rate of change of q. Heuristically, at the optimal level, the value marginal productivity of k is equal to the user cost of capital, allowing for the appreciation of the price of the capital good and the cost of adjustment. All the variables in (24) are functions of time. Obviously, the decision on the time path of k requires knowledge of the time path of all the state variables and within this framework they are replaced by expectations. An extension would add measures of uncertainty with respect to the future time path of the exogenous variables, including the available technology.

The values of the quasi-fixed inputs which appeared as state variables in the short-run optimization can now be replaced by the values obtained by the intertemporal optimization, as summarized by (24) in order to obtain the time path of

output. However, (24) was obtained for constant factor prices and as such it is not applicable to the sector as a whole. Our next step is to bring in the factor supply. We discuss here the two main factors, labour and capital.

Labour

The labour supply to agriculture can be considered within the framework of choice of occupation and as such it requires an evaluation of lifetime income. Making a lifetime choice, the individual compares at time t the expected lifetime income in agriculture, $v_a(t)$, and non agriculture, $v_n(t)$.[8] Changing occupation has a cost, to be referred to as the cost of migration, $c(t)$. The individual will decide to migrate at t when $v_n(t)-v_a(t)>c(t)$. Under this formulation it is expected that the rate of off-farm migration will increase monotonically with the wage differential between agriculture and non agriculture. The determinants of income differ for landless labour and land owners, but the criterion is the same. Individuals differ in their expected earnings and costs of migration. Hence, the larger is the intersectoral wage differential, the more individuals will find that differences in earnings justify the change. This reasoning is particularly important when applied to age as the source of differences among individuals. The older the person, the smaller the present value of future income on the one hand and the higher the cost of migration. Consequently, one expects younger people to migrate. By definition, young people constitute only a fraction of the labour force and therefore the response of the labour supply is not sufficiently strong to close the wage differential in one period.

Using this framework, the following equation was developed for the empirical analysis, (Mundlak, 1979):

(25) $\ln(m+c_0) = \beta_0 + \beta_1 \ln(\Delta - c_1) + \beta_2 \ln l + \beta_3 \ln(1+n) + \beta_4 \ln z + u$

where m is the proportion of the agriculture labour force which migrated in a given period, Δ is the ratio of labour income in non agriculture to that in agriculture, l is the ratio of the labour force in non agriculture to that in agriculture, n is the natural rate of population growth and z represents exogenous variables, such as education, c_0, c_1 and the βs are coefficients to be estimated from the data.

We review some empirical work using this model. The equation was initially estimated from a sample of 70 countries for the decade 1960-1970 and for 17 OECD countries for 1950 -70. The coefficients of $(\Delta-c)$ and l were significant and positive as expected. Kislev and Segal (1987) obtained similar results for the decade of the 1970s. The formulation was also applied with some modifications, to time series data; Mundlak and Strauss (1979) report results for Japan, Cavallo and Mundlak (1982) report results for Argentina and indicate that the elasticity of migration with respect to Δ was quite high, varying between 3.5 and 5.4, depending on the equation. The equation was extended to allow migration to depend on unemployment in non agriculture, and the result indicates that unemployment discourages migration. A more elaborate treatment of unemployment using this framework is introduced by Coeymans and Mundlak (1992) in their work on sectoral growth in Chile.

All these studies indicate that the rate of migration depends on the intersectoral differences in income. The importance of this result is that it endogenizes the speed of intersectoral allocation of labour, in that it allows it to depend on the state of the economy. As such, the time path of labour supply to agriculture is not exogenously given, but it is rather determined by economic forces. The dynamics of labour supply to agriculture, L_a, and non agriculture, L_n, is then described by the following process:

(26) $\qquad L_a(t) = L_a(t-1)(1 + n - m)$

$$\Lambda_v(\tau) = \Lambda_v(\tau-1)(1 + v + \mu \frac{\Lambda_\alpha(\tau-1)}{\Lambda_v(\tau-1)})$$

where m is determined by (25). The response of the agricultural labour to a change in

the differential income is given by:

$$\partial L_a/\partial\Delta = L_a(t-1)\partial m/\partial\Delta$$

The response of the labour supply to a change in the agricultural price depends on the sensitivity of Δ to a change in such price, $\partial\Delta/\partial p$, where p is the price of agriculture in terms of the price of non agriculture, or simply the agricultural terms of trade. The evaluation of $\partial\Delta/\partial p$ taking into account the economy wide changes requires a more elaborate specification which can be found in the forementioned studies.

Capital

The intersectoral allocation of capital is carried out primarily through the allocation of gross investment. The demand for capital at the firm level is summarized in (24) above. This expression includes the cost of adjustment, an idea developed to account for the fact that firms close the gap between the existing and the optimal stocks of capital gradually rather than in one step. It postulates that investment requires diversion of resources away from production so that there is a trade-off between output of the final product and the build-up of the capital stock of the firm.

When dealing with the industry as a whole there is another important force that dictates a gradual adjustment of the capital stock, the availability of resources as reflected in the supply of capital goods. This represents limitations which are external to the firm and are referred to as the external cost of adjustment. External cost of adjustment was recognized in the original work of Eisner and Strotz (1963).[9] It is postulated that the main force that drives the intersectoral allocation of investment is related to the competition of a particular sector with other sectors for existing resources. The limitation of resources reflect saving behaviour, at the household and public sectors, as well as international mobility of capital. These are not very responsive to sectoral investment decisions and can therefore be considered to be exogenous in the present analysis. As a consequence, similarly to the analysis of intersectoral allocation of labour, the allocation of investment will depend on the

intersectoral differential rates of returns.

The optimization problem has been outlined above, leading to the optimal time path of capital, summarized in equation (24). When at time t, k*(t) is different from the available capital, k(t), a demand for investment is generated at the firm level:

$$I_\iota^\delta(\theta,\tau) = \kappa_\iota^*(\theta,\tau) - \kappa_\iota(\tau).$$

Summing over all firms in the industry, we obtain the industry

demand $\quad I^\delta(\theta,\tau) = \sum_\iota I_\iota^\delta(\theta,\tau)$. By this formulation, $\partial I^d(q,t)/\partial q = \partial k^*/\partial q < 0$. Let the supply of capital goods be $q^s(I,t)$, $dq^s/dI > 0$, write the inverse function, $I^s = I(q,t)$, then q is determined by equating

(27) $I^d(q,t) = I^s(q,t).$

This analysis shifts the gradual response of investment to scarcity of capital. The scarcity simply reflects the fact that at any time, resources are finite and if more of them are demanded in one industry they have to be bid away from another industry, a process which requires adjustment in price to equate supply with demand. The price, so determined, allocates the investment goods among all producers. The essence of this analysis is that there is a difference between the price of the investment good perceived by the firm to be constant and the supply price to the industry which varies with the level of investment.

The supply of the investment good to agriculture $I_a^s(q,t)$ is equal to the overall investment less the demand by non-agriculture. The latter depends on the profitability in non-agriculture. This analysis provides the framework for the empirical analysis and leads to an equation similar to (25) used for labour migration. We will write it in a general form:

(28) $\theta = \theta(\Delta_r, \rho, z)$

Where θ is the share of agriculture in total investment, Δ_r is the ratio of the rate of return to capital in agriculture to that in non-agriculture, ρ is the share of agriculture in the total capital stock and z represents other variables which are not important for our current discussion. The equation was estimated by Cavallo and Mundlak (1982), Mundlak Cavallo and Domenech (1989) for Argentina and by Coeymans and Mundlak (1992) for Chile. The results show that the share of agriculture in total investment increases with the relative profitability of agriculture as measured by the Δ_r.

The time path of the agricultural capital stock is obtained from:

(29) $k_a(t) = k_a(t-1)(1-\delta) + \theta(t)I(t)$

where δ is the depreciation rate, $\theta(t)$ is determined empirically as a function of Δ_r, and other variables as well, and total investment, $I(t)$, is determined either as a behavioral equation with foreign saving being a residual or, alternatively, it is determined by total saving in the economy. Thus, the response of $k_a(t)$ to a change in the agricultural terms of trade is obtained from

$$\partial \kappa_\alpha(\tau)/\partial \pi = I(\tau) \frac{\partial \theta(\tau)}{\partial \pi} + \theta(\tau) \frac{\partial I(\tau)}{\partial \pi}.$$

Public Inputs

The discussion so far has considered all inputs to be private inputs. Next we turn to public inputs which are of great importance in agriculture. The decisions on public inputs are influenced by considerations which are completely different from those relevant to the decisions on private inputs. How important are the public inputs in determining output? This is an empirical question that can be best answered by analyzing a sample with a wide spread in the variables representing public inputs. Such a spread exists in cross-country data. Cross-country data were used to examine the importance of infrastructure in determining productivity by Antle (1983). A more comprehensive analysis of such data directed at supply appears in Binswanger, Mundlak, Yang and Bowers. The analysis indicates substantial positive effects on output of research, extension, irrigation, life expectancy, literacy, roads, and a measure of comprehensive capital.

The public inputs take on various forms, serving different purposes, some of which fall in the category of human capital while the others are physical capital. What comes out clearly is that physical capital is at least as important as human capital. That is, technical change is enhanced by physical capital. For instance, roads and communications integrate remote areas with the markets. Roads were found to be important in affecting crop supply during the transition period to the modern varieties in the Punjab, McGuirk and Mundlak (1991). The integrated areas change from a closed to open economy and this generates gains from trade. The integration with the market increases the proportion of aggregate output that is price responsive and as such, causes an increase in the price elasticity.[10] Thus, the integration affects both the level and the slope of the supply function.

It is interesting to note that the relationships between the level of public inputs and the agricultural terms of trade can be negative rather than positive, as in the case for the private inputs. Many developing countries discriminate substantially against agriculture using instruments such as export tax, protection to non-agriculture or overvalued exchange rate. All these depreciate the terms of trade of agriculture. At the same time these countries provide the infrastructure in terms of physical and human capital that facilitates the growth of output even though prices are suppressed. This policy may make political sense but it lacks any economic sense. Once investment is made, it would be more productive if it were fully utilized. However, deteriorating terms of trade reduce the level of activity and therefore reduce the advantage of the public investment.

V. POLICY AND PRODUCTIVITY

The foregoing discussion provides a framework for analyzing and examining productivity changes. The essence is that resource productivity is an economic concept in the sense that it is determined by economic variables and not merely by the technology. The available technology offers producers a choice over a wide range of products and methods of production in which they can employ their resources. The factor requirements of the various techniques are not the same. As the example of the green revolution indicated, modern varieties of wheat and rice are more responsive to fertilizers and irrigation than the traditional varieties. Therefore, the productivity of a unit of water depends on the crop to which it is applied and a choice is to be made how to allocate water, fertilizers and other inputs to the various varieties. The choice between the traditional and modern varieties had not existed prior to the introduction of the latter. This shows how the appearance of new techniques affected the resource allocation and productivity.

The problem of resource allocation across techniques would not have existed if the resources necessary for production were supplied in unlimited quantities at a constant price. As this is not the case, an increase in demand for such limited resources can not be fully met and therefore the product composition has to be determined so as to conform to the supply, and this forms the resource constraint. Again, in terms of the green revolution example, the limited supply of fertilizers and irrigation facilities prevented an immediate shift of all the sown area to the modern varieties of wheat and rice. At the same time, the appearance of new more productive varieties increased the productivity of, or the rate of returns to, the constraints. This change attracted resources to the production of fertilizers and irrigation facilities. As the quantity of these inputs increased, farmers could increase the area sown to the new varieties.

This process illustrates the more general situation with respect to capital goods which tend to move in the direction of higher rate of returns and facilitate an increase in the use of techniques which are more intensive in these inputs. This is true for the flow of resources within agriculture between techniques, products or farmers as well as between sectors and more generally between countries. Thus, for a country to draw more investment from abroad, it should pursue policies which encourage investment. This in turn will help to introduce new productive capital intensive techniques.

The discussion can be generalized to include all products, not only varieties of the same product, where producers have to chose what products to produce according to their profitability, which in turn depends on the demand conditions. Changes in demand affect the product composition because different products have different resource requirements, and this in turn affects the resource productivity. It is in this sense that output and productivity depend on the available technology, product demand and factor supply, or more generally on incentives and constraints, referred to as state variables.

Let us now review briefly how economic policy can affect each of the groups of state variables. Starting with the available technology, much of the research in agriculture is publicly financed and by and large, produced in public laboratories and experimental stations whose level of activity depends directly on decisions on research expenditures. The basic research in science and technology is done mostly in the developed countries. First, this research is expensive and second it is largely unnecessary for the developing countries because resource constraints prevent them from using all the technology which is already available. Nevertheless, there is a great deal to be gained by domestic research geared at transforming general knowledge to local conditions, Evenson (1989). This is related to the view of Hayami and Ruttan on induced innovation as was discussed above. Thus, policies affecting the improvements in available technology have a direct effect on productivity.

Incentives are affected directly by price policy and indirectly by macro and trade policies. The effect of the latter can be analyzed through the response of the real exchange rate and the sector's degree of tradability. Such policies also affect the real interest rate and thereby the cost of production according to the sector's capital intensity as measured by the factor shares. By this measure, agriculture is capital intensive in the more advanced countries, whereas the situation in developing countries is not uniform.

Changes in incentives also affect the intersectoral resource allocation and thereby the level of the quasi-fixed inputs in agriculture which in turn affect the choice of techniques. It is important however to note that, as seen above, labour and capital are allocated within an intertemporal optimization framework and therefore the direction of their movement in any given year may not be in line with the price changes in that year. For instance, labour may move out of agriculture even if in a given year the prices change in favour of agriculture. The exodus of labour from agriculture in the process of development is an outcome of the changing opportunities in and out of agriculture. Changes in productivity which result from such changes in resource allocation were attributed by Hayami and Ruttan to induced innovation, but this is an oversimplification which does not reveal the underlying economic forces.

The appearance of new techniques increases the shadow price of the factors which constrain the implementation of these techniques and thereby helps to attract resources to the sector in question and to alleviate the constraint. This process holds true also for the country as a whole. The appearance of new techniques, or for that matter the improvement in economic policies which increases profitability, helps the country to attract resources from abroad and thereby to take advantage of the changes in the available technology. It is for this reason that developed countries attract capital from abroad. As resources are finite, it is easy to blame developed countries for expanding at the expense of developing countries. From a purely economic point of view, the only way to overcome this situation is to create the necessary environment for investment, including the reduction of uncertainty, and with it for technical change that will come about from the implementation of the new techniques.

The studies of Argentina, Chile and the Punjab referred to above quantify empirically the effect of the various state variables on productivity, on resource changes and on the performance of the economy. There is no point in repeating the results here. Instead, we can give some summary information which speaks for itself. The first example is given in Figure 4, showing the growth path of Argentina in the period 1913-1984 in comparison to that of Canada and Australia, two countries which, like Argentina, are well endowed in land and were open to immigration. These countries lagged behind Argentina in their economic growth in the period 1880-1920 but the wheel of fortune turned around in the post-war period. The shocks that caused the deterioration in the performance of Argentina were initially the Great Depression of the 1930s, but more importantly, the Peronist policies which the country has recently begun to discard. These policies, even when they were well-meaning, were notorious for their time-inconsistency, as well as internal inconsistency. Perhaps, more important, they not only did damage the natural comparative advantage of the country: they also ruined the competitive structure of the economy by generating monopolies in key industries.

One aspect of this process is reflected in Figure 5 which shows the differential growth of crop yields between Argentina and the United States in the period 1913-84. In the late 1920s, crop yields were similar, but after 1930, yields in Argentina were always below the US levels. Comparing the average yields for the periods 1913-30 and 1975-84, agriculture in the United States tripled its yields. In Argentina they did not even double.[11] The reason for the slower progress in productivity in Argentine agriculture is a direct consequence of the taxation of agriculture. Taxation was direct, through export tax, and indirect through the protection of non agriculture and macro policies which resulted in low real exchange rate. The indirect tax was far more important. The tax affected the returns to the farmers, or simply the incentives, and thereby the choice of techniques and their yields. It also affected the flow of resources into agriculture and thereby the investment needed to take advantage of the new technology that became available.

A second example is Chile, presented in Figure 6 which shows the growth of per capita income over the period 1936-90. Two things are striking. First, the steady growth over a relatively long period of 1936-70. The "envelope" line reflects a fairly stable growth at an annual compounded growth rate of 1.6 per cent. Second, the consequences of the shocks to the economy introduced by the Allende government (1970-73) and the difficulties of returning to normality, by whatever definition of normality one wishes to use. Basically, there are two periods of catching up, 1974 to 1981 which was followed by a deep recession in 1982, and the subsequent period up to date of a continuous growth. Both — the fall off the envelope line and the partial return to it — are results of policies, some of course with negative effects. Sectoral performance in this period is well captured by our framework.

The effect of the introduction of the modern varieties on the growth of the quasi-fixed inputs in the Punjab was illustrated in Figure 2.

To show the potential of this analysis, we return to Figure 4 which presents an alternative growth trajectory for Argentina that was obtained by assuming alternative,

more restrained, macro policies and trade liberalization. This trajectory was obtained by estimating a structure which takes into account the effect of policies on sectoral incentives, the effect of such incentives on intersectoral resource flow and the direct and indirect effect of all these on productivity. It appears that had Argentina followed a different course in its economic policies, it could have performed like Australia. As this is a very timely example, it can be added that no explicit account was taken in this exercise of the elimination of the monopolistic structure of the economy. Current policies deal with this issue head on and if continued should produce a still better trajectory.

1. The introduction of uncertainty changes the objective function of producers, and profit maximization is replaced by a more general criterion and the production plans are affected accordingly. Thus, producers may prefer a crop variety with low, but robust, yield to that with a higher yield which is at the same time subject to wide fluctuations.

2. The term modern variety gives the impression that there is only one variety for each crop. This is not the case and in fact there are numerous varieties which are being constantly developed, (cf. Evenson and Davis, 1992). However, from the point of view of our discussion the dichotomy to traditional and modern varieties is legitimate because all the modern varieties share the property that their expected performances assume similar practices as far as irrigation, fertilizers and other modes of cultivation are concerned. The dichotomy to traditional and modern varieties serves the illustration, but the analytical development that follows accommodates the real case of numerous varieties.

3. It is noted that in this equation fertilizer is the actual quantity applied, rather than expected quantity which is the variable used in the area equation.

4. Note that $dy/Ds = y_2 - y_1$.

5. Basically, the translog function is a quadratic equation in the log of the inputs. The reference to the translog model, rather than function, implies here that the function is considered as a description of the production process with all the implications thereof.

6. This information is based on Tables 16 in Wen (1989) which reports the following numbers for the index of gross value added in agriculture in 1952 prices: 1957 - 124.8, 1978 - 202.7, 1984 - 327.9 and 1988 - 383.3. The source for some Wen's data is Tang (1982).

7. These figures are derived from Table 17, op. cit.

8. More appropriately, the criterion should be utility and not income, in which case v_a and v_n are the indirect, lifetime, utility functions in agriculture and non-agriculture respectively.

9. In some sense, the limitation of the factor supply function is similar to the limitation that the demand for the final product imposes on a competitive industry, a subject incorporated by Lucas and Prescott in their study of investment.

10. This proposition is proved in Mundlak (1985).

11.   The weights for the Divisia index are those of Argentina.

Table 1

PUNJAB: ESTIMATES OF AREA ALLOCATION EQUATIONS

	Irrigated Wheat				Irrigated Rice		
Variables	MV	Trad.	Dry Wheat	Variables	MV	Trad.	Dry Rice
Incentives				**Incentives**			
MV Wheat	0.00123	-0.00089		MV Rice	0.00020	-0.00012	
	(6.15)	(-6.20)			(3.36)	(-2.80)	
IT Wheat	-0.00089	0.00041		IT Rice	-0.00012	0.00011	
	(-6.20)	(2.81)			(-2.80)	(1.64)	
I Gram	-0.00005	-0.00008		I Maize	-0.00004	0.00001	
	(-1.12)	(-1.59)			(-1.24)	(0.2)	
D Wheat			-0.00077	I Cotton	0.000085	-0.00002	
			(-3.04)		(3.35)	(-0.89)	
D Gram			0.00009	D Rice			0.00021
			(0.53)				(3.79)
				D Maize			0.00003
							(0.97)
				D Cotton			0.00004
							(2.05)
Constraints				**Constraints**			
IRR Priv	0.74701	-0.73056	0.12686	IRR Priv	-0.17733	0.03924	0.04272
	(6.24)	(-8.59)	(1.68)		(-3.06)	(0.91)	(1.68)
IRR Govt	0.23259	-0.17860	0.88662	IRR Govt	-0.11958	-0.13078	-0.00294
	(1.55)	(-1.63)	(7.28)		(-1.79)	(-2.69)	(-0.09)
E Fert	0.00125	-0.00090	-0.00177	E Fert	0.00053	0.00018	0.00010
	(3.3)	(-3.08)	(-4.57)		(3.55)	(1.49)	(0.96)
Roads	0.02376	-0.00590	-0.00272	Roads	0.05195	-0.01477	-0.00097
	(2.35)	(-0.75)	(-0.33)		(11.16)	(-3.69)	(-0.45)
Environment				**Environment**			
JS	0.00123	-0.00095	0.000749	May	-0.00083	0.00014	-0.00007
	(3.16)	(-3.30)	(2.58)		(-1.00)	(0.23)	(-0.14)
				June	-0.00051	0.00093	0.00067
					(-1.13)	(2.64)	(2.49)
R-Square	0.949	0.8097	0.9261	**R-Square**	0.9621	0.8759	0.9058

a. The incentive variables are expected revenues per thousand hectares deflated by wage for the indicated variety. MV, IT, I, and D indicate whether the particular crop variety is modern, irrigated traditional, irrigated, or dry. IRR Pvt and IRR Govt are net irrigated area by private and government sources deflated by net cropped area ('000 ha.). E Fert is expected fertilizer available (nutrient kgs. per 1,000 ha. of net cropped area available in previous year). Roads measures km. of roads in district/1,000 ha. JS (June-Sept.), May, and June are pre-planting rainfall variables (.01 mm.). District intercept shifters and a pre-green revolution intercept shifter are in the estimated equations but not included in the table. The Kharif irrigated and dry area equations (including rice) are all adjusted to correct for positive first-order autocorrelation following Parks (1967). T-statistics are in parentheses.

Source: McGuirk and Mundlak (1991).

Table 2

PUNJAB-ESTIMATES OF YIELD EQUATIONS

Explanatory Variable	Dependent Variable: Yield				
	Wheat	Gram	Rice	Maize	Cotton
Technology					
MV Wheat	1.19928	...	...	...	...
	(12.12)				
Irrigated Gram	...	0.2215	...	...	...
	(0.64)				
MV Rice	...	...	1.32789	...	...
	(7.18)				
Irrigated Maize	...	...	...	2.07472	...
	(4.66)				
Irrigated Cotton	...	...	...	...	0.41771
	(3.15)				
American Cotton	...	...	...	...	0.11413
	(4.49)				
Constraints					
Fertilizer	0.00316	0.00141	0.00189	0.00201	0.00116
	(1.30)	(1.66)	(1.00)	(1.46)	(2.2)
Fertilizer Technology	-0.00301	-0.00314	-0.00115	-0.00121	-0.00135
	(-1.27)	(-1.69)	(0.59)	(-0.74)	(-2.45)
Environment					
Rain*	-0.00955	-0.00437	0.00212	-0.00118	0.002306
	(-2.12)	(-0.64)	(0.94)	(-0.36)	(1.58)
Rain* Technology	0.00342	0.00622	0.00183	-0.01200	-0.002679

The numbers in parentheses are t-statistics.
The district effects are not reported here.

The technology variables are:
        Irrigated cotton, gram and maize - proportion of irrigated area.
        MV Rice and wheat - proportion of MV in rice and wheat areas respectively.
        American cotton - proportion of American cotton in cotton area.

The rain variables are:
        Cotton - District rainfall June-September.
        Maize and rice - District rainfall July-September.
        Wheat and Gram - District rainfall October-April.

Source: McGuirk and Mundlak, Tables 15 and 16.

Figure 1

Figure 2

Punjab: Selected Inputs, 1960-80

Figure 3

Production Function

Figure 4

Growth Trends in Argentina, Australia, and Canada, 1929-84

Figure 5

Crop Yields, Argentina and the United States, 1913-84

Figure 6

Chile: Per Capita GDP, in 1977 pesos

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