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Macroeconomic Adjustment and Growth

Country Economics Department
The World Bank
September 1989
WPS 279

Public Disclosure Authorized

What Determines the Rate of Growth and Technological Change?

Paul M. Romer

Policies to encourage more open trading and accumulation of human capital may be as important to growth and technological change as additional foreign lending.

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After analyzing cross-country correlations between economic growth and other variables, Romer concludes the following:

There is little direct support for the idea that exogenous increases in the savings rate by themselves cause increases in the rate of technological change. Apparently exogenous increases in the rate of savings and investment seem to be associated with lower rates of return to capital.

Increased openness to international trade speeds up growth. So does an increase in the number of scientists and engineers. Increased investment in physical capital alone does not.

The rate of technological change, and therefore the marginal product of capital, seem to increase when there are more scientists and engineers, as one would expect.

Increased openness to international trade also seems to increase the rate of technological change. Countries more open to trade have a higher level of investment and capital growth — which is not associated with a fall in the marginal product of capital. Countries that become more integrated with world markets seem to have a higher marginal product of capital.

Increases in capital investment associated with a higher per capita GDP are associated with a fall in the marginal product of capital. Increases in capital investment associated with increases in trade are not.

This suggests that policies to encourage more open trading may be as important to growth as additional foreign lending — especially in their cumulative effects — and at the same time enhance the efficient use of foreign loans.

Method: Romer summarizes known correlations between growth in per capita income over time and other economic variables, particularly those related to investment and international trade. He presents some regression evidence that extends the existing correlations. But his main contribution is to interpret these correlations — particularly correlations between the rates of technological change and capital accumulation — in the context of an aggregate theory of growth that explicitly models technological change.

This paper is a product of the Macroeconomic Adjustment and Growth Division, Country Economics Department. Copies are available free from the World Bank, 1818 H Street NW, Washington DC 20433. Please contact Raquel Luz, room N11-057, extension 61760 (45 pages with tables).

What Determines the Rate of Growth and Technological Change?*

by
Paul M. Romer

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* This work was supported by the Macroeconomic Adjustment and Growth Division of the World Bank and by NSF Frant #SES-8821943. The author is grateful for comments that were made by seminar participants at the World Bank.

There is a substantial body of evidence that documents cross section and time series correlations between economic growth and various economic, social, demographic, and political variables. For economists who want to understand the growth process and policy makers who want to influence it, the basic challenge is to find some way to uncover the causal connections that explain these statistical regularities. Fundamentally, causality can be identified only in situations where we have evidence about the exogeneity of the variables that are conjectured to play a causal role. By design or by accident, we must have something like a classical experimental setting where a variable that is conjectured to play a causal role takes on values that are independent of any other variable and where the subsequent outcomes for other variables are observed.

In disciplines like pharmacology where experiments are relatively inexpensive to carry out, theory is not always necessary. If a randomized clinical trial shows that a drug is safe and effective, it can be used with confidence, whether or not there is an accepted theoretical explanation of the underlying biological mechanisms. In a discipline like economics, where experimental design is prohibitively expensive and where natural experiments are rare, theory plays a much more important role. Theory provides the link between one set of correlations that may be of little inherent interest but where the causal relationships are understood, and another set of correlations where identifying the causal connections is more important. It is the tool that we use to generalize results from a familiar setting, where we have enough experience to infer causal relations, to a less familiar setting.

This paper briefly summarizes some of the known correlations between growth in per capita income measured over long time intervals and other economic variables, particularly those relating to investment and international trade. It also presents some regression evidence that extends the existing set of correlations. Compared to earlier work on development, the main contribution here is an attempt to interpret these correlations in the context of an aggregate theory of growth that explicitly models technological change. Of particular interest is the interpretation of the apparent correlation across countries between the rate of technological change and the rate of capital accumulation.

The most important conclusions that emerge from this analysis are as follows:

1) There is little direct support for the idea that exogenous increases in the savings rate cause increases in the rate of technological change. On the contrary, apparently exogenous increases in the rate of savings and investment seem to be associated with lower rates of return to capital, much as one would expect in a neoclassical model.

2) Increases in openness to international trade do seem to cause increases in the rate of technological change. Countries that are more open have a higher level of investment and capital growth, but contrary to the finding noted above, this higher level is not associated with a fall in the marginal product of capital. Countries that are expanding their degree of integration with world markets seem to have have a higher marginal product of capital.

3) Intuitively obvious measures like the number of scientists and engineers also seem to be related to increases in the rate technological change and therefore in the marginal product of capital.

The tentative nature of these conclusions should be clear. What this paper shows is that there is a theoretical model with the specified causal links which is consistent with the patterns of correlation found in the data. There may be other theories that explain these correlations in very different ways. At a minimum, the analysis here has broadened the task that alternative other theories must attempt. In discussions of the correlation between capital accumulation and growth, it will no longer be enough to put forward an explanation for the correlation between these two variables alone. An alternative theory must do what the theory here does, simultaneously explain this correlation and other correlations with trade and human capital data.

No doubt other such theories can and will be put forward. However, the theory suggested here seems to have the additional strength that it conforms to our experience at the micro or firm level, where something closer to controlled experiments are feasible and where we therefore have a firmer grip on the nature of causal connections. Just as informal experience and formal evidence at a less aggregate level would suggest, the theory described here attributes an important causal role for the creation of new goods, especially new producer durables, in the cumulative process of growth and technological change. It suggests that the stock of inputs used in the research and development process influences the rate at which new goods and technologies emerge. And it suggests that variables like the degree of patent protection that affect the returns to innovation will matter for the aggregate rate of technological change. All of these intuitive obvious observations are markedly absent from most discussions of aggregate growth, both in the older neoclassical models and in many of the more recent models as well.

In a strict formal sense, the data presented here do not solve the problem of endogeneity. At the aggregate level there simply are no clearly exogenous variables. The main support for the causal interpretation suggested here comes from the fact that the theory can be applied at both the aggregate and at a much finer level, and that its implications at the less aggregate level seem sensible.

Section 2 describes the rationale for the type of model used here, an aggregate, equilibrium model. Section 3 gives an informal description of the the model itself. Section 4 describes how the model is implemented empirically. Section 5 presents new regression results using cross country data. Section 6 summarizes related evidence from other studies. A final concluding section reiterates the main findings and illustrates their quantitative significance.

Section 2: Theoretical Framework

The model used in what follows differs in two ways from models that are widely used in development. First, it is explicitly in the tradition of equilibrium models. Even though it departs from the competitive, price taking assumption that has become standard in equilibrium models, it starts from an explicit specification of preferences, an aggregate technology, and an equilibrium concept. As suggested in the introduction, the rationale for this modeling strategy is that it offers the most power for generalizing across different types of evidence to reach conclusions about causality. Models that start from the assumption that there is something unspecified that is different about aggregate level analysis that makes standard tools not apply do not have this property.

Discussions of growth by early classical economists allowed for the possibility that increasing returns to scale in manufacturing were an important factor in explaining the rapid growth of output observed in this sector. Once the formal theory of market structure and competition was recognized as being applicable at the aggregate level, it became clear that the assumption of increasing returns required other assumptions as well. Since most industries have many firms, it must be the case either that there are important external effects so that the increasing returns are external to any individual firm, as suggested by Alfred Marshall, or that firms do not sell goods that are perfect substitutes, as emphasized by Joan Robinson and Edward Chamberlin. These alternatives have implications for other observations about industry and firm behavior that can be compared with data. Thus, formal theories of market equilibrium show how evidence about industrial organization and firm behavior can be brought to bear on the fundamental questions about growth. Absent these theories, economists were free to assume whatever they wanted about returns to scale.

On these grounds, a complete, general equilibrium model is to be preferred. It is much harder to relate a model like the Harrod–Domar model to industry data. At the aggregate level, the reference standard for an equilibrium model is the neoclassical model, a model that has fallen out of favor in studies of development. In part, this is because it has little explanatory power in comparisons of growth rates across countries; most of the action is in the exogenous variation in the rate of technological change. Apparently because of dissatisfaction with this model, the modeling strategy in development has been to use models that are less restrictive but that therefore have much less power to integrate evidence from many different quarters. Because they are less restrictive, Harrod–Domar models that emphasize fixed coefficients for labor and capital in the production of output and assume that a supply of unemployed labor is available, or disequilibrium models that focus on exogenously given differences in the marginal productivity of inputs in different sectors and on the reallocation of resources across sectors offer richer and more suggestive ways to summarize the data than the rigid growth accounting framework of the neoclassical model. Without these less rigid models, it is hard to motivate examination of a variable like trade policy or to entertain the possibility that variation in the rate of investment might play a causal role in the growth process. However, these restrictions are specific to the neoclassical model, not to all equilibrium models. The next section describes an equilibrium model that is much less restrictive.

In addition to following an equilibrium strategy, the model here is essentially an aggregate model. No distinction is made between major sectors like agriculture and manufacturing, and the growth process faced by less developed economies is assumed to be qualitatively the same as that faced by developed economies. This second choice is partly a matter of convenience and simplicity, but it also reflects a judgment that it does much less violence to the data than is commonly supposed. It is true that the composition of demand changes systematically with the level of income, but this does not necessarily have strong implications for the rate of growth of output or productivity. In developed countries, productivity growth or technological change has been as dramatic in agriculture as in manufacturing. In the one part of the service sector where outputs can be adequately measured, telecommunications, productivity growth has been equally impressive. Moreover the authors of a major synthesis of cross country studies of industrialization comment:

> Although sectoral differences in productivity are significant, differences among countries are equally so. Total factor productivity growth tends to be higher in all sectors in countries of high growth. (Chenery, Robinson, and Syrquin, 1986.)

It is this country specific element of productivity growth that the model described here seeks to address.

Section 3: Description of the Model

The basic model used here is drawn from Romer (1988) . In many respects, it is quite close to the neoclassical model with technological change. The key difference is that the dependence of technological change on economic decisions is explicitly modeled. To do this, it is necessary to depart from the usual framework of perfect competition and adopt instead a framework with differentiated commodities and monopolistic competition. Since differentiated commodities imply an important role for trade, the attempt to model endogenous technological change has the unintended benefit of showing why trade policy may be important for growth.

The basic difficulty in introducing endogenous technological change into the neoclassical model is well known. Suppose that net national output takes the form

$$Y = F(L,H,K,A)$$

where L is the total stock of physical labor, H is the total stock of trained human capital, K is capital, and A is an indicator of the level of the technology. L grows with increases in the population and the labor force participation rate. Since H here is measured in total, not average terms, it grows when L does. It also grows relative to L when the level of training or education increases. (Many formulations make L and H perfect substitutes so that they can be added together to get a single measure of effective labor. This is a special case of the general formulation described here.) The rate of growth of the capital stock depends on savings behavior,

$$\dot{K} = Y - C = sY,$$

where s is the aggregate savings rate out of net national income.

Decisions about the allocation of resources determining the rates of growth of H, L, and K are all made by self interested individuals. For example, individuals save to earn a rate of return on their capital or invest in education to earn a rate of return on human capital. To complete a description of the evolution of the model, one would like to introduce a sector that explains why individuals make investment decisions that cause A to grow as well.

Formally, it is easy to introduce a research and development sector that produces A. Let

$$\begin{aligned} Y &= F(A, K_1, L_1, H_1), \\ \dot{A} &= E(K_2, L_2, H_2), \end{aligned} \tag{1}$$

with the understanding that $K_1 + K_2 = K$, ... The difficulty for this kind of model comes in explaining why any self-interested individual would devote any resources to the A producing sector. The crucial assumption on F is that it exhibits constant returns to scale in the arguments K, L, and H alone. The rationale for this assumption is inherent in what we mean by the technology. Since the technology is intended to capture abstract knowledge, production processes, designs, etc. that can be used as many times as desired, a simple replication argument suggests that by doubling K, L, and H and exactly replicating an existing productive activity, it should be possible to double output.

If firms are price takers, K, L, and H are paid their marginal products. By the properties of constant returns to scale functions, total revenue Y (measured in units of output) will be exactly equal to compensation paid to K, L, and H:

$$Y = \frac{\partial}{\partial L}F(L,H,K,A)\cdot L + \frac{\partial}{\partial H}F(L,H,K,A)\cdot H + \frac{\partial}{\partial K}F(L,H,K,A)\cdot K.$$

A competitive firm that pays anything at all for the technology that it uses will not break even. Without some explanation for how A is compensated, there is no way to explain how the resources devoted to the A producing sector earn a return.

In a literal sense, the neoclassical model faces this difficulty by assuming that A does not receive any compensation, but grows nonetheless. The stock of A is like a public good of unknown provenance. A somewhat more reasonable interpretation of the model is that A is a conventional public good supplied by the government through its support for basic research. No doubt, there is some merit to this view in the post-war US economy, but its relevance for earlier eras and for other countries is questionable. Moreover, even in the post-war US, this view does nothing to help explain the large quantities of resources that private firms devote to research and development.

To someone who is innocent of economic theory, the resolution of this difficulty is obvious. Firms that invest large amounts in the research and development activities leading up to the introduction of a new good do so with the expectation of being able to sell the good for more than its cost of production. Assuming a constant cost of producing each unit of the good, firms expect to be able to charge a price higher than marginal cost.

A good example of such a good is a microprocessor or a piece of software that has a very large development cost but a very low, constant marginal cost of production. As the markets for these goods shows, a large gap between price and marginal cost can be supported in an equilibrium with no restrictions on entry. All that is needed is that the agent who incurs the fixed development costs has property rights over the good so created, for example through patent protection, copyrights, or secrecy. This means that another new good introduced by different firm cannot be a perfect substitute for some existing good, so competition takes the form of monopolistic competition between suppliers of similar, but distinct goods.

The way this is captured in the model described here is to assume that output of final goods is a function of labor L and human capital H, but is also a function of a list of differentiated or specialized intermediate inputs in production, $\{x_i\}_{i=1}^{\infty}$. To capture the idea that there is no ultimate limit to the potential for innovation, the list of conceivable inputs is assumed to be infinitely long.

Thus, output can be written as a function

$$Y = G(L,H,\{x_i\}_{i=1}^{\infty}). \tag{2}$$

(Subscripts distinguishing good used in this sector from total goods other sectors will be reintroduced below.) Because of the replication argument noted above, this expression is assumed to be a constant returns to scale function. Instead of appearing explicitly as an argument, capital appears indirectly through the inputs x_i. For example, x_7 could be a dump truck, x_8 a lathe, x_9 a computer. Each of these specialized inputs requires raw capital in their production. Capital can be reintroduced in a reduced form expression as follows.

Although there is an infinite number of potential inputs that could be used in production, at any point in time, the set of available inputs x_i is limited to the set of goods that have been invented and introduced. At time t, let $A(t)$ denote the upper bound of this set, so intermediate inputs $i \in \{1, \ldots, A(t)\}$ are in use at time t. Let $K(t)$ denote the total stock of capital (in units of foregone consumption) that are embodied in the stock of intermediate inputs in use. As a simplification, the list $\{x_i\}$ that is in use at time t can be characterized by the two values $A(t)$ and $K(t)$, and output can be written as

$$Y = \tilde{G}(L,H,K,A). \tag{3}$$

Starting from the function G in equation 2, two key properties of the reduced form function $\tilde{G}$ follow immediately. First, $\tilde{G}$ exhibits constant returns to scale in the arguments L, H, and K for a fixed level of A because doubling the quantity of all goods L, H, x_1, ... , x_A that are in use does not imply any change in the number of goods in use as measured by A. Secondly, as K increases for fixed L and H and A, the marginal product of capital will decrease for the same reason that it decreases in the neoclassical model. Increases in K will be spread across increases in the goods x_i, and the marginal productivity of each x_i falls as the quantity increases relative to the quantities of L and H.

The behavior of $\tilde{G}$ as A changes can be derived by reference to Figure 1. This plots output Y as a function of a representative intermediate input x_i when all other inputs are held constant. For simplicity, assume that once a good i has been invented, designed, and introduced (costs of doing this to be described below), units of good i can be produced from units of capital and measured in in these units. For a fixed level of A, all of the goods x_i for $i = 1$, ... , A will be used at a level that equalizes their (net of depreciation) marginal product. Thus, input i is used at the level $\bar{x}_i$ in the figure.

When A increases, it creates a new investment opportunity for capital. Starting from a value equal to 0, the marginal productivity of a unit of the new good, and therefore of capital invested in the new good, will be very high. Thus, the initial effect of an increase in A is to raise the marginal productivity of capital. Assuming that capital in place in other inputs cannot be diverted to production of this new input, output grows only as new investment takes place. Thus, growth in A does not directly increase output, but rather increases the marginal product of capital, and may also induce a higher rate of investment. Once the stock of capital fully adjusts, an increase in A will be associated with an increase in K such that the marginal product of capital remains constant.

Literally, the model here equates increases in the technology with increases in the number of productive inputs in the economy. An example of an improvement in the technology would therefore be the introduction of a new input like a numerically controlled lathe. More generally, A can be thought of as an index of the creation of new investment opportunities.

In a closed economy, growth in the technology as measured by A occurs through research and development. Suppose that the final output sector is designated sector one, so that the expression for output is

$$Y = G(L_1, H_1, \{x_{1i}\}_{i=1}^{\infty}). \tag{4}$$

Output of new designs and goods can be written formally as

$$\dot{A} = R(L_2, H_2, \{x_{2i}\}_{i=1}^{\infty}). \tag{5}$$

The adding up constraint for the economy is that the sum of input usage in the two sectors equal the total supply, $L_1 + L_2 = L$, $x_{1i} + x_{2i} = x_i$, etc. Using the simplification from above that the list $\{x_i\}$ can be summarized by the number of non-zero components A and by the total amount of capital embodied in these goods K, these equations can written in reduced form

$$Y = \tilde{G}(L_1, H_1, K_1, A),$$
$$\dot{A} = \tilde{R}(L_2, H_2, K_2, A). \tag{6}$$

Note that the level of K is split between the two sectors, but the level of A is the same. If A increases because personal computers are introduced, they can be used either in research or in final output production. K_1 and K_2 will increase depending on the number of PCs used in each sector, but the basic good is available for use in both.

As always, capital accumulation depends on savings,

$$\dot{K} = Y - C = sY. \tag{7}$$

For fixed L, H, and A, a fixed savings rate leads to falling a marginal productivity of capital and a rate of growth that approaches 0 just as it does in the neoclassical model. Even if K and H grow together, fixed L will ultimately imply slowing growth and diminishing marginal productivity to accumulation of K and H together. The view captured in this model is that if growth were based solely on increases in the level of training and experience with a fixed set of tools and increases in the per capita quantity of these tools, rates of return to investment in additional copies of the existing tools and in more training with these tools would fall rapidly. (Think of holding the set of tools used in the 19'th century constant and increase training and the number of tools per capita.) Ultimately, growth in per capita income must be driven by increases in the technology, as represented here by increases in the set of tools, or intermediate inputs that can be used in production.

From this perspective, the long run prospects for growth in a closed economy are ultimately determined by the resources that are allocated to the sector that produces the new intermediate inputs or tools. This allocation is determined by the interaction of the following effects. To produce a new tool requires a design, that is, a one unit increase in the quantity A. This is accomplished by devoting resources to the production function R or $\tilde{R}$ in equations 5 and 6. The crucial observation about this kind of cost is that it does not contribute to the marginal cost of producing units of the good. Once this fixed cost has been incurred, there is a separate constant marginal cost of producing units of the tool or input.

For simplicity, it is sufficient to imagine that each individual unit of the new tool requires a fixed quantity of capital. Since capital is accumulated as foregone output, this is equivalent to assuming that the physical units of the intermediate input are produced according to the same technology as final output. Output of the intermediates goes up as productive inputs are shifted in constant proportions out of final goods production and into production of intermediate inputs.

By assumption, each new tool x_i is introduced by a different firm i. Because it is the unique supplier of the tool i, firm i can charge the monopoly price for its output, a price that is higher than the marginal cost of production. This creates the mechanism missing from the neoclassical model that enables a private firm to pay for increases in the stock of A. The flow of income generated by a price that is higher than marginal cost constitutes the return to the creation of a new good.

Equilibrium in this model occurs when each of the firms $i=1, \ldots, A$ and all of the potential new entrants to be firm $A+1, A+2, \ldots$ earn zero profit in an intertemporal sense. If P_A denotes the implicit cost of producing the next design, in equilibrium, P_A must be equal to the present value of this flow of net revenue arising from monopoly pricing.

It is now clear what determines the allocation of resources between the productive sector and the research and development sectors in this economy. If P_A is equal to the present value, measured in units of output goods, of the stream of monopoly profits associated with a new good, inputs like L, H, and K will be allocated to equalize their value marginal products in the two sectors:

$$
\begin{aligned}
\frac{\partial}{\partial L}\tilde{G}(L_1,H_1,K_1,A) &= P_A \cdot \frac{\partial}{\partial L}\tilde{R}(L_2,H_2,K_2,A), \\
\frac{\partial}{\partial H}\tilde{G}(L_1,H_1,K_1,A) &= P_A \cdot \frac{\partial}{\partial H}\tilde{R}(L_2,H_2,K_2,A), \\
\frac{\partial}{\partial K}\tilde{G}(L_1,H_1,K_1,A) &= P_A \cdot \frac{\partial}{\partial K}\tilde{R}(L_2,H_2,K_2,A).
\end{aligned}
\tag{8}
$$

These equations determine the levels of inputs in $\tilde{R}$, and thereby determine the rate of growth of A. As in the neoclassical model, for any fixed level of savings, the rate of growth of A ultimately determines the rate of growth of output.

One immediate, and intuitively obvious implication of this model of growth is that in a closed economy, any intervention that reduces the value P_A will reduce the resources devoted to R, and therefore reduce long run growth. Some kind of protection for intellectual property rights that can prevent ex post competition between an innovating firm and knock off firms that incur only the production costs is essential for P_A to be greater than zero. Explicit or implicit taxes on innovating firms, even taxes that appear ex post to be pure profits taxes, will reduce P_A and thereby reduce growth. Anecdotal evidence suggests that implicit taxes, especially those related to entry, may be very high compared to explicit taxes. (See for example the estimates from de Soto, 1989, on the regulatory and bureaucratic cost of starting even the simplest firm in Peru.)

A less obvious implication concerns the effects of increases in the total quantities of the inputs H, L, and K. Romer (1988) shows that in a case where the research sector is assumed to be human capital intensive relative to the production sector, (specifically, where raw labor L is of negligible important in research compared to human capital H), an increase in the total stock of human capital causes a higher fraction of human capital to be devoted to the research sector. Thus, increases in H lead to increases in output not only through its direct role in production of Y as captured in growth accounting exercises, but also through its indirect effect on the rate of growth of A, an effect that would show up in the accounting exercise as a positive relation between total level of H and the size of the growth residual.

Less clear cut is the effect of increases in L or of the savings rate on the rate of growth. Romer (1988) solves the model for a special case that relies on unit elasticities of substitution throughout the production sector. In this case, neither an increase in L, nor an increase in the savings rate causes an increase in the growth of A. They do increase the level of output for any fixed A. Thus, as in the neoclassical model, these variables have level effects but not growth rate effects. Using more general functional forms, it is clear that changes in these variables can affect growth either positively or negatively. For example, in the case where H and L are complements in producing final output and where final output production is more labor intensive than the sector producing A, an increase in L, holding H constant, leads to a decrease in the rate of growth. No direct evidence on this point is presented here, but this case would correpond to the general impression in the development literature that increases in the work force do not have as large an effect on output as a growth accounting exercise would suggest. Conversely, periods of labor scarcity may generate relatively high rates of growth of technology and productivity as has often been suggested in historical analyses. The argument here is that they can induce reductions in the rate of growth of the technology. Evidence that this may also have been a factor in the long run behavior of productivity movements in the US is presented in Romer (1987).

The other possibility that can arise if more general functional forms are used is that an increase in the savings rate could induce changes in the price P_A that could induce increases in the rate of growth of A. In this case, contrary to the result from the neoclassical model, an increase in savings could have a permanent growth effect in addition to the conventional level effect.

The model has very strong implications for the beneficial effects of free trade. This is partly to be expected from the existing work on trade with monopolistic competition in consumer goods. However, the emphasis here on differentiated intermediate inputs in production generates effects that show up in increases in measured GDP, whereas much of the effect of increased trade in differentiated consumption goods shows up in welfare effects that are not measured. (Differentiated consumption goods can be added to the present model with little change in its predictions about growth.)

The main effect from integration with world markets comes from the fact that it is inefficient to incur a fixed design or research and development cost for a specific good more than once. Suppose that there were two identical closed economies, each devoting the same level of resources to the creation of the same new goods at the rate g_A. Suppose now that these countries were to engage in trade in newly created intermediate goods. Suppose that the first country develops only the new goods with an odd index i, and the second country develops the new goods with an even index. Without changing in any way the allocation of resources between production on the one hand and new good development on the other, this will double the worldwide rate of growth of A and the worldwide rate of growth of final output.

This observation offers a clear interpretation of why import substitution strategies are dominated by export promotion. With respect to the intermediates modeled here, import substitution is a strategy of local design and manufacturing of goods that are available in other countries, a movement toward the closed economy equilibrium described above. By reproducing all the elements of A that are used domestically, this strategy cuts off a small country from many of the benefits of worldwide growth in the variety of goods represented by worldwide growth in A. The alternative strategy, export (and import!) promotion, involves a decision to design new goods, thereby increasing the worldwide stock of A, and to exchange the new locally produced goods for different goods produced elsewhere.

One qualification on the usual presumption in favor of free trade is that the arguments here pertain only to intermediate goods in production. The model suggests that restricting the range of producer durables that can be used by firms to those few that are locally produced has strong negative implications for growth of GDP, but restricting the range of consumer durables that are available may not. It presumably will have negative effects on the level of welfare, but not necessarily on measured rates of GDP growth.

The model also suggests that the threat perceived by less developed countries in their trade with producers of sophisticated goods may not be real. The implication of the model is that for final goods production, the real advantage lies in being able to buy a new good like a personal computer, not in being able to design it or produce it. Consider once again Figure 1, and interpret it as output of final goods as a function of the a new good like a computer. To make the example as sharp as possible, suppose that this country has no capacity for the design of new goods (that is for the creation of A) and saves none of its income. All of its L and H are used in the production of final goods. All of the intermediate inputs are imported, paid for with exports of the final goods.

Figure 1 shows what the effect is of trade in this new intermediate. In terms of final output, the rental price of the new input will be r_i. In the small country, the new inputs will be used at the level $\bar{x}_i$ such that the slope of Y as a function of x_i is equal to r_i. If the small country allows imports of the new good, it leads to an increase in final goods output equal to $Y(\bar{x}_i)$ that is achieved at a cost $r_i\bar{x}_i < Y(\bar{x}_i)$. Trade in this new good is very different from trade in an existing good. At the margin, an additional unit of some traded good has an effect on output that is just equal to its price. Because output goes up by more than the payment for the new factor, payments to the existing factors L and H will increase. The surplus associated with the creation of a new intermediate input in production accrues to the other inputs that are used in combination with it.

Worldwide, this surplus represents the growth accounting residual, the part of growth in output that cannot be explained in terms of increases in the market value of inputs. In the small country (as in the rest of the world), this surplus will show up through increased marginal productivity and compensation for the inputs L and H. Initially, the new opportunity represented by $\dot{A}$ increases the marginal productivity of capital, but eventually, the stock of capital responds and drives the rate of return back to its equilibrium level.

The trade effect described so far arises from the fact that for an open economy, the relevant stock of A is the worldwide stock, not the local stock. A second, more subtle, effect is present as well. The relevant stock of human capital is also the world wide stock, not the local stock. Since the fraction of human capital devoted to research is an increasing function of the total stock of H, a small country that opens itself to trade will not only receive the benefits of growth in A in the rest of the world. It will also devote more resources to the A producing sector and produce a higher domestic rate of growth of A.

4. Empirical specification

Testing the implications of the model in cross country data is complicated by the fact that measures of most of the variables of interest are not available. Direct measures on the rate of growth of capital are available for relatively few countries. For large cross country comparisons, one must rely instead on measures of investment as a share of GDP. The distinction between being in or out of the labor force is less sharp in poorer countries, especially ones where agriculture plays an important role. No direct measures of A or its rate of growth are available.

The available data can be used as follows. For any variable X, let $\hat{X} = \frac{d}{dt}\ln(X)$ denote the time derivative of the natural logarithm of the variable and let $\epsilon_X = \frac{\partial \ln(\tilde{G})}{\partial \ln(X)}$ denote the elasticity of $\tilde{G}$ with respect to X. Logarithmic differentiation yields the usual growth accounting expression,

$$\hat{Y} = \epsilon_L\hat{L}+\epsilon_H\hat{H}+\epsilon_K\hat{K}+\epsilon_A\hat{A}. \tag{9}$$

Using the fact that $\frac{d}{dt}K = I - \delta K$, where I denotes investment and δ is the depreciation rate, this can be written as

$$\hat{Y} = \epsilon_L\hat{L} + \epsilon_H\hat{H} + \frac{\partial\tilde{G}}{\partial K}\frac{I}{Y} - \epsilon_K\delta + \epsilon_A\hat{A}. \tag{10}$$

Let $y=Y/L$ denotes output per worker. Then because $\epsilon_L+\epsilon_H+\epsilon_K$ are assumed to sum to 1, we can write

$$\hat{y} = -\epsilon_k\hat{L} + \epsilon_H(\hat{H}-\hat{L}) + \frac{\partial\tilde{G}}{\partial K}\frac{I}{Y} - \epsilon_K\delta + \epsilon_A\hat{A}. \tag{11}$$

Because A is not observed, its effects can be detected only indirectly through its effects on the marginal product of capital $\frac{\partial \tilde{G}}{\partial K}$ and through its effects on the rate of investment $\frac{I}{Y}$. Suppose first that there is a permanently higher rate of growth of A in one country compared to another, and suppose that savings behavior adjusts so that the rate of return on capital is the same in the two countries. Assume that A is measured so that interest rates stay constant when the opportunities for investment A and the stock of capital K grow at the same rate. Assume as well that output is approximately log linear so that the marginal product of capital is proportional to the ratio of Y to K. (An example with these property is worked out in Romer, 1989.) Since $\hat{K}$ is proportional to $\hat{A}$, and Y/K is constant, we can write,

$$\hat{A} = \hat{K} = \frac{I}{K} - \delta = \frac{I}{Y}\frac{Y}{K} - \delta. \tag{12}$$

Thus, in this long run sense, variation in $\hat{A}$ will show up as variation in $\frac{I}{Y}$ that occurs with no variation in the marginal product of $\frac{\partial \tilde{G}}{\partial K}$; that is, with no variation in the coefficient on $\frac{I}{Y}$ in equation 11.

Thus, variation across countries in A that is of long enough duration that the economy is able to adjust to keep interest rates constant will be collinear with variation in the share of investment in GDP. In a regression equation that included $\frac{I}{Y}$, this variable would pick up all of the effect of the variation in $\hat{A}$.

Consider now variation in $\hat{A}$ that does not induce completely offsetting variation in $\frac{I}{Y}$ over the time interval during which data are collected. In this case, one would expect to find that an increase in the rate of growth of A is associated with an increase in the rate of growth of per capita output, even after taking account of the effect of $\frac{I}{Y}$. One would also find that the increase in A relative to K was associated with an increase in the marginal product of capital.

Suppose then that z is a variable that is thought to be a proxy for variation in $\hat{A}$, and that z is not correlated with variation in $\frac{I}{Y}$. Then one could estimate a regression equation of the form

$$\hat{y} = c_1 + c_2\hat{L} + c_3(\hat{H} - \hat{L}) + (c_4 + c_5 z)\frac{I}{Y} + c_6 z. \tag{13}$$

This is the basic equation that is estimated in the next section. Most of the emphasis is on variables that play the role of z.

In practice, if there is variation in A across over time, there is reason to expect that the process of convergence to equilibrium levels of interest rates would be slow. Neither aggregate time series evidence and nor panel data on individuals suggests that there is a large interest elasticity of savings, yet most of the adjustment of savings in response to new investment opportunities must take place domestically. In terms of quantities, international capital flows tend to be rather small. (Feldstein and Horioka, 1980). In terms of prices, real interest rates seem to diverge appreciably even between the advanced economies that presumably are most closely linked. (See for example Miskin, 1984.) Thus, it is not unreasonable to expect to find cases where growth in A outstrips growth in K, even over the 25 year horizon considered in the data examined here.

The last effect one might hope to identify with these data is some indication about whehter exogenously higher levels of $\frac{I}{Y}$ are associated with a lower marginal product of capital. In increases in the savings rate do not induce increases in the rate of growth of A, exogenous variation in $\frac{I}{Y}$ has the same effects here that it has in the neoclassical model. It causes offsetting variation in the marginal product of capital. If the interval of time is long enough to ensure that the capital output ratio has converges to its steady state value, the offset is complete, and variation in $\frac{I}{Y}$ is not associated with any change in $\hat{y}$. If the variable z in equation 13 is one that causes variation in savings and investment without causing any change in A, one would expect to estimate a coefficient c_5 that was negative.

5. Results from estimation

Table 1 gives definitions of variables used in what follows. Table 2 gives summary statistics for these variables. The set of variables that cover the largest set of countries are those for basic national income accounts concepts of GDP, the share $i = I/Y$ of investment (both private and government) in GDP, and the share of noninvestment spending by the government. Data for these variables for 112 countries from 1960 to 1985 are taken from Summers and Heston (1988). These data have the advantage that they are corrected for deviations from purchasing parity, so that comparisons of per capita income are more meaningful than comparisons made in terms of official exchange rates. Trade data on exports and imports covering this same period are available from the World Bank for 90 of these original 112 countries. Most of the subsequent analysis is done with this set of countries. Finally, data on numbers of scientists and engineers are available for a subset of 22 of these countries.

Table 3 shows the basic finding for these data that has been confirmed in many different data sets by many different authors. If variables are measured over long time periods, the share of investment in GDP is closely related to the rate of growth of GDP. By itself, it explains 34% of the cross country variance in growth rates. This finding suggests that the result for the developed countries (noted for example in Romer 1987) carries over to a broad sample of countries weighted towards less developed countries. Growth in output and in capital are both correlated with growth in technological change.

The theory outlined above offers two suggestions about how to untangle causality in this correlation. It suggests that cross country variation in openness to international trade and in the amount of scientific human capital should cause variation in the rate of technological change. If these variables are treated as exogenous, then this gives a source of exogenous variation in $\hat{A}$ that can be exploited. As suggested above, in the long run, variation in $\hat{A}$ should show up ultimately through variation in the investment share. Table 4 presents the results of attempts to link trade, scientists, and any of the other variables variables used here, with the rate of investment.

Of all the variables considered here, only two have any explanatory power for the investment share, the average share of exports in GDP and the average level of real income, both measured over the full 25 year period from 1960 to 1985. Neither the change in the export share over this period, nor either the levels or rates of change of the scientific variables have any explanatory power in this regression. Nor do any of the other variables that do have explanatory power for the rate of growth, the dummy variables for Africa and Latin America and the share of government in GDP, have any explanatory power for the share of investment.

The interpretation offered here for the finding that of all the potential influences on technological change, only the average level of exports influences the average level of investment is that it is the only effect of long enough duration to have influenced the rate of investment averaged over 25 years.

The finding that the investment share is strongly related to the level of income, or more broadly to the general level of development, is not predicted by the theory. In particular, there is no reason to expect that a higher level of development is correlated with a higher rate of technological change. On the contrary, one would expect just the opposite since less developed countries can catch up with the level of technology in developed countries. Presumably, this relation reflects something about institutions or preferences that varies systematically with the level of development and leads to a level of investment that is higher for reasons that have nothing to do with the rate of technological change.

The results from Table 4 are most striking in comparison with those from Table 5. This represents an attempt to estimate equation 13 with a variety of different variables playing the role of z. The first finding is that the variable AVG_EX, the average level of export, that is significant for explaining the investment share i, does not appear in this table because it has no explanatory power for the growth rate in an equation that includs the investment share. This is true whether it is entered directly in the equation or as an interaction term with i; it neither increases the growth rate directly nor increases the marginal product of capital. Thus, the combined finding from the two tables is that openness, as measured by the average level of exports, increases the rate of investment without decreasing the marginal productivity of capital. This is consistent with the view that persistent openness increases the rate of growth of A and the rate of investment.

The finding for the level of income, AVG_Y is just the opposite. Increases in i caused by increases in AVG_Y seem to be strongly negatively related to the average level of income. If this variation in i can be treated as exogenous relative to the rate of technological change, then this finding is consistent with a neoclassical view of the world, and is inconsistent with the view that increases in the stock of capital by themselves can cause increases in the rate of technological change large enough to keep the marginal product of capital constant.

In fact, for the richest countries, the findings suggest that the absence of any variation between i and the growth of income, as the neoclassical model would suggest. The coefficient on i is .22, suggesting that an increase of i from 10% to 20% would lead to an increase in the growth rate of 2.2% for the poorest countries with a value of AVG_Y close to 0. Since AVG_Y varies from $300 to $10,000, the coefficient of $-3.2 \cdot 10^5$ suggests that the implied coefficients for the richest countries in the world are close to 0 or slightly negative.

Several other studies have shown that there is a negative relationship between some measure of the level of development and the rate of growth in an equation like this. (See for example Barro, 1989a,b.) Table 5 shows clearly that the negative dependence arises through its effect on the marginal product of capital. The coefficient on AVG_Y by itself is positive but not significant.

The fact that this equation distinguishes between the role that AVG_Y plays as in an interaction term with i and the direct role it plays in explaining growth is something of a surprise. For all of the other variables considered here, collinearity between the level term and the interaction term with i makes it impossible to discriminate between the two roles. In these other cases, the variables are jointly significant, but their separate effects cannot be distinguished.

The change in the share of exports is one such variable. Overall, it is positively related to growth, but it is impossible to distinguish the extent to which this takes place through an interaction with i and the extent that it arises from a direct positive effect on growth. The regression reported here lets this effect enter through an estimated effect on the marginal product of capital. The somewhat arbitrary convention followed here for variables other than AVG_Y is to let variables that the theory suggests should influence the rate of growth of A enter as interaction terms. This makes the estimated magnitudes comparable, stated in terms of effects on the marginal product of capital. The other variables not suggested by the theory are entered into the regression on their own.

The finding that export growth is correlated with higher growth of output and/or a higher marginal product of capital is consistent with the view that the change in the export share between 1960–64 and 1981–85 induces an increase in the rate of growth of A that is not fully compensated for by an increase in i. As noted in the discussion of Table 4, EX_DIFF does not have any explanatory power for i. The theory suggests that it should induce an increase in A. In this case, the theory suggests that the relatively rapid increase in A compared to K should causes the marginal product of capital to go up and should cause the rate of growth to go up as well.

The dummy variables for Latin America and Africa are entered as a kind of diagnostic check. They have been found to be significant in other regressions of this kind, (Barro 1989a), and they remain so here. They are indications that there is something that the theory is missing or that is not being measured. Entered on their own, they suggest that growth will be slower by 1.3% per year for countries in these regions after holding constant all the other variables here. When they are entered as interaction terms with investment, they suggest that the marginal product of capital is lower by 8–10% in these regions (e.g. the coefficient on i will be smaller by .08 to .10..)

The last variable, government spending, is a possible indirect measure of distortions in the economy. First, government spending must ultimately be financed, so higher spending should be associated with higher direct taxes. As was noted above, government spending could also be associated with high implicit taxes on firms through regulation, so increased spending may signal distortions other than those implied by the taxes needed to fund the spending. The estimated effect here is significantly negative, and not small. An increase in the share of government from 10% to 20% cause a reduction in the growth rate of about 1% per year.

The interaction term between the increase in the share of exports and i is statistically significant, but its magnitude is not large. One concern about this variable is that there could be a great deal of variation in the export share that has little to do with the mechanisms described by the theory. There is also concern about possible endogeneity. It is quite possible that high income growth fuels high growth in trade rather that vice versa. Table 6 reports an attempt to gauge the importance of these two possible effects. It reports a two stage least squares regression that uses independent indicators of openness as instruments for EX_DIFF. These instruments include membership in a trade union for developed countries (EEC and EFTA) and a set of indicators for openness of less developed countries reported in the 1987 World Development report. The first stage regression of EX_DIFF on these instruments is sensibly behaved. The R^2 is around .3. EEC countries had greater growth in the export share than did EFTA countries, and the ranking of the openness given by the World Bank corresponds with that in the regression.

Whether EX_DIFF is entered on its own or as an interaction term in the reported result, the effect of using two stage least squares is to increase the magnitude of its coefficient by 3 or 4 fold. Now, a increase in the share of exports of 10% (e.g. from 10% to 20%) causes an increase in the marginal product of capital of about a 4% (e.g. from 10% to 14%.) The coefficient on the Latin American dummy falls slightly, but remains significant, a hint that trade performance is part of what distinguishes this area. Otherwise, the results from Table 6 are very close to those from Table 5.

In the estimates of equation 13 reported in Tables 5 and 6, the theory suggests that measures of labor force growth and growth in human capital should enter as well. Attempts to find an effect using (admitted weak) proxies for these variables were not successful. Population growth was used as a proxy for labor force growth, but it did not have any significant explanatory power either for the investment share i or for the growth rate of GDP. Presumably there is much room to improve on this variable, but there is a limit to what can be done given the vague distinction between being in and out of the labor force in less developed countries. At a minimum, the working age population would be an improvement.

Attempts to use measures of changes in human capital per capita were similarly unsuccessful. There is some indication that a measure of the change in the rate of literacy was positively related to the share of investment. The estimated effect is relatively large, implying that a 10% improvement in literacy is associated with a .5% increase in i, but the coefficient is not precisely estimated, (t=1.8). The change in literacy had no independent effect on growth when it was entered in the regressions reported in Tables 5 and 6.

Table 7 reports the results of attempts to make use of data on scientists and engineers to identify further instances of variation in the growth rate of the technology. Because of data limitations, the resulting sample consists of only 22 of the most developed countries, and the initial measurement for the number of scientists is from 1970 rather than 1960. (See Table 8 for a list of the countries in this sample.) In this admittedly very small sample, nothing had any explanatory power for the investment share i. In the growth regression, both the (natural logarithm of) the number of scientists and the change in the number of scientists are correlated with growth. The log transformation fit the data much better than the levels or the numbers of per capita.

The theory suggests that for a closed economy, it is the total stock of human capital that matters for rate of growth of A and the rate of growth of output. The findings here are consistent with the interpretation that because of transportation or other transactions costs, these economies are still only partially integrated, and that the local rate of growth of A, and therefore the local inputs into the rate of growth of A, still matters more that what is happening worldwide. Because of the logarithm transformation, the a coefficient of .05 on SCI_DIFF implies than a doubling of scientists over the period is associated with an increase in the marginal product of capital of around 3.5%.

This regression also offers some indication of the presence of an interaction between trade growth and the allocation of resources to a research sector. If the interaction term with SCI_DIFF is excluded from the regression, the interaction term with the growth in the export share (EX_DIFF) has a t-statistic greater than 2. When both terms are present that is at best weak evidence of an effect of growth in trade that is separate from the other effects. Also, in this sample, there is only weak evidence of the negative effect of AVG_Y on the marginal product of capital that was identified earlier. This is matched by the finding noted above that no variable, not even AVG_Y, has any statistically significant explanatory power for i in this very small sample.

6. Comparisons with other results

As noted in the beginning, there is a great deal of evidence on cross country correlations between growth and a variety of other variables. Some of the studies approaching this question from the point of view of development economics are summarized in Chapter 1 of Chenery, Robinson, and Syrquin (1986.) Studies that have approached the question from the perspective of trade theory and the effects of liberalization are summarized in Edwards (1989). Two very robust conclusions emerge from these studies. First, the investment share has an estimated coefficient that is generally between .1 and .2 that is highly significant. It is almost always the variable with the most explanatory power in such equations.

The second finding is that some measure of openness, usually export growth, is correlated with growth as well. Edwards (1989) is an exception that uses instead a measure of deviations from predicted trade patterns based on a Hecsher-Olin model. Like export growth, it has a signficant, positive, partial correlation with growth. Edwards makes a strong case for greater precision in the definition of what we mean by openness or liberalization and for attempts to develop better cross country measures of these concepts for use in studies such as this. The trade-off in such cases is that the use of more sophisticated measures of openness is likely to restrict the sample of countries that can be considered because of data limitations.

Moreover, enough evidence has already accumulated linking openness with higher growth that it is highly unlikely that a refined measure will overturn this basic finding. Rather, refinements are likely to be important for refining the question that is asked, for example, to ask as Edwards does whether it it a rapid rate of growth of exports that matters for growth or instead a policy of nonintervention in international trade. Both for addressing these more refined questions and for bringing other evidence to bear on the question of causality, a some kind of theory that links technological change and exports is required.

Given the previous findings, the finding here that investment and trade performance are correlated with growth is not a surprise. What is new is the systematic attempt to place these findings in the context of a theory that makes it possible to consider the causal connections between technological change, invesment, trade performance and growth. For example, the finding here that the share of exports, not the change in the share, has explanatory power in a regression for the investment share, but does not have any significant relation with the marginal product of capital, is a potentially revealing result that has been missed in regressions of growth on investment and other variables. Combined with the contrasting finding that investment is increasing in the level of income and that the marginal product of capital is strongly negatively related to the level of income, this result offers support for a direct link between technological change and openness. There have been attempts to relate growth to measures of human capital accumulation like school enrollement rates. For example, Barro (1989b) finds that these measures have explanatory power for the investment rate but not for growth of GDP in an equation that includes the investment rate. The evidence presented appears to be the first cross country evidence supporting the idea that scientists and engineers are important inputs in the sector that produces technological change.

The fact that the initial level of income has a negative effect on growth rates in a regression analysis that holds invesment constant has been demonstrated before. See Barro (1989a, 1989b). Romer (1989) raises concern about the possibility that this effect may arise largely because of measurement error in a regression that has the differnce in the levels of income on the left hand side and the intital level of income on the right hand side. This is why the analysis here uses the average level of income intead of the initial level.

Barro (1989a) decomposes investment into government and private components and finds that the effects on output of the two kinds of invesment are similar. He also finds that higher public goods investment is associated with higher private goods investment. Barro (1989b) uses a measure of deviations from purchasing power parity for investment goods as an index of distortions, and finds that it is negatively related to growth. Since he does not include trade variables, it is not possible to tell whether this is capturing the effect of a different distortion from the effect picked up by the trade variables, or is an independent measure of openness.

There are other correlations that have been identified. For example, Kormendi and MeGuire (1985) find that in a sample of 46 countries, both the rate of inflation and the standard deviation of the rate of growth of the money supply have negative coefficients in a regression equation for the growth rate. They also find postive effect for a measure of civil liberty. Barro (1989a,b) finds negative effect for measures of war and revolution. Londregan and Poole (1989) find a signnificant relationship between coups d'etat and reduced growth.

This last analysis is unusual in the sense that it explicitly allows for two way causality; because of the discrete nature of a coup, they can use an event study methodology to study both economic performance leading up to a coup and subsequent performance. They find that the probability of a coup decreases significantly with increases in economic well being, and that economic growth is lower and political instability higher after a coup.

The problem for interpreting all of this evidence is that of establishing causality. Even in the Londregan and Poole study that relies on timing evidence is susceptible to multiple interpretations. It could be that coops cause slower subsequent growth, or that the factors that lead to low growth are persistent, and that all of the causality runs from economic performance to political events. Until more detailed theory helps us corroborate the possible causal channels with other kinds of data, these effects are likely to continue to be difficult to interpret.

7. Conclusions

Taken together, the evidence provided here suggests that the rate of growth technological change exhibits more systematic variation with economic variables and more variation across countries than than one might previously have suspected.

This finding is very important for the interpretation of the finding that the rate of investment is highly correlated with the rate of growth. Under the plausible presumption that the rate of technological change does not vary much across countries, the correlation between investment and growth seems to offer evidence against diminishing returns to capital accumulation. (Prior to the analysis undertaken here, this line of argument seemed persuasive to the author.)

The evidence here undermines the presumption that the rate of technological change is roughly the same across countries. Much of the variation in the rate of investment may indeed be caused by variation in the rate of growth of the technology. This removes a presumption that the correlation between investment and growth reflects causality from invesment to technological change. The finding that investment is increasing with the level of development and rates of return are descreasing offers additional direct evidence that diminishing returns to capital accumulation may be an important factor.

From the point of view of policies designed to foster growth in less developed countries, this results cuts two ways. On the one hand, the finding that less developed countries have a higher rate of return to capital, and implicitly that capital is relatively scarce there, buttresses the conventional rationale for international lending. There appear to be static output gains that can be had by shifting some investment from developed to less developed countries. On the other hand, the results here suggest that international lending probably will not have a large effect on long term growth rates.

If the theory and the inferences drawn here are correct, the key determinant of the growth rate in less developed countries is the rate of expansion of investment opportunities. Opening a country to increased trade seems to be one way to increase these opportunities, in part because it allows for the purchase of the broad range of highly developed producer inputs available world wide. Another way may be to encourage the development of the scientific talent for the production of new goods and new investment opportunities domestically, but one should be careful about generalizing the results here for scientists too far beyond the sample of relatively developed countries in which it is identified. There results here also offer a suggestions that controlling the size of the government, and reducing tax and other distortions in private markets, may be important in encouraging growth.

In closing, it is useful to use the numbers from the regressions to indicate the relative magnitude of the growth and level effects just decribed. For Argentina, the implied coefficient for invesment from Table 6, that is the implied rate of return for capital, is about 11%, a representative figure for Latin America countries. (If the dummy variable for Latin America is entered as an interaction term with the investment share instead of as a direct effect on growth rates, the rate of return for Argentina falls to around 8%.) The effect of additional foreign lending designed to take advantage of the higher rate of return on capital in Argentrina than in the rest of the world can be calculated as follows. Suppose that the additional lending is equal to 1% of GDP, and all of it is devoted to new investment, with no offsetting reduction in investment by private individuals. If the real rate of interest is 3% and the depreciation rate on capital is 3%, the net increase in GDP is (11%-3%-3%)*(1%) = 0.7% of GDP per year.

This can be contrasted with the effect of a one percent increase in the share of exports as a percent of GDP. Over the last 25 years, the investment share for Argentina has averaged around 20%. The coeffcient of .004 on the interaction term between the increase in the export share and the investment share implies that a planned increase in the export share of .01, spread over a 20 year period, will lead to .004 increase in the rate of return on investment. Assuming that this effect applies only to new investment, output will increase by (.004)*(20%) = .8% of GDP. According to Table 3, the increase in the export share should ultimately lead to a small increase in the investment share as well. This is in contrast to the increase in foreign lending, that may have the effect of reducing rates of return and partially crowding out existing investment spending.

Thus, even in terms of the impact effects, policies designed to encourage openness may have effects comparable in magnitude to the effects of additional lending designed to take advantage of rate of return differentials. Over time, the growth effect induced by the increase in openness will strongly dominate the level effect from additional borrowing. The level effect leads to a constant flow of .7% of additional GDP per year. As new investment takes place each year, the growth or rate of return effect of addtional accumulates, with a .008% increase in the first year, .008+.008% in the second year, etc.

The implied standard errors for these calculations are quite large, and the specific numbers should be taken only as indications of orders of magnitude. But if the general conclusions of the analysis here are correct, policies like a move toward greater openness may have cummulative effects that are very large compared to standard policies designed to mitigate capital scarcity. The same conclusion might equally well be applied to reductions in distortions, but the support for the effects of distortions on growth rates is at present somewhat tenuous.

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Table 1. Variable Definitions:

i	Share of investment in GDP. Average value of the variable ci for from HS for the years 1960-85.
Growth	Average annual rate of change of RGDP2 from HS, 1960-85.
AVG_Y	Average value of real income, 1960-85, in 1980 US$. RGDP2 from HS.
GOV	Share of non-investment government spending in GDP. Average value of cg from HS.
AVG_EX	Average share of exports in GDP. From the World Bank.
EX_DIFF	Export share in GDP for years 1981-85 minus share for the years 1960-64. World Bank.
AF_DUM	Dummy variable for countries in Africa.
LA_DUM	Dummy variable for Latin American, that is, South America, Central America, and Mexico
SCI70	Logrithm of the number of scientists, and engineers employed in R&D for years around 1970. From UNESCO (1972).
SCI_DIFF	Difference in the logarithm of the total number of scientists between the years 1970 and 1985. From UNESCO (1972, 1986).

Growth rate and share variables measured in percent *100. (See Table 2 for descriptive statistics for the variables.) HS refers to Heston Summers (1988). All averages are taken over the years 1960 to 1985 unless indicated otherwise. For the variables SCI70 and SCI_DIFF, a trunction rule was used to remove from the sample countries that had very small numbers of scientists and engineers. The resulting list of countries is reported in Table 8.

Table 2. Descriptive statistics

Number of countries: 112

Series	Mean	S.D.	Maximum	Minimum
i	14.797229	6.4061605	29.113850	2.9930770
GROWTH	1.9553791	1.9564617	6.6401340	-2.8898990

Number of countries: 90

Series	Mean	S.D.	Maximum	Minimum
i	14.967188	6.4236602	29.113850	4.1057690
GROWTH	1.8184393	1.8576269	6.3931320	-2.8898990
AVG_Y	2838.1538	2744.0510	9985.8080	289.92310
GOV	15.827137	5.3758415	31.088850	4.0023080
EX_DIFF	4.2248946	14.987000	34.257690	-49.197690
AVG_EX	0.2770491	0.1614817	0.8545491	0.0510950

Number of countries: 22

Series	Mean	S.D.	Maximum	Minimum
GROWTH	3.0094120	1.2517190	5.7479920	0.4096714
i	20.724458	3.7639637	29.113850	13.643850
GOV	14.353934	5.4558241	31.088850	6.6923080
SCI70	9.3231164	2.1063328	13.216580	5.6733230
SCI_DIFF	0.6142574	0.5324369	1.7416300	-0.8944078
EX_DIFF	15.527562	7.7671210	34.257690	4.9030120
AVG_EX	0.2480606	0.1166470	0.4609159	0.0914310
AVG_Y	6331.6189	2197.9358	9985.8080	1638.5770

Table 3.

LS // Dependent Variable is GROWTH
Number of observations: 112

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	-0.6865793	0.3806635	-1.8036384	0.075
i	0.1785441	0.0236245	7.5575699	0.000

R-squared	0.341778	Mean of dependent var	1.955379
Adjusted R-squared	0.335794	S.D. of dependent var	1.956462
S.E. of regression	1.594493	Sum of squared resid	279.6650
Durbin-Watson stat	1.831269	F-statistic	57.11686
Log likelihood	-210.1664		

Notes: Least squares regression of growth rates on investment. Full Summers-Heston sample.

Table 4

LS // Dependent Variable is i
Number of observations: 90

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	7.9921210	1.0685418	7.4794653	0.000
AVG_Y	0.0013847	0.0001841	7.5215358	0.000
AVG_EX	0.1099152	0.0312828	3.5135998	0.001

R-squared	0.472971	Mean of dependent var	14.96719
Adjusted R-squared	0.460856	S.D. of dependent var	6.423660
S.E. of regression	4.716665	Sum of squared resid	1935.483
Durbin-Watson stat	2.233394	F-statistic	39.03821
Log likelihood	-265.7781		

Notes: Least squares regression of investment share on level of income and average export share. Sample with trade data.

Table 5

LS // Dependent Variable is GROWTH
Number of observations: 90

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	1.5007432	0.6644834	2.2585112	0.027
i	0.2159812	0.0355887	6.0688194	0.000
i*AVG_Y	-3.240E-05	1.200E-05	-2.6999165	0.009
AVG_Y	0.0003994	0.0002414	1.6547624	0.102
i*EX_DIFF	0.0011491	0.0004971	2.3116570	0.024
AF_DUM	-1.3552696	0.4212235	-3.2174599	0.002
LA_DUM	-1.3078399	0.4089565	-3.1979924	0.002
GOV	-0.1059372	0.0288536	-3.6715428	0.000

R-squared	0.584176	Mean of dependent var	1.818439
Adjusted R-squared	0.548678	S.D. of dependent var	1.857627
S.E. of regression	1.247963	Sum of squared resid	127.7077
Durbin-Watson stat	2.038543	F-statistic	16.45695
Log likelihood	-143.4515		

Notes: Least squares regression of growth rates on investment, level of income, and interaction terms with investment. Sample with trade data.

Table 6

TSLS // Dependent Variable is GROWTH
Number of observations: 90
Instrument list: C i i*AVG_Y AVG_Y AF_DUM LA_DUM GOV EEC EFTA WB1 WB2 WB3 WB4 WB5 WB6 WB7

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	1.3291252	0.7878811	1.6869617	0.096
i	0.2195068	0.0419658	5.2306159	0.000
i*AVG_Y	-3.278E-05	1.414E-05	-2.3183639	0.023
AVG_Y	0.0002961	0.0002894	1.0233960	0.310
i*EX_DIFF	0.0039522	0.0015720	2.5141259	0.014
AF_DUM	-1.4148416	0.4971947	-2.8456493	0.006
LA_DUM	-1.0175087	0.5049148	-2.0152088	0.048
GOV	-0.0945953	0.0345000	-2.7418903	0.008

R-squared	0.422907	Mean of dependent var	1.818439
Adjusted R-squared	0.373643	S.D. of dependent var	1.857627
S.E. of regression	1.470176	Sum of squared resid	177.2363
Durbin-Watson stat	2.266644	F-statistic	8.584498
Log likelihood	-158.1998		

Notes: Two stage least squares regression of growth rates on investment, level of income, and interaction terms. Change in exports (EX_DIFF) treated as endogenous or measured with error. Sample with trade data. Additional intruments are dummy variables indicating membership in a trade union (EEC and EFTA) and indicators of degree of openess for developing countries reported in the 1987 World Development Report (WB1-WB7).

Table 7

Panel A:

LS // Dependent Variable is GROWTH
Number of observations: 22

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	0.9979581	1.1848868	0.8422392	0.412
i	-0.0392770	0.0697337	-0.5632424	0.581
i*AVG_Y	-7.866E-06	5.542E-06	-1.4194179	0.175
i*SCI70	0.0130618	0.0052966	2.4660435	0.025
i*SCI_DIFF	0.0529528	0.0182842	2.8960965	0.011
i*EX_DIFF	0.0021432	0.0014871	1.4412136	0.169

R-squared	0.569331	Mean of dependent var	3.009412
Adjusted R-squared	0.434748	S.D. of dependent var	1.251719
S.E. of regression	0.941083	Sum of squared resid	14.17020
Durbin-Watson stat	2.554860	F-statistic	4.230308
Log likelihood	-26.37774		

Panel B:

Series	Mean	S.D.	Maximum	Minimum
i_COEF	0.0984995	0.0434956	0.2245623	-0.0135211

Notes:

Panel A: Least squares regression of growth rates on investment, level of income, and interaction terms with investment. Sample with trade and scientific data. (See Table 8 for a list of the countries.)

Panel B: Descriptive statistics for the coefficient on investment predicted by the estimates in Panel A.

Table 8. Countries with data for scientists and engineers

Israel
Japan
Korea, Rep. of
Austria
Belgium
Denmark
Finland
France
Germany, Fed Rep
Greece
Ireland
Italy
Netherlands
Norway
Spain
Sweden
Switzerland
United Kingdom
Canada
United States
Argentina
Chile

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