# ON THE EMPIRICS OF ECONOMIC GROWTH[1]

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A graph of per capita income in the US shows an upward trend, and the longer is the period covered by the graph, the smoother it looks. By changing the scale of the graph, however, it is revealed that the growth is subject to fluctuations. A similar picture, usually with more pronounced variability, is observed for other countries. The increase in income is accounted for in terms of resource accumulation and technical change. This explanation is more applicable to the first graph, but in itself it is insufficient to account for the variability observed in the growth rates. Similarly, it does not explain why some countries grow faster than others and some hardly grow at all. This disparity in performance indicates that the search for explanations is not exhausted.

It is commonly agreed that there is no long-term growth without technical change. But if the technical change triggers growth in some countries, why does it fail in others? This question suggests that there are two pertinent concepts of technology: Available technology (AT) and implemented technology (IT). The first concept covers the total knowledge generated everywhere up until the present. The second concept covers that part of the AT that is actually implemented. Knowledge is generated by research which involves human effort and calender time. Past experience suggests monotonic relationship between research inputs and output. However, not much more can be said for future reference beside this qualitative empirical observation. The reason is that there is no production function that summarizes the research effort. The results of today's research are the inputs for tomorrow's research. Therefore, past experience does not offer replicas for estimating or quantifying the production structure of research, (Mundlak 1993, 2000). This is unfortunate because without this information there is no pure quantitative basis for society to evaluate the consequences of resource allocation to research. For instance, in terms of the Lucas (1988) model, it is impossible to determine the productivity of resources devoted to the enhancement of human capital. For this reason, and for the fact that it is the implemented technology which generates the data, the domain for empirical discussion is the determination of the IT. This is the case whether or not it is actually recognized in the analysis. In what follows, we outline implications of this recognition.

We start the discussion with a partial summary of the evidence followed by a partial review of the literature in order to highlight the approaches taken to explain the data. With this background, we review a more general framework with empirical orientation for the evaluation of the growth process. Qualitative implications of this framework are presented, followed by a cross-country analysis of the

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agricultural production function evaluated in terms of the given framework. Concluding remarks summarize the paper and some of the implications.

**Evidence** (Chari et al, 1995, Rebelo 1995, de la Fuente 1997, Easterly and Levine 2000, among others).

Cross-country spread

1. Large disparity in per capita income or average labor productivity. Bigger spread between countries than over time.
2. The inequality has increased due to a faster growth in the richer countries.
3. At the same time, the inequality has declined among the richer countries. Thus, divergence in the large but convergence in the group of richer countries.
4. Economic activity is highly concentrated, with factors of production flowing to the richest areas.
5. Countries with high average labor productivity have high capital-output ratio.

Variability over time

6. Growth rates declined in the 1980s and 1990s. The decline from 1973 was quite pervasive, suggesting a response to common shocks. However, the OECD countries suffered less than the poorer countries.
7. Factor accumulation is persistent while growth is not persistent. Growth rates show little persistence[2]

**Explanations**

Basically, the growth is attributed to three triggers: physical capital (K), human capital (HK), and technical change (TC). Models vary in their specifications of the process, as the following incomplete list demonstrates:

- Physical capital and exogenous technical change (Solow, 1967, 2000, Mankew, Romer, and Weil (MRW)).
- Investment in human capital (HK), (Lucas, 1988, Jones and Manuelli 1990, Rebelo 1991, Stokey 1991)
- Externalities, (Romer, 1986, Caballero and Lyons, 1992, Benhabib and Jovanovic, 1991). Externalities are not essential for growth, (Jones and Manuelli, 1990, Rebelo 1991, Lucas 1988, Solow, 2000)

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[2] The European experience serves an example of changing growth rates. The average annual growth rate in the period 1830-1990 was moderate, a little above 1 percent with a slight positive trend from 1830-50 till War II ( a dip in the big depression and in the war). It jumped after the war to ? percent in 1950-70 and declined thereafter to a little over 2 percent in 1970-90, (de la Fuente 1997).

- Research and development (Romer, 1990, Grossman and Helpman, 1991, Aghion and Howitt, 1992).
- Learning by doing, (Arrow,1962, Romer 1986, Stokey, 1988, Young 1991).

The allocation of growth to inputs and to productivity changes is largely perceived as an empirical exercise, but there is more to it as it will become clear below.

- Investment is important: (Levine and Renelt, 1991, De Long and Summers, 1991, Young 1992, 1995). It is important to note that those countries that invest heavily in physical capital also invest in education.
- Total factor productivity (TFP) - The main trigger of growth: (Prescott 1998, Easterly and Levine, 2000)
- Implementation of the available technology, (Mundlak, 1988, 1993, 2000), this is also the main theme of this paper.

The performance is affected by public policy, and more generally by the economic environment:

- Inflation - Negative effect of inflation due to uncertainty, (Fischer 1993).
- Trade policy - openness contributes to growth (Mundlak, Cavallo and Domenech, 1989, Grossman and Helpman, 1991, Rivera-Batiz and Romer 1991, Ben-David, Nordstr`m and Winters, 2000)
- Financial intermediation - Efficient financial intermediation system helps to allocate capital in most efficient way, and to pool risk (King and Levine, 1993)
- Infrastructure investment - Helps market integration (Aschauer, 1985, Barro, 1990, Easterly and Rebelo 1993)
- Political process - The obsolescence of traditional techniques generates political resistence. (Persson and Tabellini, 1994, Alsina and Rodrick 1991).
- Policies and growth - (Cavallo and Mundlak, 1982, Mundlak, Cavallo and Domenech, 1989, Easterly and Rebelo, 1993), Knack and Keefer, 1994).
- External shocks - (Easterly, May 2000)

Most of the foregoing subjects can be grouped under the title of the economic environment. The challenge is to show the channel for their influence.

**Empirics of the classical model**

Even though the growth process evolves over time, the empirical analysis commonly employed is largely cross-country analysis which does not focus on the process itself but only on its outcome. The motivation is perhaps twofold: First, the desire to understand the reasons for the differences in growth rates across countries, a prerequisite to finding solutions to improve the performance of the laggards. Second, country-panel data show that most of the spread in the pertinent economic variables is between countries rather that between time.[3] The dependent variable is either the level of average labor productivity or its growth rate. Working with growth rates is costly in terms of unutilized information due to averaging the data over a long time period and thereby ironing out important dynamics. In interpreting regressions in terms of levels it is necessary to differentiate between shocks that affect only the levels and those that carry on to the steady state values. This is similar to the problem, known from supply response analysis, of differentiating empirically between short-run and long-run response to changing economic environment. The same problem, however, exists in growth regressions where it is appropriate to differentiate between growth associated with convergence to the steady state and that associated with movements along the steady state.

The main work-horse of the empirical analysis is a Cobb-Douglas production function. The function is the same for all countries, and in many cases an exogenous technological change at a predetermined rate is imposed on the equation. Such an imposition is an acknowledgment that the analysis is not covering changes in the available technology. In many cases, the focal point is checking the validity of the Solow model, which requires that the marginal productivity of capital is sufficiently declining to produce a steady state solution. This is generalized to cover all reproducible inputs. For this it is sufficient that the sum elasticities of the reproducible inputs will be *eventually* smaller than one.

An important issue in these studies is the difference between the elasticities and the factor shares. In the event of a difference, doubt can be raised as to the quality of the results. For those who never doubt, it is necessary to adjust the theory accordingly, and for this to be useful, it has to be checked out on other samples. Robustness is persuasive.

## Findings

*Physical capital*

There is a trend of capital deepening, which suggests that capital has a lot to do with growth. This is confirmed by various studies in different forms. In most studies it is found that capital elasticity is larger than its factor share, and sometimes the difference is substantial. A question is raised on the causality by Blomstrom, Lipsey, and Zejan who argue "[t]hat growth induces subsequent capital formation more than capital formation induces subsequent growth."(pp 275-6). This is an important issue to which we return below.

*Human capital*

The variable most commonly used to represent human capital is some measure of schooling. The results are not robust, some studies report positive impact of schooling while others do not, (Pritchett, 1996).

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[3] For instance, in the panel discussed in the last part of the paper, the between country spread in the inputs and outputs accounts for more than 95 percent of the total spread in the data. On it face, this large spread leads to more precise estimates. This does not imply, however, that the variability over time is less valuable.

*Economic environment*

Levine and Renelt (1992) conclude that many measures of economic policy are related to long-run growth. However, the relationship between long-run growth and any specific policy indicator is fragile. Thus, they propose, that there is no reliable, independent statistical relationship between a wide variety of macroeconomic indicators and growth.

*Total factor productivity*

Easterly and Levine assert that the “residual” rather than factor accumulation accounts for most of the income and growth differences across nations. “We suggest that these facts are more consistent with technology explanation of growth rather than factor accumulation explanation.” These are not two independent events as we shall see below. Prescott (1998) argues that differences in physical or human capital cannot account for the big international differences in income today. The culprit is the spread in the TFP. The suggested reason for the spread is the resistence to the adoption of new technologies and to the efficient use of currently operating technologies. This in turn reflects the policy arrangement employed by society.

**Formulation**

This foregoing brief review illustrates the nature of the analysis needed for our discussion. All the explanations are pertinent, but partial. This is an outcome of the tendency to try to catch all the actions in a simple model. This practice has limitations. Going back to the basics of the aggregate model, output is produced with labor, physical capital and human capital and the outcome depends on the technology. The unknown is technology, which is an abstract concept and cannot be observed directly, and it is therefore inferred from observations. As mentioned above, many of the studies impose on the model a constant rate of technical change and move on with the exercise (MRW, Prescott, Romer 1987, 1989a...). Furthermore, generally, the technology growth is assumed to be the same for all countries, because every one can go to the home library, or perhaps travel to Europe or the US for a richer library. However, when this traveler returns to his country he/she is reminded that the technology used in the country, like his library, is not up-to-date as of yesterday, and perhaps not as of last decade. This is the reason we have to deal with the two concepts of technology. Empirical economists (for the others it may not matter) generally ignore this important distinction and apply theoretical models to the data under the assumption that the available technology is fully implemented. To avoid being caught up in this trap, it is necessary to study the forces that determine the implemented technology, which amounts to endogenize it. We begin with a simple, but insightful, graphical illustration (Figure 1) of the approach and some of its consequence.

Initially AT consists of $\{f_1\}$, the capital labor (or land) ratio is given by $k$ and the output labor ratio, average labor productivity, is given by $y$. The economy is at $A$ with wage $(w)=OE$, and the return to ‘scarce’ factor $(K\}= r_0$. Technical change is introduced with the appearance of a new technique, and AT becomes $\{f_1, f_2\}$.[4] Note that the new technique is capital-intensive. For simplicity, it is assumed that there is no set-up cost involved in the implementation of the new technique. The response of the economy to the technical change depends on factor supply, and this is demonstrated by two extreme possibilities:

- The supply of *K* is perfectly elastic - the economy moves to *M*, with $r_0$ unchanged, but *w* increases to *OH*.

- The supply of *K* is perfectly inelastic: the best strategy is a convex combination of the two techniques as given by *N* (analogy of division of labor). The resources are allocated between the two techniques. It is required that the gain from the implication of the new technique covers the setup costs. If not, remains at *A* and does not employ $f_2$.

The composite production function is the locus $0, \tilde{A}, \tilde{M},$ and thereafter along $f_2$. The output at point *N* is a convex combination of the outputs at $\tilde{A},$ and $\tilde{M}.$ The move from *A* to *N* causes a rise in the return to capital from $r_0$ to $\tilde{r}$ and a declines of *w* from *OE* to *OD*.

Some implications

The changes in the economy induced by the change in AT are determined largely by the resource supply.

*Factor prices*: In the process of transition, when the economy is on the tangent line the return to the scarce factor rises and that of the abundant factor declines, relative to the initial point. Eventually, once the accumulation allows the economy to pass $\tilde{M}$ and the production is carried out along a concave function with decreasing marginal productivity of capital and the returns to capital start declining and that of labor increases. In this description, it is assumed that capital is homogeneous and can be reallocated between the two techniques. For instance, in the case of the green revolution, think of k as fertilizers (or irrigation)/land ratio, and the two techniques representing two varieties. The appearance of the more productive variety results in allocating the land and the fertilizers between two varieties.

When capital is not homogeneous, and the two techniques require different forms of capital, the pace of the implementation of the new technique will be determined by the pace of the change in the composition of the capital goods.

*Resource flow*: In response to the rise in *r*, k increases with time and this will result in a gradual

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[4] See Atkinson and Stiglitz (1969) for an early discussion of technical change and the choice of techniques within the framework of activity analysis.

convergence to $\tilde{M}$. The green revolution serves a good example. In spite of the superior varieties of wheat and rice the process of their adoption took a long time because these varieties have been water and fertilizer intensive and the pace of the process was determined by the pace of resource mobility into agriculture, (McGuirk and Mundlak, 1991). A more familiar example is the impact that the development of the computers industry has had on the flow of skilled labor to the industry. To conclude, the pace of convergence to a new optimal point is largely determined by the pace of resource flow.

*Wage rigidity* - If the wage rate is fixed at the original level (or a level above AD) the transformation to the new technique may be hindered and unemployment might result. Discussions in favor of wage rigidity (e.g. Easterly, Islam, and Stiglitz) assume a homogeneous technology and do not apply to the case under discussion..

*Income distribution* - When the new technology is intensive in a particular factor, the share of that factor in total income rises and this may augment income inequality. An example is the differences in income between the 'new' and 'old' economies. This change in distribution reflects two changes, the rise in the price of the scarce factor and the decline in the price of the saved factor. Such changes affect the income distribution of skilled and unskilled labor.

*Polarization of global wealth*: A similar reasoning applies to the explanation of the international income inequality. Global factor supply is finite, and the allocation is determined by expected returns and their stability. This results in the polarization. The richer countries are more affluent in the resources needed for the implementation of the new technology, and they benefit from it. Countries that do not have sufficient supply of the scarce factors will lag behind whereas the others will advance.

*Learning by doing*: The concept of learning by doing can be applied at different levels. Following the original example presented by Arrow (1962), the learning applies to the use of a new technique. Thus the discussion is made conditional on a change in the AT, and as it is not a substitute for that change. Countries cannot simply converge to the frontier technology of the more advanced countries if they do not have the resources to implement the new technique. The speed of convergence reflects, therefore, the combined effect of the speed of learning and of resource flow. The scope of the concept of learning by doing is more limited when it is applied to cover the evolution in research. As the input to today's research is the result of yesterday's research, the ones who learn are the ones who are engaged in research, and again it acts against the progress of the poor countries.

*TFP*: The measured impact of the technical change depends on the location of the economy before and after the change, and this in turn depends on resource mobility. If factor supply is perfectly elastic, the economy moves from $A$ to $M$, and the change in the TFP is given by $BM$. If, on the other hand, the factor supply is inelastic, the economy moves from $A$ to $N$. Thereafter, as more resources become available, the efficient move is along the tangent $\tilde{A}$, $\tilde{M}$ which is associated with new factor prices. If the evaluation of the TFP is done with the new prices, the change in the TFP disappears. But this underestimates the impact of the technical change. The upshot is that the computed TFP is path dependent and in order to fully capture the impact of the technical change, the TFP should be evaluated with the prices prevailing under the old technology.

*Prices* For the discussion to cover different products, output is measured in value terms. Thus a change in relative prices amounts to a shift of the production function. The pace of the implementation becomes dependent on product demand. Furthermore, if the output is value added, then the prices of raw materials also affect the pertinent production function. This was clearly the case when energy prices spiked in the early 1970s. Thus the choice, as well the mobility of resources to durable activities with high set up cost, becomes a function of expected prices and their stability. The framework is broad in scope. For instance, in an open economy it includes world prices and policies that determine the real exchange rate.

*Empirical implication*: When the new technology is $k$-intensive, y becomes positively correlated with $k$. A similar analogy holds for per capita human capital ($h$). As the rich countries have more $k$ and $h$, they are in a better position to adopt the new technology.

The factor share of capital when measured from the production function should be evaluated at the base factor price, $r_0$. When the observations fall on the segment $\tilde{A}, \tilde{M}$, the elasticity obtained from empirical Cobb Douglas function is expected to exceed the factor share. The difference is due to the fact that k captures the technical change. In such cases, we can infer that capital is a constraint to the 'modernization'. The concept is equally applicable to human capital, or components thereof. To overcome this bias, the empirical analysis should allow the elasticities to be depend on variables representing the economic environment.

*Demand and the extent of the market* - Empirical growth analysis shows that export is an important regressor. Without rejecting other explanations for this result, the present discussion draws attention to the importance of the size of the market. National economies are open but the global economy is closed and thus tradable products face declining demand. This is well recognized in the discussion of agriculture, and it is should be also applicable to other tradables, and specifically manufacturing. In a competitive industry like agriculture the individual producer has no marketing power. The situation, however, is different in manufacturing. Changes in technology that amplify the internal scale economies generate a tendency for concentration leading to few players with over capacity. This generates pressure to increase export, and the more efficient producers prevail. Thus, an association between productivity growth and export is generated.

**Consequences**

A formal presentation of the above approach calls for expressing the optimization problem at the firm level as a choice of the techniques to be implemented and their level of optimization given the available technology, product demand, factor supply and constraints, (Mundlak 1988, 1993, 2000). This approach has important implications for the empirical analysis that we now state without proofs

- *Endogeneity*: The implemented technology is endogenous, and is determined by the state varaibles.
- *Jointness*: The implemented technology is determined jointly with the level of intensity at which the inputs are used.
- *Duality*: Prices are insufficient statistics for identifying the implemented technology.
- *Production path*: The output path is determined by the evolution of the state variables.

The production function that aggregates outputs over techniques is subject to the following limitations:

- *Identification*: In general, the aggregate production function is not identifiable.
- *Concavity*: When the sample is generated by more than one technique, the empirical production function is not subject to a concavity constraint, even though each of the techniques is represented by a concave production function.

To identify the aggregate production function it is necessary to break the decisions on the implemented technology from those on the level of inputs. This is achieved when deviations from the first order conditions are more pronounced in the input decisions than in the choice of techniques. With a second degree approximation, the aggregate production function takes the form of a Cobb-Douglas function where the elasticities are functions of the state variables representing the economic environment:

$$\begin{aligned} \ln y &= '(.) + B_1(.)\ln x + (1/2)B_2(\ln x)^2 \\ B_1(.) &= ''_{01} + ''_{11}s + u_x \\ '(.) &= ''_{00} + ''_{10}s + s''_{20}s + u_0 \end{aligned}$$

where y is the value added per worker, *s* is the vector of state variables, "s and *B*s are the coefficients to be estimated, and $u_x$, $u_0$ are the stochastic terms. The estimation is done by imposing the equality of the factor share and the production elasticity, $S = E_{y/x}$, up to a stochastic term. In the present case, the production elasticity is $E_{y/x} = B_1(\cdot) + B_2 \ln x$, and thus it is not necessarily the same as the factor share. The discrepancy between the two is accounted for by the state variables. Because we restrict ourselves to a second degree approximation, $B_2$ is a constant, whereas $B_1$ is allowed to vary with the state variables. Variations in the state variables affect the production function coefficients directly as well as indirectly, through their effect on inputs. This, to be sure, is a description of reality. For this reason, estimates obtained under the assumption of constant coefficients provide a distorted view.
The empirical presentation of the elasticity is given by

$$S = ''_{01} + ''_{11}s + ''_{x1}\ln x + u_x.$$

**Evidence**

The foregoing discussion provides a framework for the interpretation of empirical results, including the lack of robustness often encountered in empirical analysis. In general, at each sample point, the data consist of aggregated techniques, the composition of which changes over the sample points. As such, the production path is determined by the evolution of the state variables and the aggregate production function is not identifiable. In several studies, the subsistence conditions of the neoclassical production function, monotonicity and concavity, were not met. For detailed evaluation of the empirical production functions see Mundlak (2001).

In terms of the present discussion, we note that because of the dependence of the coefficients on the state variables, there is no reason to impose the same constant function to all countries, or to a given country over a lengthy period of time. To illustrate what is at stake, we present in Figure 2 the capital share in Argentina over a period of 70 years. Obviously, imposing a constant value over the whole period leads to a loss of valuable information. To do it for all countries is worst.

The approach was used in country growth studies using time series data. Those studies are too comprehensive to summarize here. Instead, we examine an application to pooled country data in order to highlight some of the results reviewed above.

**Cross-country agricultural production function.**

The estimation of the system requires data on factor shares, which is not readily available. This makes it impossible to apply the model in the form presented above to pooled cross-country data until the needed data become available. The task is then to see what can be learned from the available data. In what follows we review such an attempt by Mundlak, Larson, and Butzer (1999) in estimating agricultural production functions to a sample of 37 countries over the period 1970-1991. The size of the sample is determined by the data availability. The pooled data are used to fit three regressions: *Between countries* (based on country means), *between time* (based on year means) and *within-time-country* (based on the deviations of the observations from country means and year means). These three regressions constitute the canonical set of pooled data in the sense that all linear estimators based on the sample can be expressed as matrix-weighted averages of these regressions. Under the hypothesis, the coefficients of a Cobb-Douglas production function are affected by the economic environment, and therefore the coefficients of these regressions should be different. The *within* variables are deviations, free of the influence of country and time effects, not captured by the state variables, and as such represent a more stable technology, to be referred to as the *core technology*.

The state variables consist of incentives, constraints, technology, and physical environment. The variables are:

*Output* - agricultural GDP in 1990 US dollars.

<u>Inputs</u>

*Land* - Hectares of arable, permanent cropland, and permanent pastures.

*Labor* - economically active population in agriculture. It is not actual employment, and as such it is a stock, rather than a flow, concept.

*Fertilizers* - total fertilizer consumption in metric tons.

*Capital* - fixed capital stock used in agriculture, plus capital in livestock and orchards. The capital

variable serves the dual role of an input and a of a constraint. We return to this below.
Incentives - Two measures are used to capture the direct effect of incentives on productivity, over and above their indirect effect that comes through resource allocation and accumulation:
*Price* - the ratio of the prices of agriculture to manufacturing.
*Price variability* - a moving standard deviation of the price, calculated from the three previous periods. The variable reflects the market risk faced by agricultural producers.
*Inflation* - In addition to the sector-specific risk, there is an economy-wide market risk, that of price volatility for the economy as a whole measured by the inflation rate, calculated as the rate of change in the total GDP deflator.
Technology - The technology block consists of several variables:
*Schooling* - The mean school years of the total labor force serves as a proxy for the embedded human capital.
*Peak yield* - country-specific Paasche indices (1990=1) of the historical peak commodity yields, weighted by land area, used to measure the level of technology in agriculture.
*Development* - The state of development of the economy is measured by the per capita output in the country relative to that in the United States.
Physical environment - Two variables are used to describe the physical environment for agriculture, *potential dry matter* production (PDM) and a *factor of water deficit* (FWD).

Some of the measures have to be modified for the *between-country* analysis: *Peak yields* are replaced by their average growth rates for the period. The average rate of growth in the relative price over the period replaces the level of such price. The standard deviation of the relative price over the entire period is used in place of the moving standard deviation.

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

The average annual growth rates (percent) of the variables in question are: output 3.82, capital 4.25, land 0.12, labor -0.04, fertilizers 3.04, schooling 1.8, peak yield 1.9, development -0.29, and relative price -0.30.

**Empirical results**

The table presents estimates for the three blocks of the base model. The three regressions display constant returns to scale. The null-hypotheses that blocks can be omitted are rejected, and therefore the information in the three blocks is all pertinent. The coefficients of the variables common to the various equations are quite different. This confirms the basic hypothesis that the regressions summarize the combined effect of changes in inputs and technology obtained under different economic environments. We now turn to interpret some of the results.

*Inputs*

Perhaps the most interesting result is the magnitude of the elasticity of capital, 0.37 in the *within* regression, 0.34 in the *between-country*, and 1.03 in the *between-time regression*. The latter represents the response common to all countries in the sample. It indicates that, on average for the sample, an increase in capital was accompanied with a proportional increase in output. This strong response is consistent with the view that physical capital has been a constraint to agricultural growth. Accordingly, the implementation of changes in the available technology were strongly affected by investment in agriculture.

The *between-time regression* shows that the shift to more productive techniques is associated with a decline in labor. The labor coefficient in the *core* technology is also relatively low, whereas that of the *between-country* regression is more in line with other cross-country studies. This is no surprise because those studies are in general based on cross-country regressions. Recall that the labor variable measures with error the actual employment, and thus variations over time in this variable, which on average are small, do not affect output. On the other hand, the cross-country variations of the labor variable are sizable, so that the signal to noise ratio is relatively large, and seem to have a substantive impact on output.

These results highlight the importance of capital in agricultural production, and indicate that agricultural technology is cost-capital intensive compared to nonagriculture. This conclusion is further reinforced by the magnitude of the land elasticity in the *core* technology. The sum of capital and land elasticities is around 0.8 in various formulations, making it clear that agriculture should be more sensitive than nonagriculture to changes in the cost of capital and less to that of labor (Mundlak, Cavallo, and Domenech, 1989). This value of the sum might seem to be a bit high. In part, it may reflect the result of a somewhat low labor elasticity. It is also possible that a different choice of countries and time periods would lead to somewhat different results. In any case, a sum of 0.8 for land and capital elasticities leaves room for the conclusion on the importance of capital to remain intact.

There is a big difference in the elasticity of fertilizers between the various regressions. A value of 0.08 obtained in the *within-country-time regression* is considerably lower than the typical values obtained in cross-country studies of the agricultural production function, which are closer to our *between-country* coefficient. This requires an explanation. Recall that the dependent variable is the log of value added, which is net of expenditures on fertilizers. Using the envelope theorem, under the competitive conditions, the coefficient of fertilizers should be close to zero. The difference from zero should reflect only interest charges for working capital, reflecting the time lapse between the purchase of the inputs and the time of the sale of the output. A coefficient of .08 indicates that about 8 percent of the changes in agricultural output are to be attributed to fertilizers over and above their cost. Moreover, this result is obtained for the aggregate agricultural output, whereas fertilizers are used only on plant products. It is likely that a production function for plant products alone would show a larger elasticity for fertilizers. Thus, a value of 0.08 for aggregate output may even be biased upward which means that we have to explain why it is high rather than low. A mechanical explanation is that fertilizers capture the impact of other chemicals and more generally, the modern inputs, as indicated above. Still, by the envelope theorem, the coefficient of this "extended" input should be near zero. The more substantive explanation for this deviation is that fertilizers were scarce and the elasticity reflects a high shadow price of fertilizers. This is consistent with the large increase in fertilizers supply over time. This is also consistent with the high fertilizer elasticity obtained from *between-country* regression, which is indicative that the new technology is fertilizer-using. Accordingly, the locus of country means represents a changing technology package where the improvement in the implemented technology is fertilizer-using. At the same time it is also capital-using but land-saving.

*Technology*

The technology variables play a dual role in the analysis. First they serve as technology shifters and as such reduce the bias caused by the correlation of inputs and technology. Second, they provide an empirical examination of how well they describe the data and thereby guide us in the search for appropriate technology indicators.

The *peak yield* serves well as a shifter of the agricultural productivity - measured by the *core* technology - with an elasticity of 0.83. The *peak yield* is a proxy for the frontier of the *implemented* technology. A low value for this elasticity indicates that the economic environment was not sufficiently favorable to allow the current productivity to repeat its historical records. An elasticity of 1 indicates that the current productivity is moving along with this frontier. The frontier itself progresses in response to changes in the state variables but, in the longer run, such a progress is triggered by changes in the *available technology*. We thus deal with a ratchet process. A jump in *available technology* translates itself into a change in productivity, which in turn raises the peak. The persistence of this performance depends on the economic environment. Can the elasticity take on values larger than one? The answer is yes. This can happen when initially the available technology was not fully utilized, then improvements in the economic environment allow a catchup at a fast pace.

The level of development of the country relative to the U.S. is also an important explanatory variable of agricultural productivity. Note that the contribution of this variable is over and above that of the peak yield, which shows that the yield level is not exhaustive as a technology indicator; first, the yield variable does not represent the productivity in livestock production which accounts for about one third of output, and second, there is a scope for improving efficiency under a given technology by coming closer to the frontier, as represented by the performance of the US.

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

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

*Prices*

The test of the null hypothesis that the price block can be omitted from the analysis is rejected. It appears however that the allocation of the price effect to the individual price components is problematic. On the whole, the signs of the coefficients are in line with expectations, but the precision is low. The small quantitative price effect on agricultural productivity should not be misleading; it is obtained conditional on given inputs and on technology. Thus, there is little scope for additional price effects. The fact that this effect is at all detected is of prime importance. The channels for the price effect are the level of inputs and the choice of technology, and these are represented by explanatory variables.

**Concluding remarks**

The available technology is changing with time and a large component of this change is not predictable. The basic premise is that the implementation of the technology is endogenous within the economic system and it depends on a set of variables referred to as the economic environment. This is the essence of the empirical explanation of growth. Following this line of thinking, the implemented technology is determined jointly with the level of inputs. The changes in the available technology affect the demand for inputs, it increases the demand for those inputs in which the new technology is intensive. The implementation of the new technology is not necessarily immediate or pervasive. It depends largely on the supply of inputs in which the new technology is intensive. The data, and therefore their analysis, provide information on the *use* made of the changes in technology. Since the choice of inputs and the implemented technology is determined jointly, it is not always meaningful to assign causality in the relation between these two elements.

In this paper we discuss one cross-country study, interpreted in light of the presented approach. It illustrates very clearly that the coefficients of the production function depend on the economic environment and thereby support the hypothesis that the coefficients are not constant. This raises a question on the information we get from cross-country studies which impose constant coefficients for the sample as a whole. Many of the results obtained in those studies can be interpreted in light of the present discussion. The specific result with respect to agriculture are discussed in greater details in the source of the study. We should however indicate that this is only one cross-country study which uses this approach, and other samples may yield different results. Of course, non robustness of results is one of the attributes of the model, and therefore this will only reinforce the conclusions.

To sum up, to the extent that our views on growth are base on empirical analysis, it is important to adhere to the implications of the dynamics of the growth process. The observations are generated in process of convergence to changing new frontiers and the pace of this process is determined by the economic environment. This environment is largely affected by what countries do. This view suggests an important scope to the role of economic policies.

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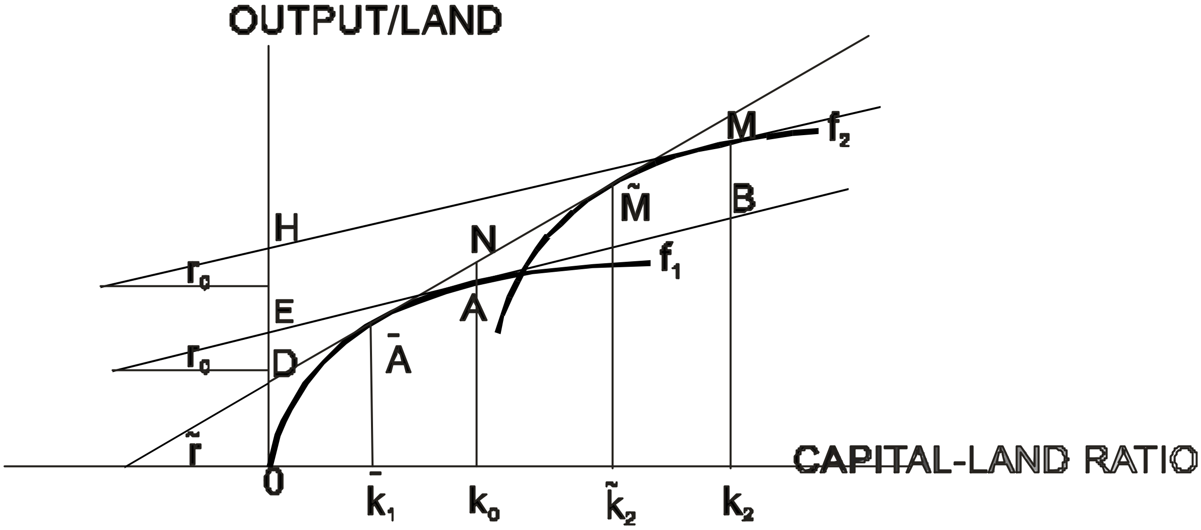


FIGURE 1 THE CHOICE OF TECHNIQUE

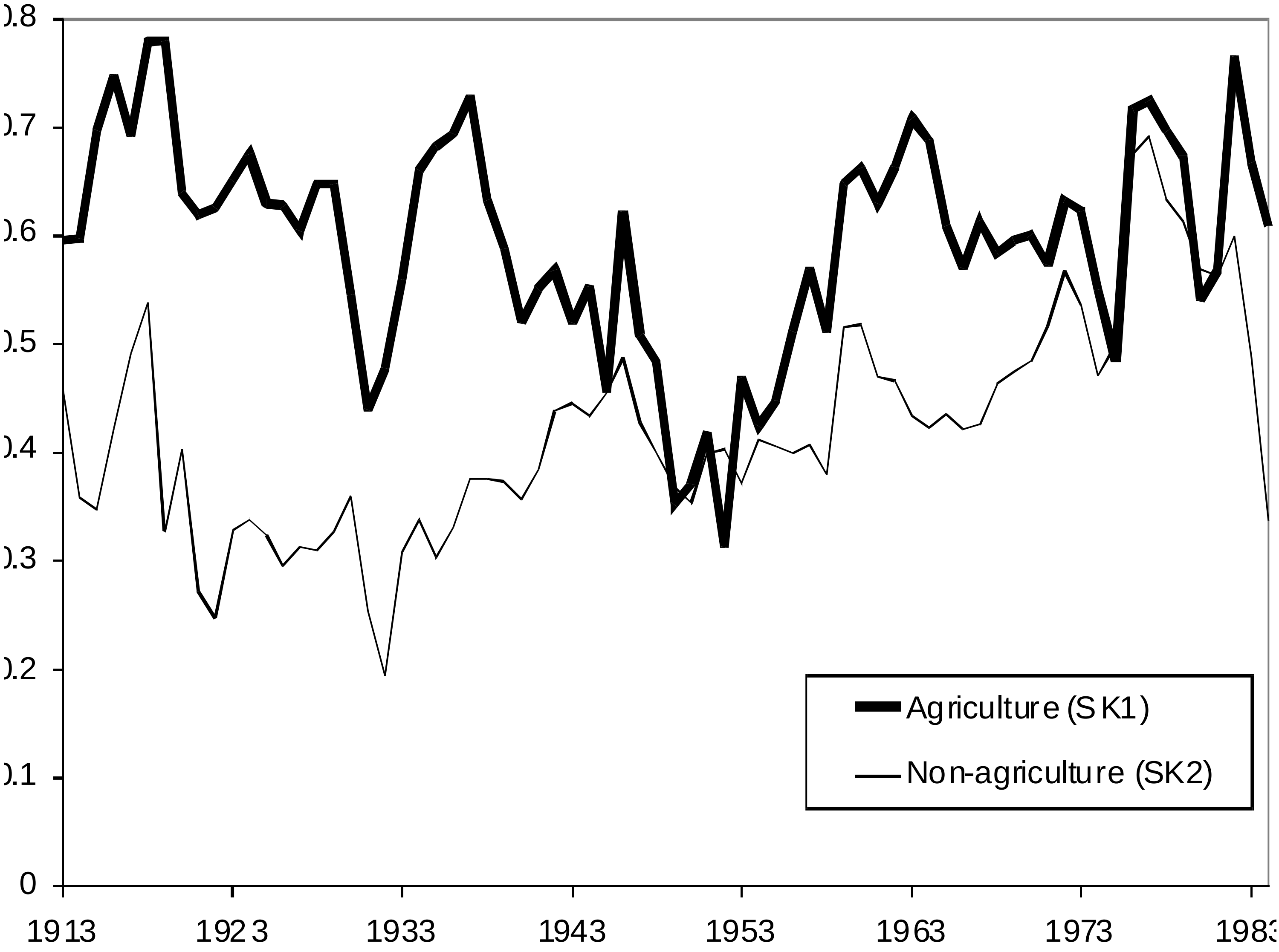


Figure 2 Argentina Capital shares

### TABLE – AGRICULTURAL PRODUCTION FUNCTION

| | W(time, country) | | Between time | | Between country | |
|---|---|---|---|---|---|---|
| **Variable** | **Estimate** | **t-score** | **Estimate** | **t-score** | **Estimate** | **t-score** |
| **Inputs**: | | | | | | |
| Capital | 0.37 | 6.9 | 1.03 | 6.01 | 0.34 | 13.13 |
| Land | 0.47 | 3.78 | | | -0.03 | -2.82 |
| Labor | 0.08 | | -0.16 | -0.16 | 0.26 | 13.67 |
| Fertilizer | 0.08 | 1.53 | 0.14 | 0.33 | 0.43 | 21.91 |
| **Technology**: | | | | | | |
| Schooling | 0.09 | 0.55 | -0.28 | -0.06 | 0.02 | 0.52 |
| Peak yield | 0.83 | 3.8 | -0.32 | -0.07 | 0.06 | 4.19 |
| Development | 0.52 | 3.36 | -0.21 | -0.33 | 0.31 | 2.97 |
| **Prices**: | | | | | | |
| Relative prices | 0.04 | 1.78 | 0.02 | 0.09 | 0.01 | 1.95 |
| Price variability | -0.03 | -0.97 | -0.07 | -0.26 | -0.08 | -2.82 |
| Inflation | 0 | -0.75 | 0.04 | 0.71 | 0.07 | 4.25 |
| **Physical Environmental:** | | | | | | |
| Potential dry matter | | | | | 0.16 | 2.68 |
| Water availability | | | | | 0.44 | 7.96 |

Note: R-square for 777 obs. = .9696
Source: Mundlak, Larson, and Butzer, 1999.