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IN SEARCH OF SCALE EFFECTS IN TRADE AND GROWTH

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ABSTRACT

We look for the scale effects predicted by some theories of trade and growth based on the dynamic returns to scale that arise from learning by doing, investment in human capital, or development of new products. We find little empirical evidence of a relation between the growth rate of GDP per capita and the measures of scale implied by the theory. Restricting attention to the manufacturing sector, however, we find a significant relation between the growth rate of output per worker and the relevant scale variables. We also find that growth rates are significantly related to measures of intra-industry trade.

Keywords: increasing returns to scale; external effects; international trade; learning by doing; human capital; research and development; specialization indices; intra-industry trade.

JEL Classification Numbers: 110, 226, 410

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1. Introduction

The relation between increasing returns and economic growth has been a recurring theme in both economic development and the theory of international trade. Smith [42] suggested more than two centuries ago that static increasing returns might account for some of the differences in national levels of per capita income. He conjectured, for example, that low costs of water transport gave the ancient Egyptians a large effective market, which permitted them to exploit economies of scale in production and enjoy a relatively high standard of living. In a dynamic context, scale economies can lead to growth. Starting with Arrow [3], a larger number of theoretical papers have based growth on dynamic increasing returns to scale. Some examples include Aghion and Howitt [1]; Chipman [7]; Dinopoulos, Oehmke, and Segerstrom [12]; Glomm [17]; Grossman and Helpman [20]; Krugman [26]; Lucas [27]; Parente [33]; Rivera-Batiz and Romer [34]; Romer [35, 36, 39]; Schmitz [41]; Stokey [43]; Uzawa [50]; and Young [54]. Most of these theories posit scale effects at the national level. Other things equal, they suggest that large countries, with large suitably defined, grow faster than small ones.

This scale effect on growth is the theme of our paper. Our objective is to relate differences in growth rates across countries to differences in the scale of production and factor inputs. We derive theoretical relations between scale and growth from three stylized theories of growth, chosen to illustrate important features of recent work. In all three growth is driven by dynamic scale economies, but the source of the economies differs. In one they derive from learning by doing; in another, from investment in human capital or in research and development; and in the third, from development of specialized inputs to production. Each of these sources of dynamic increasing returns has distinct implications for the measurement of scale and the relation of scale to growth and trade.

One motivation for looking at scale effects is that, in a variety of theoretical models, they provide an important mechanism linking growth to trade. In these models, opening to trade generally increases the size of markets for producers, thus leading to greater specialization and a higher average scale of production. In some other theories, there is another mechanism at work: trade in specialized inputs raises both the level and the rate of growth of real output. In both types of theories, countries that are more open to trade grow faster. They suggest, however, different measures of the influence of trade.

We look for evidence of the scale effects on growth predicted by these theories in cross-country data obtained from a number of sources. The statistical methodology that we employ is simple: we look at a large number of possible relationships among data series. Our data work is intended to be exploratory in that we are looking for simple statistical regularities rather than performing sophisticated hypothesis testing. Thus we view finding, for example, that there is a positive relationship between measures of manufacturing scale within a country and growth in manufacturing output per worker more as indicating directions for future research than as a confirmation of a particular theory.

In all of our theories the extent of external effects, or spillovers, determines the unit of analysis over which increasing returns operate: Do they extend over industries, over regions, over countries, or over even broader aggregates? We presume that spillovers operate at the national level, either within a single national industry or across industries within a country. The reason, first and foremost, is that we take the central question of development economics to be why *countries* differ in levels and rates of growth of national income. Certainly the state of development economics would be much different if we could provide a satisfactory answer to this question. A second reason for looking at scale economies at the national level is that there is clear evidence of national differences in the data. There is a large dispersion of per capita growth rates across countries, even over periods as long as several decades, and these differences generally apply across industries within a country. In countries with rapid productivity growth in the aggregate, most industries also exhibit faster productivity growth; see, for example, Christensen, Cummings, and Jorgenson [8], Conrad and Jorgenson [10], and Nishimizu and Robinson [32] for studies of both developed and developing countries. In this sense, national boundaries appear to be associated with differences in growth experience.

We develop the theory in the next section. We focus exclusively on the technology, the source of dynamic scale economies and growth, and thus avoid some of the complications that arise in characterizing equilibrium trade and growth in many endogenous growth models. Some models, such as that of Rivera-Batiz and Romer [34], predict that more openness in international trade would lead to convergence of growth rates. Others, such as Young [54], predict that trade leads to divergence. A strength of our analysis, we think, is that our theoretical relation between scale and growth is a feature of the technology alone, a relation between inputs and outputs that does not depend on subtleties of market structure or economic policy that arise in defining an equilibrium in economies with nonconvex technologies. These subtleties play a role in the equilibrium, but their effect on growth is summarized by the scale of production. A tariff, for example, may well affect the scale or specialization of production and, therefore, may influence the rate of growth, but it has no other effect in our theory. Its influence is measured completely by the scale variable. In short, tariffs give rise not to shifts of the dynamic production function, but to movements along it.

Learning by doing theories imply that countries with larger industries grow faster. If there are significant spillovers across industries within a country, the relevant measure of scale is the total output of all industries in which learning by doing operates. We use both total GDP and total output of manufacturing sectors. If, instead, spillovers across industries are small, the theory dictates that we weight these measures by an index of specialization: everything else equal, a country that is able to specialize grows faster. We find little evidence for scale effects in determining the growth of GDP per capita. Our results are even more unfavorable to the scale effects hypothesis when we weight by specialization indices. When we focus on the manufacturing sector, however, using differences across countries in measures of scale in manufacturing to explain differences in growth rates of output per worker, we find significant evidence of scale effects.

Human capital theories lead us to look at both the scale of inputs into the human capital accumulation process and per capita measures, which we refer to as intensity variables. We construct scale and intensity variables from data on students and teachers. Although we find some evidence that intensity is related to growth of GDP per capita, there is little evidence here of a scale effect. The theory that relates research and development to growth rates is analogous to the human capital theory. As measures of inputs into research and development we use total scientists, engineers, and technicians in a country, and total expenditures on R&D. Here we find little evidence of either scale or intensity effects, perhaps because of the relatively poor quality of the data. Once again, however, there is significant evidence of a relation between growth of manufacturing productivity and the scale of both inputs into the human capital accumulation process and inputs into research and development.

In theories with specialized inputs to production, in which growth may be generated by any of the above sources of dynamic increasing returns, importing new products that are used as inputs into production can lead to faster growth. We explore the relation of growth rates to two indicators of trade in specialized inputs designed to capture this phenomenon. We find that productivity growth in manufacturing is related to both of these measures and to scale.

Given the limited quantity and quality of cross-country data of the sort that we use, it makes little sense to experiment with many regressions of relations not directly implied by our theories. Nonetheless, the surprisingly positive results that we obtain for the effects of both manufacturing scale and our measures of intra-industry trade lead us to investigate the robustness of our findings. We do this in two ways: We run our regressions on subsamples based on initial per capita GDP. This procedure allows for the possibility that our theory is not capable of explaining productivity growth differences, either among very poor countries or among very rich countries. We also introduce a number of ancillary variables into the regressions. As we explain, these variables, used by such other researchers as Barro [4] and Romer [37, 38], have a limited role to play within our theoretical framework. We find that the significant effects of manufacturing scale and of our measures of intra-industry trade persist throughout both of these procedures.

2. Scale Effects in Theories of Trade and Growth

We derive theoretical relations between scale and growth in three stylized theories of growth, based respectively on learning by doing, investment in human capital or in research and development, and development of specialized inputs. For each one we describe the technology and sketch the implications for an increase in scale on the growth rate of per capita output. Depending on the model, the set of goods can be regarded as either fixed and finite or variable and potentially infinite. We start with a fixed and finite set of goods produced with Cobb-Douglas production functions, which both simplify the presentation and point out directions for the subsequent empirical work. We then investigate the implications of learning by doing in a model with an infinite number of differentiated inputs.

Learning by doing. The potential of learning by doing to account for economic growth was first recognized by Arrow [3]. Recent studies of its role in theories of growth and trade include Boldrin and Scheinkman [5], Clemhout and Wan [9], Lucas [27], Stokey [43], and Young [54]. The micro evidence has a long history. Wright's [53] study of airframe manufacturing found that productivity increased with cumulative output at the firm level. Later studies have confirmed this relation at both the firm level and, in some cases, at the industry level; see, for example, the studies cited in Argote and Epple [2]. The latter presupposes, apparently, an external effect or "spillover" across production units. In our theory such spillovers serve two purposes. First, they allow us to distinguish between industries. Depending on the form of the spillover, the scale of production might be the size of an industry, the size of the manufacturing sector as a whole, or a function of the sizes of a number of industries. Second, spillovers motivate the absence of diminishing returns to experience in our theory. Microeconomic studies clearly document such diminishing returns and imply that learning by doing in a single activity cannot generate sustained growth. There is, however, additional evidence that experience in one product may increase productivity in related products. Stokey [43] formalizes this idea and shows that this increased productivity can lead to sustained growth at a more aggregated level.

We consider a model with a finite number of industries. Value added in industry i, i = 1, ..., I, is produced according to the function

(2.1) $$Y_{it} = \gamma_i A_{it} N_{it}^{1-\alpha_i} K_{it}^{\alpha_i}.$$

Here Y_{it} is real value added of industry i in period t, N_{it} is labor input, and K_{it} is capital services. The variable A_{it} measures the external effects of learning by doing. When spillovers are industry specific, we assume that

(2.2) $$A_{it+1} = A_{it}\,(1+\beta_i Y_{it})^{\rho},$$

where β_i and ρ are positive constants. Thus, the rate of increase in learning is proportional to total output. This is slightly different from the standard experience curve, in which productivity is an increasing function of cumulative output, but has the same flavor: current production raises future productivity. Defining $y_{it} = Y_{it}/N_t$ to be real output per capita and similarly defining n_{it} and k_{it}, we obtain

(2.3) $$y_{it} = \gamma_i A_{it} n_{it}^{1-\alpha_i} k_{it}^{\alpha_i},$$

which implies that the growth rate in per capita output is

$$(2.4)\quad 1 + g(y_{it}) = \frac{y_{it+1}}{y_{it}} - 1 = (1+\beta_i Y_{it})^{\rho} \left[\frac{n_{it+1}}{n_{it}}\right]^{1-\alpha_i} \left[\frac{k_{it+1}}{k_{it}}\right]^{\alpha_i}.$$

Notice the scale effect: If two countries have identical capital-labor ratios and distributions of labor across industries, then all of the industries in the larger country grow faster. Alternatively, if we consider a growth path in which the capital stock in each industry grows at the same rate as output and the fraction of the labor force in each industry is constant, then we can calculate

$$(2.5)\quad 1 + g(y_{it}) = (1+\beta_i Y_{it})^{\delta_i},$$

where $\delta_i = \rho/(1-\alpha_i)$. Again, the country with the larger industries grows faster.

When spillovers occur across industries within a country, we assume

$$(2.6)\quad A_{it+1} = A_{it}\left[1 + \sum_{j=1}^{I} \beta_{ij} Y_{jt}\right]^{\rho}.$$

Defining variables as above, the per capita growth rate is

$$(2.7)\quad 1 + g(y_{it}) = \left[1 + \sum_{j=1}^{I} \beta_{ij} Y_{jt}\right]^{\rho} \left[\frac{n_{it+1}}{n_{it}}\right]^{1-\alpha_i} \left[\frac{k_{it+1}}{k_{it}}\right]^{\alpha_i}.$$

Once again the scale effect is obvious.

Human capital/research and development. Uzawa [50], Lucas [27], and Stokey [44] have proposed human capital accumulation as a possible explanation of sustained growth. There are obvious external effects here: we learn more because we interact with other people who are educated or are being educated. Unlike learning by doing, however, human capital accumulation must have some effect that is internalized; otherwise no one would spend a valuable resource to accumulate it. There are a number of ways in which the external effects of human capital can be introduced, and the choice affects the implications for scale. We discuss several variations of one such model to illustrate how the formulation influences the relation between scale and growth.

We define the aggregate production function

$$(2.8) \quad Y_t = \gamma(N_{1t}h_t)^{1-\alpha}K_t^{\alpha}.$$

Here Y_t is aggregate value added, or GDP, in period t, N_{1t} is total time spent working or size of the labor force, and h_t is average amount of human capital. Multiplying N_{1t} by h_t converts labor units into effective labor units. We assume that

$$(2.9) \quad h_{t+1} = h_t(1+\beta n_{2t}A_t^{\delta}).$$

Here n_{2t} is the average fraction of time spent accumulating human capital and A_t measures the external effect of human capital accumulation. We also assume that

$$(2.10) \quad A_t = N_{2t},$$

where N_{2t} is the total amount of time spent on human capital accumulation or the size of the human capital sector. Thus, there are positive external effects in the process of accumulating human capital.

Again, letting lower case variables denote per capita values, we can rewrite (2.8) as

$$(2.11) \quad y_t = \gamma(n_{1t}h_t)^{1-\alpha}k_t^{\alpha}.$$

The per capita growth rate of output is

$$(2.12) \quad 1 + g(y_t) = [1 + \beta n_{2t}(N_{2t})^{\delta}]^{1-\alpha} \left[\frac{n_{1t+1}}{n_{1t}}\right]^{1-\alpha} \left[\frac{k_{t+1}}{k_t}\right]^{\alpha}.$$

Again, notice the scale effect of N_{2t}: countries with larger human capital sectors grow faster.

An alternative way of modeling the spillovers from human capital accumulation is to put the external effects into the production function itself. Following Lucas [27], we define

(2.13) $Y_t = \gamma(N_{1t}h_t)^{1-\alpha}K_t^{\alpha}A_t^{\delta}$.

Lucas defines A_t, again the spillover term, as

(2.14) $A_t = h_t$;

the external effect depends on the average level of human capital in the labor force. With no spillovers in the process of accumulating human capital (2.9), the per capita growth rate becomes

$$(2.15)\quad 1 + g(y_t) = (1+\beta n_{2t})^{1-\alpha+\delta}\left[\frac{n_{1t+1}}{n_{1t}}\right]^{1-\alpha+\delta}\left[\frac{k_{t+1}}{k_t}\right]^{\alpha}.$$

Notice that in this case there are no scale effects. By formulating spillovers as affecting the production function (2.13) rather than the accumulation function (2.9), Lucas generates growth without scale effects.

Yet another alternative would be to assume that the external effect in production depends on the total stock of human capital held by the labor force: the more educated workers there are, the more new ideas to improve productive efficiency there will be, above and beyond the internal effect, the more effective labor will be embodied in the labor force. In this case (2.14) would be

(2.16) $A_t = N_{1t}h_t$,

and the per capita growth rate would be

$$(2.17)\quad 1 + g(y_t) = (1+\beta n_{2t})^{1-\alpha+\delta}\left[\frac{N_{t+1}}{N_t}\right]^{\delta}\left[\frac{n_{1t+1}}{n_{1t}}\right]^{1-\alpha+\delta}\left[\frac{k_{t+1}}{k_t}\right]^{\alpha}.$$

Notice that there is no direct scale effect, although there is a population growth effect.

In many respects investment in research and development is similar to investment in human capital. Indeed, if we think of n_{2t} as being the proportion of labor devoted to R&D, then we can interpret our results for an economy with investment in human capital as an economy with investment in R&D. There are even stronger arguments for scale effects here than with human capital accumulation; see, for example, Rivera-Batiz and Romer [34]. This interpretation of R&D is best thought of as investment in improving the production technologies of an existing set of goods. Applications of research and development include Chipman [7], as well as many of the references in the next paragraph.

Specialized inputs. Our final model is a variant of Romer's [35] theory of growth through new product development and product differentiation. As in Stokey [43] and Young [54], learning by doing leads to the development of new or improved inputs to production. Final output is produced according to the production function

$$(2.18)\quad Y_t = \gamma N_t^{1-\alpha}\left[\int_0^{\infty} Z_t(i)^{\rho} di\right]^{\alpha/\rho},$$

where $1 > \rho > 0$. There is a continuum of differentiated intermediate and capital goods, with $Z_t(i)$ denoting the quantity of inputs of type i, $0 \leq i \leq \infty$. The parameter ρ is positive, allowing output even if there is no input of some goods. This type of production function, proposed by Ethier [15] as a reinterpretation of the utility function of Dixit and Stiglitz [13], embodies the idea that an increase in the variety of inputs leads to an increase in measured output. The same device has been used in models of growth through research and development by Aghion and Howitt [1]; Dinopoulos, Oehmke, and Segerstrom [12]; Glomm [17]; Grossman and Helpman [18, 19, 20]; Rivera-Batiz and

Romer [34]; Romer [35, 36, 39]; and Schmitz [41]. Stokey [44] uses this production function to study the effects of human capital accumulation.

Growth arises from an increase in the number of available intermediate and capital goods. In period t, only goods in the interval $0 \leq i \leq A_t$ can be produced. Production experience results in the expansion of the interval, the development of new specialized inputs,

$$(2.19)\quad A_{t+1} = A_t(1+\beta Y_t).$$

The resource constraint on intermediate and capital goods is

$$(2.20)\quad \int_0^{A_t} Z_t(i)di = K_t.$$

If the production functions for these inputs are identical, then the most efficient allocation of resources results in equal production of all goods that are actually produced. Let us assume that all goods in the interval $0 \leq i \leq A_t$ are produced in equal amounts. Under suitable assumptions, this is the equilibrium outcome (see, for example, Romer [35, 39]). Let $Z_t(i) = \bar{Z}_t$, $0 \leq i \leq A_t$. Using (2.14), we obtain

$$(2.21)\quad \bar{Z}_t = K_t/A_t,$$

which implies

$$(2.22)\quad Y_t = \gamma N_t^{1-\alpha} K_t^{\alpha} A_t^{\alpha(1-\rho)/\rho}.$$

The growth rate of output per worker is

$$(2.23)\quad 1 + g(y_t) = (1+\beta Y_t)^{\alpha(1-\rho)/\rho} \left[\frac{k_{t+1}}{k_t}\right]^{\alpha}.$$

If we assume, in addition, that the inputs of intermediate and capital goods grow at the same rate as output, then growth is simply a function of the scale of production:

$$(2.24) \quad 1 + g(y_t) = (1+\beta Y_t)^{\delta},$$

where $\delta = \alpha(1-\rho)/[\rho(1-\alpha)]$. Again there is a scale effect at the country level: countries with larger outputs grow faster.

The most interesting aspect of this theory, however, is the perspective it gives us on trade and growth. In models of growth based on learning by doing and on human capital accumulation, the natural interpretation is that technology is embodied in people and is not tradeable. Trade may influence the pattern of production, including both the scale of production and the pattern of specialization, and in this way affect growth. We may see, for example, that, with trade, a country has a larger scale of production or output that is more highly concentrated in a subset of industries. Either one, in our formulation, increases growth in a way that is captured by the right-hand side of the growth equations, (2.5) and (2.9). In the model of growth through development of specialized inputs, technology is embodied in product varieties and there is a more subtle interaction between trade and growth. Recall that increases in the number of varieties of intermediate and capital goods raise output. If these varieties are freely traded, a country can either produce them itself or purchase them from other countries. By importing these inputs a small country can grow as fast as a large one. We use this model to motivate an investigation of the relation between growth and the propensity to import specialized inputs. When there is less than perfectly free trade in specialized inputs, we might expect to find that both scale and trade in differentiated products, are positively related to growth.

3. The Scale and Specialization of Production

Our search for scale effects begins with the size of national industries. In our model of growth through learning by doing, as in those of Stokey [43] and Young [54], learning by doing leads to pure scale effects: countries with larger industries grow faster. We look for this below in the data. As in Barro [4], Romer [37, 38], and others, our measure of the GDP per capita series is from the Summers-Heston [45] dataset, described in greater detail by Kravis, Heston, and Summers [25], which adjusts national incomes for differences in purchasing power. (See also Summers and Heston [46].) These growth rates are measured as percentages; GDP per capita in the United States, for example, grew at an average rate of 1.88 percent between 1970 and 1985.

The simplest example of a scale effect is for countries with larger aggregate output to grow faster. Our learning by doing model provides two equivalent interpretations. The first, based on (2.4), treats the country as a single industry. The second, based on (2.7), is for a multi-industry economy with complete spillovers across industries within the country and $\beta_{ij} = \beta$, all i, j. In this case countries with the largest GDPs are predicted to grow the fastest, holding constant growth rates of labor and capital inputs.

The bivariate relation between growth and aggregate GDP is reported in the first row of Table I. Figure 1 plots the data. This row reports statistics from a regression for a cross section of countries of the annual growth rate of per capita GDP on the logarithm of a scale variable. There is little evidence of a scale effect, in the sense that the coefficient, although positive, is little larger than its standard error, with a heteroskedasticity-consistent t statistic of 1.64. The magnitude of the coefficient implies that a hundredfold increase in total GDP is associated with an increase in per capita growth of 0.85 (= 0.167 $\times$ log 100) percent per year. This difference in scale corresponds, for example, to a comparison of the United States and New Zealand, or Nigeria and Lesotho.

Similarly, when the scale refers to manufacturing, we find little evidence that scale is related to growth of GDP per capita.

Equation (2.4) suggests a more complex relation between national GDP and growth if spillovers operate at the industry level, with complete spillovers between establishments within a national industry but little across industries. The aggregate growth rate is the weighted average of growth rates of individual industries, with weights given by shares in aggregate output:

$$(3.1) \quad 1 + g(y_t) = \sum_{i=1}^{I} (Y_{it}/Y_t)[1 + g(y_{it})].$$

Using (2.5) we can write this as

$$(3.2) \quad 1 + g(y_t) = \sum_{i=1}^{I} (Y_{it}/Y_t)(1+\beta_i Y_{it})^{\delta_i}.$$

If, in addition, $\beta_i = \beta$ and $\delta_i = 1$ for all i, aggregate growth is

$$(3.3) \quad g(y_t) = \beta Y_t \sum_{i=1}^{I} (Y_{it}/Y_t)^2.$$

We refer to the summation in (3.3), a number between zero and one, as a *specialization index.* Its product with aggregate output operates as a scale effect on growth. In general, that is, with $\delta_i \neq 1$, the appropriate specialization index is based on other powers of the output shares Y_{it}/Y_t, but we think that this simple measure captures the dispersion of production across industries that the theory suggests is important.

We have experimented with a number of different specialization indices in regressions corresponding to equation (3.3). The results reported in Table I are based on specialization indices from 3-digit export data from the United Nations' *Yearbook of International Trade Statistics* [48]. The motivation for using export data is purely practical: the trade data permits a more detailed breakdown of commodities. To make this operational, assume that the ratio of exports to production is approximately constant across goods, but may differ across countries: $X^j_{it} = e^j Y^j_{it}$ where X^j_{it} is exports of product i by country j and Y^j_{it} is production. In this case the relevant relation between growth and scale becomes

$$(3.4) \quad g(y^j_t) = \beta Y^j_t \sum_{i=1}^{I} (X^j_{it}/X^j_t)^2,$$

where X^j_t is total exports by country j. We compute this over all 1- and 3-digit product categories, and over the subset of manufacturing categories. We refer to the sum in (3.4) as the export specialization index and the product with Y_t as the export-weighted scale variable. This index has been used previously by Michaely ([30], Chapter 4) in another context. The relevant trade data are collected by the United Nations.

Despite their motivation, scale variables weighted by specialization indices based on export data do not account for cross-country differences in growth rates of per capita GDP. The relevant regressions are reported in the third and fourth rows of Table I. We have also constructed specialization indices based on 10 sector total output data from the United Nations' *National Income and Product Accounts* and indices based on 1-digit export data. The results that we obtain are not reported in Table I since they are virtually identical to those reported for the 3-digit export specialization weighted variables.

Another possible motivation for using export data to construct specialization indices is that specialization is most important in the export sector. We observe, for example, that a number of fast growing countries have had rapidly increasing export shares (Michaely [29]) and that productivity growth is faster in tradeables than in nontraded goods (Marston [28]). To make this concrete, consider the story that learning by doing and the relevant spillovers are significant only for high-quality goods, the goods that a country is able to export. A possible relation might look something like

$$(3.5) \quad g(y_t^j) = \beta Y_t^j \sum_{i=1}^{I} (X_{it}^j, /Y_t^j)^2.$$

In regressions not reported here we find that weighting scale by a specialization index like that in (3.5) yields significant results. Clearly, more work is needed before any conclusions can be drawn about the importance of specialization indices.

The first four rows of Table I indicate that the evidence for scale effects at the level of aggregate GDP is weak. In the final two rows we repeat the investigation for the manufacturing sector. The dependent variable is the growth rate of manufacturing output per employee from 1970 to 1985, taken from the World Bank's *World Tables* [52]. Figure 2 plots this growth rate against 1970 manufacturing output. In the regressions the scale variables are manufacturing output with and without the specialization index. Here the data is much kinder to the scale hypothesis. The estimated scale coefficients are larger both absolutely and relative to their standard errors. The estimated scale coefficient with manufacturing output as the scale variable, row 5, has a t statistic of 5.37. The coefficient estimate, 0.897, indicates that a hundredfold increase in the scale of manufacturing is associated with a 4.1 = (0.897 × log 100) percent increase in the growth rate in manufacturing output per worker. This difference in scale corresponds, for example, to a comparison of Japan and Singapore. Once again, the specialization indices add little to the relation. In fact, in regressions similar to those in Table I, but not reported here, we have found that regressing manufacturing productivity on manufacturing scale and a specialization index separately, produces a negative partial correlation between productivity growth and specialization. When we use a specialization index like that in (3.5), however, we find a significantly positive partial correlation.

In retrospect, our positive results for scale effects in the manufacturing sector but not in the economy as a whole may not be that surprising. Microeconomic studies of learning by doing clearly suggest an emphasis on manufacturing. Argote and Epple's [2] comprehensive review of the evidence establishes that, while the benefits of experience appear in a wide range of industries, they show up most strongly in manufacturing. Ghemawat ([16], p. 144) concurs, noting "that manufacturing activities encounter steeper experience curves than raw materials purchasing, marketing, sales, or distribution."

4. The Scale of Human Capital and Research Activity

In the human capital model scale effects operate differently than with learning by doing. Because there must be an incentive for individuals to spend time accumulating human capital, both intensity (n_{2t}) and scale (N_{2t}) affect growth when there are spillovers in the process of acquiring human capital (2.12). We consider again an approximation in which the capital-labor ratio and the distribution of labor across production and capital accumulation are constant, and rewrite (2.12) as

$$(4.1) \quad 1 + g(y_t) = [1 + \beta n_{2t}(N_{2t})^{\delta}]^{1-\alpha}.$$

In contrast, when the spillovers enter the production process directly, as in Lucas [27] and in our equations (2.15) and (2.17), there are no scale effects. For this reason we look at both scale and intensity effects in the data analysis below.

Our human capital measures are, like the rest of our variables, determined in large part by availability. They concern inputs into human capital accumulation, namely the numbers of teachers and students at various levels of education published by the United Nations Educational, Scientific, and Cultural Organization in their *Statistical Yearbooks* [49]. In Table II we relate annual per capita growth rates of GDP from 1970 to 1985 to student and teacher inputs in or near 1970. Each is a weighted sum of three levels of education, primary, secondary, and university. We construct the weights by assuming that a secondary education has a marginal value of twice that of a primary education and that a university education has a marginal value three times a primary education. In this way a secondary student is worth three primary students, since secondary students have already completed primary school, and a university student is worth six primary students. This yields our measures for students of (primary-secondary-university) + 3 (secondary-university) + 6 university, for levels 1–3. Teachers are weighted by their marginal values: one, two, and three.

In Table II we report estimates of a semi-log linear version of (2.12), with growth rates regressed on the logarithms of scale and intensity variables. We find, as the theory suggests, that both the intensity and scale variables have positive coefficients, with the intensity coefficient larger than the scale coefficient. The former is estimated quite precisely, but the latter is not. In regressions not reported here we find very similar results if we use only primary students and teachers or aggregates of only primary and secondary students and teachers. The estimated coefficients in row 3 imply that a hundredfold increase in the number of effective students, holding intensity fixed, is associated with a 0.62 ($= 0.134 \times \log 100$) percent increase in per capita growth. They also imply that a doubling of intensity, with population fixed, is associated with 0.79 [$= (0.134+1.007) \times \log 2$] percent faster growth. Our finding of intensity effects for education conforms with Barro [4], who finds that primary and secondary *enrollment rates* help to account for growth.

The human capital model can be reinterpreted as a model of research and development, with labor allocated between production of goods and the development of new, or improvement of existing, goods. The question is how to measure inputs into the relevant dimension of research and development activity. R&D involves the improvement of existing products or the development of new ones, either of which may be the result of new applications of scientific advances. For some of these activities it is difficult to see how to measure the relevant inputs. We focus instead on narrower measures of research and development, like the numbers of scientists, engineers, and technicians and the value of expenditures on research and development.

Once more the data are taken from UNESCO *Statistical Yearbooks* [49] as described in the appendix. We measure, specifically, total numbers of scientists, engineers, and technicians; and total expenditures on R&D. Despite the efforts of UNESCO, we suspect there is less comparability across countries in measures of research inputs than there is for education or, *a fortiori,* national income and trade data. We note, for example, that the United States, which has 10 times the population of Canada but is in many other respects very similar, has only 3 times as many scientists, engineers, and technicians, and that the Philippines has half as many scientists and engineers as the U.S. with less than one-fifth the population. These examples suggest that there may be important differences in the definitions of these categories across countries. Nevertheless, the data are available for a broad range of countries, and it is possible that they contain useful information for our study.

Our findings are reported in Table II. We see, for the most part, no strong relation between growth of per capita GDP and either the scale or intensity of R&D activity. In regressions not reported here, we find similarly weak results when we measure the scale of research activity either as the total number of scientists and engineers or as the total number of scientists and engineers engaged in R&D. On the whole, the evidence is too weak to draw strong conclusions about either scale or intensity effects.

In our investigation of the relation between growth and the scale of production implied by the learning by doing theory, we have seen that the theory seems to do better in explaining differences in growth in manufacturing productivity than it does in explaining differences in growth of GDP per capita. It is tempting to speculate that all of our theories, including those relating human capital accumulation and R&D to growth, are more relevant for manufacturing than for all industries.

When we redo the first four regressions in Table II, which relate growth in GDP per capita to human capital accumulation and to science and research activity, using growth in manufacturing productivity as the dependent variable, we find that the results are indeed kinder to the relevant scale hypothesis. The final four rows of Table II report some of the results. Notice that in every case the coefficient of the relevant scale variable is significantly positive.

It seems that our theories do better in general when confronting the data for manufacturing than they do for aggregate output. At least in the case of R&D expenditures this should come as no surprise: Most R&D expenditures that are sector specific go to manufacturing. Incomplete data in the 1982 UNESCO *Statistical Yearbook* (Table 5.10) [49] reveals, for example, that 77.8 percent of such expenditures go to manufacturing in Canada, 93.8 percent in Germany, and 91.8 percent in Japan. (It is only 18.8 percent in Brazil, however, and 37.5 percent in New Zealand.)

We have investigated the possibilities of both scale effects and intensity effects in models where human capital accumulation or science and research activities drive growth. Our theory suggests yet another possible effect of scale on growth: when spillovers affect production on an absolute scale but not accumulation, there is a population growth effect but not a scale effect; see equation (2.17). In regressions not reported here, we have repeated the experiments reported in Table II, substituting either the growth rate of population or the growth rate of employment in manufacturing, as approximate, for the scale variable. The results are very unfavorable for this variant of our theory. The coefficients of population growth are all negative, often significantly.

5. Intra-Industry Trade

In the previous sections we have investigated a variety of scale variables and their relation to economic growth. International factors have not played an obvious role, operating only through their effect on the relevant scale variables. If, however, the engine of growth is the introduction of new products, then trade plays a more central role: a country can grow faster if it is able to import specialized inputs produced abroad. The problem is measurement: the kinds of differentiation used in the theory have no obvious counterparts in trade data collected for a fixed set of product categories. We construct two indicators of the propensity of a country to import differentiated products, the Grubel-Lloyd [21] index of intra-industry trade and an intra-industry import index of our own construction.

The Grubel-Lloyd index is

$$\text{(5.1)} \quad \text{Grubel-Lloyd Index} = \frac{\sum_{i=1}^{I} \{X_i + M_i - |X_i - M_i|\}}{X + M},$$

where X_i and M_i are exports and imports, respectively, of category i and X and M are total exports and imports. We compute this index for all product categories and for manufacturing only, categories 500 to 899 of the 3-digit SITC trade data reported in the United Nations' *Yearbook of International Trade Statistics* [48]. Both indices are for 1970.

The Grubel-Lloyd index measures the fraction of trade for which a country imports and exports the same commodities. If a country imports and exports equal amounts in all categories, the index is one. If it imports and exports goods in different categories, so that either X_i or M_i is zero for every category i, then there is no intra-industry trade and the index is zero. We argue that two-way trade at the 3-digit level reflects trade in finely differentiated products. Trade in category 711, nonelectrical machinery, for example, might consist of imports of steam engines (7113) and exports of domestically produced jet engines (7114). Simultaneous imports and exports of these goods provides the economy with both, and may lead to more efficient production.

Our interest is in the relation between growth and trade in specialized inputs in our theory. At one extreme, an economy completely closed to trade would have, obviously, no trade in specialized inputs. Its growth rate would be determined as in equation (2.24), by the scale of its manufacturing sector. At the other extreme of free trade, an economy would utilize the complete range of specialized inputs, the interval $[0,A_t]$, where A_t is the number of inputs available worldwide. Its growth rate would then be equal to that of every other country that has access to the same range of products. Thus, by importing specialized inputs, a small country can grow as fast as a larger one. In intermediate situations of less than free trade of imperfectly tradable intermediate and capital goods, we might expect growth to be related to both trade in specialized inputs and the scale of output or of the manufacturing sector.

In the first three rows of Table III we report estimates of regressions of growth rates in GDP and manufacturing productivity on the Grubel-Lloyd index and a measure of scale. In all three rows the relation is positive. The strongest results are obtained using the growth rate of manufacturing output per worker as the dependent variable. In the third row the index has a t statistic of 3.04. Notice that the scale of manufacturing also has a significantly positive effect.

We also experiment with a second index intended to measure the directly the extent of imports of differentiated products. We start by computing a measure of the extent of intra-industry trade worldwide for each product category,

$$(5.2) \quad \alpha_i = \frac{\sum_{j=1}^{J} (X_i^j + M_i^j - |X_i^j - M_i^j|)}{\sum_{j=1}^{J} (X_i^j + M_i^j)},$$

where X_i^j and M_i^j are exports and imports, respectively, of good i by country j. We think of this as indicating the amount of product differentiation in category i. The intra-industry import index uses these measures to construct a measure of imports of differentiated products:

$$(5.3)\quad \text{Intra-Industry Import Index}_j = \sum_{i=1}^{I} \alpha_i M_i^j / Y^j,$$

where Y^j is GDP or manufacturing output in country j, depending on the index. The all-products index is a measure of imports of differentiated products as a fraction of gross output. The manufacturing index is a measure of imports of differentiated manufactured products as a fraction of total manufacturing output.

In Table III we see that the import index has a positive partial correlation with growth. It is worth noting, however, that the positive relationship between the import index and growth in manufacturing productivity actually becomes negative if we do not control for scale: the simple correlation between these two variables is −0.189. This is in accord with our theory where small countries can partially escape the trap of small scale by importing specialized inputs; larger countries may have less of a need for such imports. Notice, in particular, that when we control for the import index the estimated effect of scale increases: the results in the final row imply that a hundredfold increase in the scale of manufacturing, everything else being equal, is associated with a 6.6 percent increase in the growth rate in manufacturing output per worker.

6. Discussion

The most striking results of our investigation are undoubtedly those related to manufacturing scale and the intra-industry trade indices. It is tempting to speculate on alternative explanations for the relationships that we have found in the data. For example, it could be economic policy, rather than scale economies, that drives growth. In such a theory, favorable economic policy would over time, and certainly by 1970, have resulted in a large manufacturing sector and would continue to result in rapid growth in manufacturing productivity. An important aspect in which countries differ, for example, is trade policy. The World Bank [51] has argued that "export promotion" policies lead to higher growth. If we found that countries following such policies also had large manufacturing sectors, then our estimated relation might reflect policy rather than the scale effects of our theory. The difficulty is that it is not easy to construct objective, univariate measures of such policies. The World Bank's measure, a division of countries into four policy categories, is highly subjective: it is not a simple function of quantifiable variables. As Edwards [14] notes, such measures run the risk of simply verify *ex post* the policy preference of the authors. Perhaps further work will detect a connection between trade policy and our measures of intra-industry trade. It is worth noting, however, that theories related to policy differences across countries would predict an even closer correlation between manufacturing output per worker and productivity growth than it would between the scale of manufacturing and productivity growth. The correlation of the log of 1970 output per worker and productivity growth is only 0.108, however, while that between the log of 1970 total output and productivity growth is 0.571. (Table VI in the appendix contains the simple correlations of many of the key variables.)

It is also tempting to ask how robust are the statistical regularities that we have found. We explore this robustness question in two ways, by looking at subsets of countries and by introducing additional variables to the growth relation. The former procedure is motivated by the hypothesis that growth requires a minimal level of development. Rosenstein-Rodan [40] and Murphy, Schleifer, and Vishny [31], for example, suggest that the behavior of the smallest countries may be different from the rest. We might expect to see that our relations apply only to countries above a minimum level per capita GDP, with no scale effects for extremely poor countries. Relations estimated for sample that exclude the poorest countries might then exhibit stronger evidence of a relation between scale and growth. Estimated scale coefficients are reported in Table IV for samples that omit the countries with per capita GDP less than 10 and 20 percent, respectively, of U.S. GDP per capita in 1970. We find little evidence that scale effects on growth are stronger for richer countries. We also consider a complementary hypothesis, that scale effects diminish as countries become more developed. Again, we find little difference in estimated scale effects on growth. Notice that in every case, the estimated scale effect is significant.

In Table V we report estimates of the partial effects of scale in regressions of growth on scale and a variety of other variables chosen from the empirical literature on growth. The issue is whether scale is correlated with other determinants of growth that we have not measured. Some are variables that might serve as indicators of institutional differences that lie outside our theory. Recall, however, that in our theory only international differences that enter the accumulation equation, equations (2.2), (2.9), and (2.19) in our various theories, or changes in the production function, (2.1), (2.8), and (2.18), are related to growth. With respect to the former, we can, for example, imagine that some institutional differences can be captured, loosely, as differences in the parameter β_i in

(2.2) $A_{it+1} = A_{it}(1+\beta_i Y_{it})^{\rho}$.

In other words, countries with, say, more civil liberties or stable governments are more able to translate production experience into technological improvement. This is in the spirit of the Argote and Epple [2] survey of learning by doing, which documents evidence at the firm level that turnover of skilled workers and variability in the rate of production reduce the benefits of experience.

With respect to the production function,

(2.1) $Y_{it} = \gamma_i A_{it} N_{it}^{1-\alpha} K_{it}^{\alpha}$, we might expect stationary differences in endowments, for example, that enter the production function to affect the level but not the growth rate of output. If endowments enter the theory by allowing greater output for given capital and labor inputs—that is, by increasing the parameter γ_i in (2.1)—then they are pure level effects: countries with valuable resource endowments have higher standards of living but do not grow faster. Changes in endowments, however, could effect the growth rate of output.

We consider a wide range of additional variables, many of them taken from Barro's [4] dataset. Some of them can be viewed, as we have argued, as changes in β_i or γ_i, but others are difficult to interpret in out theoretical framework. Consider, first, three indicators of the political environment: Gastil's index of civil liberties, the average number of revolutions per year, and the fraction of GDP consumed by government. These and related variables have been related to growth by Barro [4] and Kormendi and Meguire [24]. We might think that each variable is correlated with a country's ability to translate experience into technological progress, with civil liberties raising growth and revolutions reducing it. We can think of two conflicting stories for the effect of government spending on consumption. On the one hand, spending on social infrastructure like law enforcement may create a more stable environment and encourage growth. On the other, it may increase the tendency for government to interfere with private decisions and in this way discourage growth.

The next four variables are general indicators of the level of development: fertility, adult literacy, primary school enrollment, and GDP per capita. They are taken from Barro's [4] database and the World Bank's *World Tables* [52]. One interpretation of these variables is that more developed countries may be better able to take advantage of experience, perhaps because they are correlated with infrastructure or unmeasured aspects of the sophistication of the social system.

The last two variables are notable primarily for their widespread use in other studies of growth. The first is the population growth rate, which appears as an independent variable in Barro [4] and Romer [37] and, in the form of labor force growth rate, DeLong and Summers [11]. As we have seen, such a variable also appears in a version of our investment in human capital model (2.17). The second variable is the average investment share of GDP over the 1970–85 period. A strong relation between growth and the investment share has been documented by, among many others, Edwards [14] and Romer [38]. The question is how to interpret this variable in the context of our theory. One interpretation is that investment is required to convert experience into productivity gains, so that we can view investment as a changing β_i in (2.2). An alternative is that investment is simply the consequence of higher growth. Consider a growth path in which the capital-output ratio is constant so that output and capital grow at the same rate g. Then the ratio of net investment to GDP is $I/Y = (I/K)(K/Y) = g(K/Y)$. To the extent that countries have similar capital-output ratios, we would expect to see in a cross section relation that countries with higher growth rates also have higher ratios of investment to output. This holds in any model of growth in which cross section variations in g are larger than those in K/Y. Thus in our model we might see that countries with large manufacturing sectors grow faster and invest proportionately more. In a multiple regression of growth on scale and the investment share, we might find no partial effect of scale, even when scale economies are the engine of growth. This sort of criticism, that of simultaneity bias, potentially applies to estimates of the effects of others of our independent variables. This is especially true of variables like 1960–85 revolutions per year, whose values are at least partially determined over the period 1970–85. It is hard to argue that these variables are predetermined in our regressions.

The results of regressing the growth rate of manufacturing output per worker on the logarithm of the manufacturing output, on the logarithm of an intra-industry trade index, either the

Grubel-Lloyd index or our intra-industry import index, and on these other variables are presented in the first two columns of Table V. The only variable with a coefficient with a t statistic larger than two in each of the two regressions is the scale variable. In the first regression the Grubel-Lloyd index and the investment share of GDP are also significant. The only other variables with coefficients with t statistics larger than one in absolute value are those of the intra-industry import index, 1960–85 revolutions per year, 1970 GDP per capita, and the population growth rate. When similar regressions are run on subsets of these independent variables, the coefficient of the scale is always significant, while those of the other variables sometimes are significant, and sometimes are not.

Table V also reports the results of two regressions that use growth of GDP as the dependent variable. One uses the logarithms of manufacturing output and of the intra-industry import index for manufacturing as independent variables. The other replaces these variables with the logarithms of GDP and of the intra-industry import index for all products. Both also use all of the variables employed in the previous two regressions. Many more variables now have significant coefficients. These results, however, are very sensitive to the choice of the other independent variables in the regression. In some regressions of the growth of GDP per capita on subsets of the variables used in Table V, for example, the scale coefficient is significantly positive.

A hypothesis consistent with these results is that the models that we have described do a good job of explaining the growth of manufacturing productivity. The growth of GDP per capita also depends on productivity growth in other sectors and on labor force participation rates. It may be that no simple regression can adequately capture the complex interaction involved in the simultaneous determination of all of these variables. This suggests that we should think about developing multi-sectoral growth models to account for cross-country differences in growth of GDP per capita.

Appendix

A. Data Sources and Definitions

We describe all of the series used in the paper, roughly in the order of appearance.

Level of GDP and growth rate of per capita GDP. The source is Summers and Heston [45], the computer diskettes. Per capita GDP is their RGDP, real per capita GDP in 1980 international prices. We construct per capita GDP in 1970 as the product of RGDP and population. The annualized growth rate of per capita GDP, measured as a percent, is 100*[log RGDP(1985) − log RGDP(1970)]/15.

Scale of manufacturing and growth rate of manufacturing output per worker. The source is primarily the World Bank's *World Tables, 1989-90 Edition* [52], the computer diskettes. We construct an index of real output per worker as the ratio of manufacturing value-added at factor cost (Variable 27 on the diskette) to the employment in manufacturing index (Variable 49). The growth rate is the annualized percentage log difference, as above. If both 1970 and 1985 are available, they are used to construct the growth rate. Otherwise, we use dates nearest to 1970 and 1985, subject to the requirement that there be at least ten years between them. We refer to the starting date for the growth rate as the base year. The scale of manufacturing data required, in addition, a conversion to a common set of units. To do this we divided manufacturing value-added at factor cost (Variable 27) by GDP at factor cost (Variable 24) in the base year, and multiplied by the Summers-Heston total GDP in international prices.

Manufacturing output per worker. Sources are the *World Tables* [52], Summers and Heston [45], and the International Labour Organization's *Year Book of Labour Statistics,* 1977. The difficulty is that the output per worker series computed from the *World Tables* is an index, and the units are not comparable across countries. We have used the Summers-Heston data to convert output to comparable units above. Here we do the same thing with the number of workers using ILO data. Manufacturing output per worker is constructed as a ratio. The numerator is the manufacturing output series described above. The denominator is the number of employees in manufacturing from Table 3 in the base year or the year closest to it. If this is not available, we use the economically active population in manufacturing from Table 2, again for the base year or closest to it.

Export specialization indices. The source is the 1970 data in the United Nations' *Yearbook of International Trade Statistics* [48], the 1989 computer tape (Table 5, rev. 1). We have constructed indices using 3-digit SITC categories. The relevant formula is contained in (3.4). One index is for all categories of goods. The other is for manufacturing only, categories 500 to 899.

Educational inputs. The source is the United Nations Educational, Scientific, and Cultural Organization's *Statistical Yearbook* [49], 1982 edition. Students and teachers at the first level are from Table 3.4: total pupils enrolled and total teaching staff. Students and teachers at the second level are from Table 3.7: total second-level pupils and teachers. Students and teachers at the third level are from Table 3.11: total students enrolled and total teaching staff at universities and equivalent institutions. The data are for 1970, with occasional interpolation from surrounding years. The aggregation of these three levels is described in the text.

Research and development indicators. The source is the United Nations Educational, Scientific, and Cultural Organization's *Statistical Yearbook* [49], 1970 edition. Scientists, engineers, and technicians are from Table 3.1. Expenditures on R&D as a percent of GNP is taken from Table 3.11. This is multiplied by Summers and Heston's RGDP and population in 1970 to convert it to total R&D expenditures. Dates are mid-to late-1960s, as available.

Indicators of trade in differentiated products. The source is the United Nations' *Yearbook of International Trade Statistics* [48], the 1989 computer tape (Tables 4 and 5, rev. 1). The Grubel-Lloyd index uses formula (5.1). The trade flows are reported in U.S. dollars. From the 3-digit trade flows we computed the α's in (5.2). The intra-industry import index (5.3) for all products uses the same trade flows and GDP in 1970 dollars derived from the International Monetary Fund's *International Financial Statistics*, the 1990 computer tape, using 1970 GDP in local currency units (Series 99b) and the 1970 dollar exchange rates (Series rf). The intra-industry import index for manufacturing uses the same trade flows and manufacturing output constructed as above but adjusted to 1970 dollars using GDP from the *International Financial Statistics* as above. The date for all series except manufacturing output is 1970; that for manufacturing output is 1970 or the earliest available date as described above.

Ancillary variables. The source is the Barro-Wolf dataset described by Barro [4] and the World Bank's *World Tables, 1989–90 Edition* [52].

B. Choice of Sample Size

In each of our regressions we have used the largest possible sample rather than restricting ourselves to a small sample (32 countries) that have observations of every variable. This has the advantage of confronting each alternative theory with the maximum amount of information available. It has the disadvantage of making it difficult to compare the results of different regressions. Fortunately, however, the choice of sample size does not have a major impact on our results. When we redo all of the regressions on the common sample, we find the estimated coefficients usually change very little. In particular, the significant estimates of the effects of manufacturing scale and the intra-industry trade indices persist in the common sample. Tables VI and VII report the simple correlations between the major series. Table VI uses the maximum sample available for each pair of variables. Table VII uses a sample of 42 countries for which all of the series are available. Notice the similarities between the two tables.

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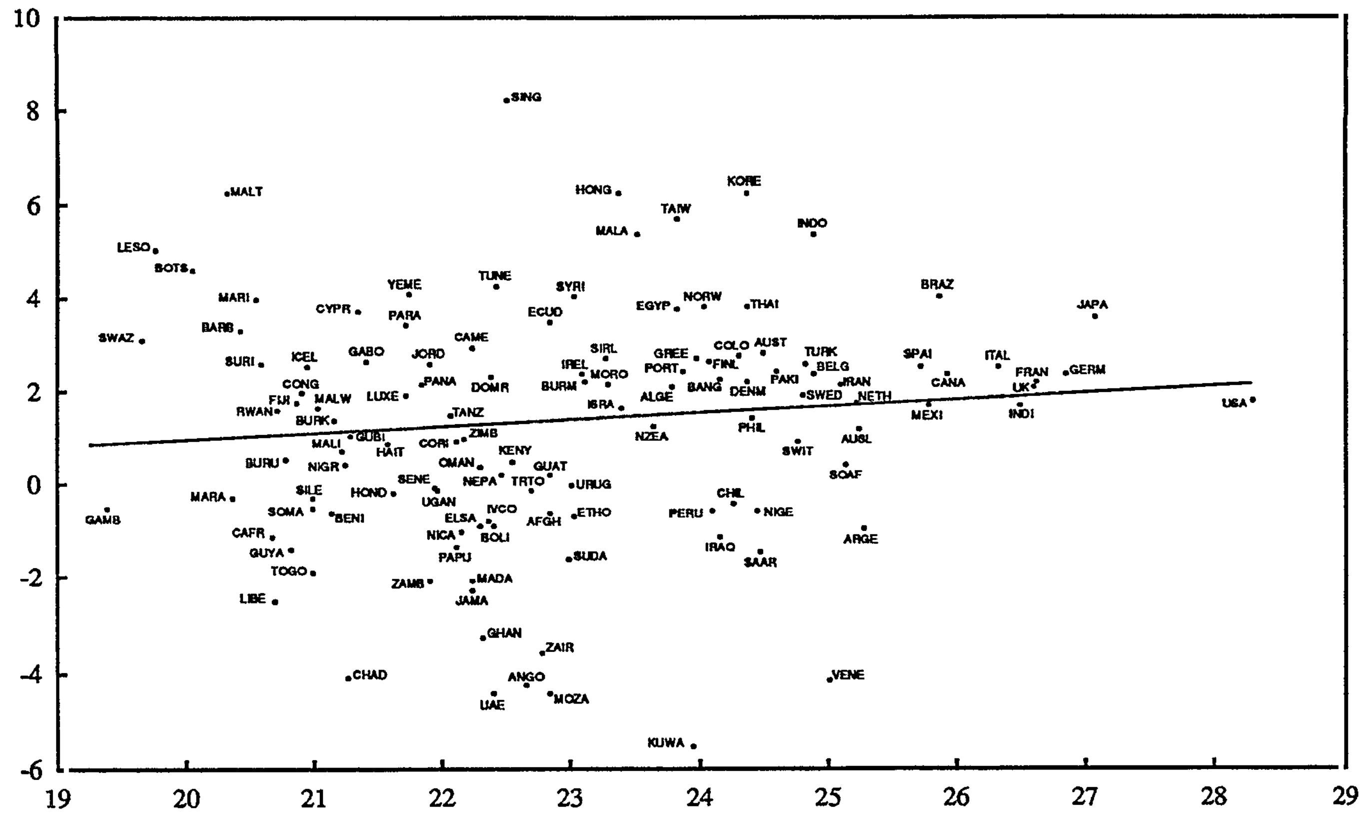
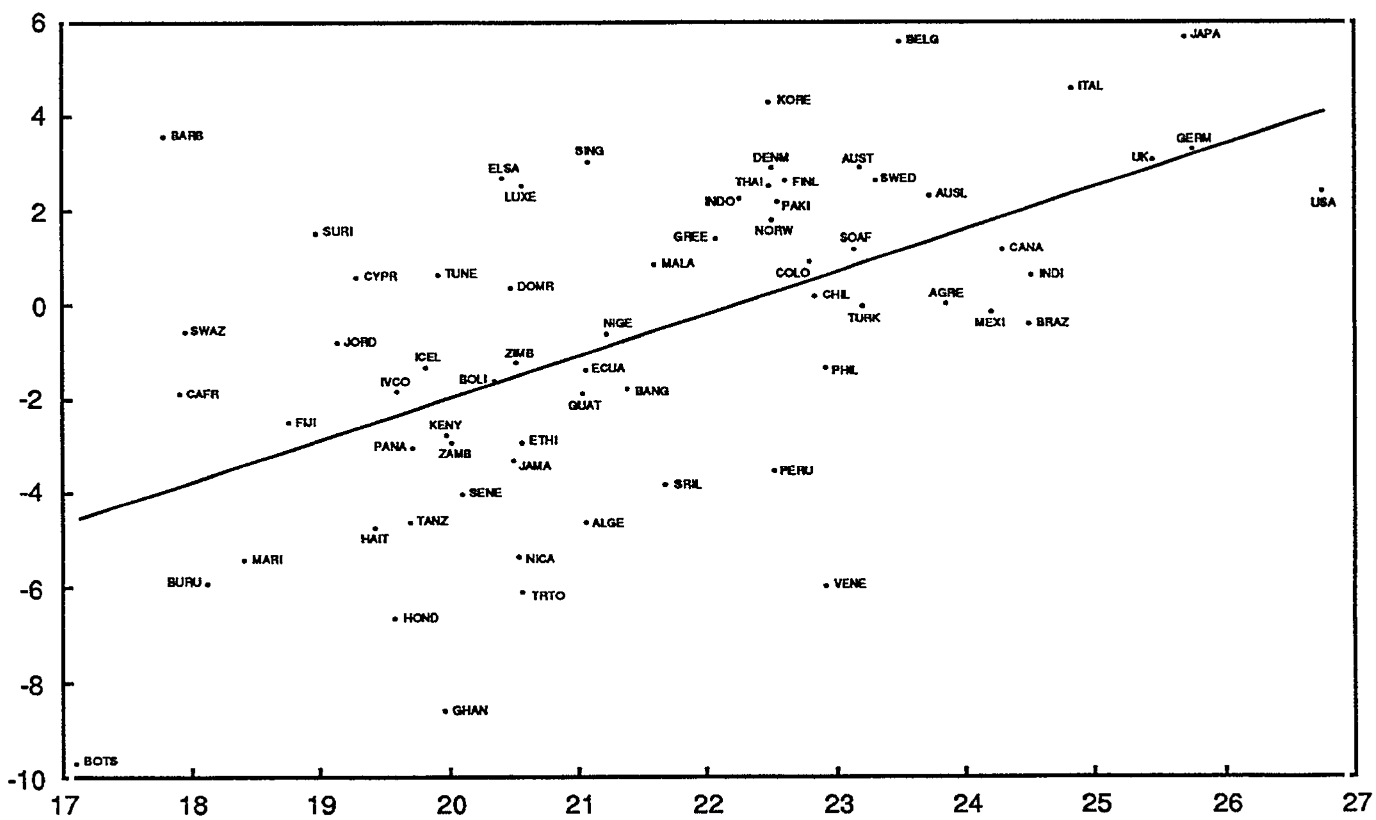


Growth of GDP Per Capita 1970-85 vs. Log of GDP

Figure 1



Growth of Manufacturing Output per Worker 1970-85 vs Log of Manufacturing

Figure 2

Table I

Regressions of Growth Rates on Scale of Industry

Growth Rate	Scale Variable	Scale Coefficient	R^2	Observations
GDP Per Capita	GDP	0.167 (0.102)	0.016	118
GDP Per Capita	Manufacturing	0.104 (0.100)	0.011	67
GDP Per Capita	Export Weighted GDP	0.026 (0.195)	0.000	91
GDP Per Capita	Export Weighted Manufacturing	0.089 (0.144)	0.005	55
Manufacturing Per Worker	Manufacturing	0.897 (0.167)	0.326	67
Manufacturing Per Worker	Export Weighted Manufacturing	0.736 (0.214)	0.162	55

Coefficients are the result of regressions of the growth rate of the specified variable 1970–85 on a constant and the logarithm of scale. Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table II

Regressions of Growth Rates on

Scale and Intensity in Education and R&D

Growth Rate	Scale Variable	Intensity Variable	Scale Coefficient	Intensity Coefficient	R^2	Observations
GDP Per Capita	Students Total	Students Per Capita	0.134 (0.139)	1.007 (0.448)	0.089	107
GDP Per Capita	Teachers Total	Teachers Per Capita	0.175 (0.150)	0.626 (0.372)	0.087	94
GDP Per Capita	Scientists etc. Total	Scientists etc. Per Capita	0.248 (0.226)	−0.065 (0.333)	0.047	57
GDP Per Capita	R&D Total	R&D Percent of GDP	0.155 (0.184)	−0.504 (0.451)	0.034	44
Manufacturing Per Worker	Students Total	Students Per Capita	0.600 (0.203)	2.046 (0.565)	0.212	64
Manufacturing Per Worker	Teachers Total	Teachers Per Capita	0.617 (0.188)	1.168 (0.400)	0.262	56
Manufacturing Per Worker	Scientists etc. Total	Scientists etc. Per Capita	0.770 (0.318)	0.057 (0.410)	0.306	40
Manufacturing Per Worker	R&D Total	R&D Percent of GDP	1.265 (0.279)	−1.082 (0.651)	0.560	32

Coefficients are the result of regressions of the growth rate of the specified variable 1970–85 on a constant and the logarithms of specified scale and intensity variables. Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table III

Regressions of Growth Rates on Scale and Index of Intra-Industry Trade

Growth Rate	Scale Variable	Intra-Industry Trade Index	Scale Coefficient	Index Coefficient	R^2	Observations
GDP Per Capita	GDP	Grubel-Lloyd All Products	−0.018 (0.146)	0.952 (0.247)	0.196	90
GDP Per Capita	Manufacturing	Grubel-Lloyd Manufacturing	0.012 (0.150)	0.634 (0.275)	0.125	54
Manufacturing Per Worker	Manufacturing	Grubel-Lloyd Manufacturing	0.581 (0.224)	1.059 (0.348)	0.416	54
GDP Per Capita	GDP	Intra-Industry Import All Products	0.243 (0.127)	0.376 (0.421)	0.026	75
GDP Per Capita	Manufacturing	Intra-Industry Import Manufacturing	0.349 (0.150)	0.877 (0.417)	0.065	49
Manufacturing Per Worker	Manufacturing	Intra-Industry Import Manufacturing	1.424 (0.198)	2.150 (0.673)	0.408	49

Coefficients are the result of regressions of the growth rate of the specified variable 1970–85 on a constant and the logarithms of the scale variable and the specified intra-industry trade index for all products or manufacturing products, as indicated. Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table IV

Regressions of Manufacturing Productivity Growth on Scale and Index of Industry Trade: The Effects of Dropping Countries with Small and Large GDP Per Capita GDP

Sample Selection Criterion	Coefficient of Manufacturing Output	Coefficient of Intra-Industry Import Index	R^2	Observations
All Countries	1.424 (0.198)	2.150 (0.672)	0.408	49
> 10% of 1970 U.S GDP Per Capita	1.208 (0.234)	2.139 (0.922)	0.304	38
> 20% of 1970 U.S. GDP Per Capita	1.403 (0.398)	2.738 (1.199)	0.316	23
< 50% of 1970 U.S. GDP Per Capita	1.356 (0.392)	2.379 (1.194)	0.214	35
< 60% of 1970 U.S. GDP Per Capita	1.558 (0.324)	2.330 (1.093)	0.337	37
< 70% of 1970 U.S. GDP Per Capita	1.423 (0.309)	2.093 (0.953)	0.303	40
< 80% of 1970 U.S. GDP Per Capita	1.460 (0.214)	2.120 (0.733)	0.400	46

Coefficients are the result of regressions of the growth rate of manufacturing output per worker on a constant and the logarithms of manufacturing output and the intra-industry import index (manufacturing). Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table V

Regressions with Additional Variables

Growth Rate	Manufacturing Per Worker	Manufacturing Per Worker	GDP Per Capita	GDP Per Capita
Scale Variable	Manufacturing	Manufacturing	Manufacturing	GDP
Intra-Industry Trade Index	Grubel-Lloyd Manufacturing	Intra-Industry Import Manufacturing	Intra-Industry Import Manufacturing	Intra-Industry Import All Products
Scale (log)	0.519 (0.237)	1.134 (0.419)	0.259 (0.186)	0.168 (0.153)
I.I.T. Index (log)	0.978 (0.359)	1.503 (0.901)	0.645 (0.519)	0.077 (0.377)
Gastil Index of Civil Liberties	−0.291 (0.372)	−0.262 (0.416)	0.170 (0.283)	−0.092 (0.198)
1960–85 Revolutions Per Year	3.434 (1.854)	1.920 (3.301)	−3.164 (1.360)	−3.522 (1.422)
1970–85 Government Share of GDP	4.366 (5.386)	−0.768 (6.696)	−10.228 (4.772)	−8.837 (3.947)
1965 Fertility Rate	0.306 (0.507)	0.071 (0.763)	0.402 (0.332)	0.426 (0.312)
1960 Adult Literacy Rate	−1.738 (3.056)	−2.583 (3.814)	0.033 (1.685)	−0.903 (1.365)
1970 Primary School Enrollment Rate	0.879 (2.671)	0.386 (3.073)	2.083 (1.306)	2.332 (0.660)
1970 GDP Per Capita (log)	−0.980 (0.868)	−0.803 (1.053)	−1.723 (0.510)	−1.362 (0.390)
1970–85 Population Growth Rate	−1.158 (0.814)	−1.571 (1.045)	−1.466 (0.391)	−1.156 (0.381)
1970–85 Investment Share of GDP	15.714 (4.866)	10.738 (6.891)	12.181 (4.250)	13.493 (3.422)
R^2	0.595	0.561	0.629	0.546
Observations	54	49	49	75

Numbers are coefficients of regressions of the growth rate of the specified variable 1970–85 on a constant and the specified variables. Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table VI

Correlations Between Variables Based on All Observations

Variable	1	2	3	4	5	6	7	8	9	10
1) Log of GDP	118	118	118	90	75	67	53	67	90	75
2) Log of GDP/Capita	0.561	118	118	90	75	67	53	67	90	75
3) Growth of GDP/Capita	0.125	0.100	118	90	75	67	53	67	90	75
4) Log of Grubel-Lloyd Index (all products)	0.486	0.580	0.443	90	75	54	46	54	90	75
5) Log of I.I. Import Index (all products)	−0.595	0.012	−0.018	−0.030	75	49	42	44	75	75
6) Log of Manufacturing	0.978	0.544	0.103	0.462	−0.679	67	53	67	54	49
7) Log of Manufacturing/Worker	0.270	0.753	−0.149	0.179	0.005	0.357	53	53	46	42
8) Growth of Manufacturing/Worker	0.525	0.501	0.478	0.628	−0.157	0.571	0.108	67	54	49
9) Log of Grubel-Lloyd Index (manufacturing)	0.454	0.613	0.350	0.934	−0.018	0.474	0.274	0.562	90	75
10) Log of I.I. Import Index (manufacturing)	−0.523	−0.019	−0.070	−0.078	0.955	−0.685	0.005	−0.189	−0.041	75

Below-diagonal elements are simple correlation coefficients between variables. Diagonal elements are number of observations in series. Above-diagonal elements are number of observations used in computing correlation coefficients.

Table VII

Correlations Between Variables Based on 42 Common Observations

Variable	1	2	3	4	5	6	7	8	9	10
1) Log of GDP										
2) Log of GDP/Capita	0.508									
3) Growth of GDP/Capita	0.084	−0.005								
4) Log of Grubel-Lloyd Index (all products)	0.464	0.561	0.298							
5) Log of I.I. Import Index (all products)	−0.708	0.029	0.069	−0.041						
6) Log of Manufacturing	0.989	0.543	0.077	0.471	−0.690					
7) Log of Manufacturing/Worker	0.370	0.763	−0.240	0.139	0.005	0.426				
8) Growth of Manufacturing/Worker	0.539	0.449	0.527	0.636	−0.163	0.554	0.081			
9) Log of Grubel-Lloyd Index (manufacturing)	0.447	0.637	0.211	0.958	−0.045	0.461	0.237	0.580		
10) Log of I.I. Import Index (manufacturing)	−0.716	0.004	0.021	−0.063	0.989	−0.698	0.005	−0.196	−0.071	