Federal Reserve Bank of Minneapolis
Research Department

IN SEARCH OF SCALE EFFECTS IN TRADE AND GROWTH

David K. Backus, Patrick J. Kehoe, and Timothy J. Kehoe*

Working Paper 451

Revised February 1991

ABSTRACT

We look for the scale effects on growth predicted by some theories of trade and growth based on dynamic returns to scale at the national or industry level. The increasing returns can arise from learning by doing, investment in human capital, research and development, or development of new products. We find some evidence of a relation between growth rates and the measures of scale implied by the learning by doing theory, especially total manufacturing. With respect to human capital, there is some evidence of a relation between growth rates and per capita measures of inputs into the human capital accumulation process, but little evidence of a relation with the scale of inputs. There is also little evidence that growth rates are related to measures of inputs into R&D. We find, however, that growth rates are related to measures of intra–industry trade, particularly when we control for scale of industry.

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

JEL Classification Numbers: 110, 226, 410.

*Backus, New York University; P. Kehoe and T. Kehoe, University of Minnesota and the Federal Reserve Bank of Minneapolis. We thank Robert Barro, Lawrence Christiano, Larry Jones, Michael Devereux, Edward Prescott, Paul Romer, and Jose Scheinkman for useful comments; Harry Bowen, Paul Emerson, Robert Evenson, George McCarthy, and David Viry for help with data; the National Science Foundation for financial support; and Hossain Amirizadeh for excellent research assistance.

1. Introduction

The resurgence of theoretical work on economic growth in the last five years has led to renewed interest in the classical question of development: why some countries are richer or grow faster than others. This "endogenous growth" literature is characterized, for the most part, by increasing — or at least nondiminishing — returns in a reproducible factor of production, referred to variously as human capital, knowledge, the degree of product specialization, or simply capital. Many of these theoretical models have an additional implication: 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 research and development, and in the third from development of differentiated products. 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.

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. Therefore, the extent to which we find such relationships, for example, that there is a positive relationship between measures of manufacturing scale within a country and growth in manufacturing output per worker, should be seen as indicating directions for future research rather than as a conclusive 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. One motivation is the large dispersion of per capita growth rates across countries over periods of several decades. If we are to account for differences between countries, the country is the logical unit of analysis. A second motivation is that we observe strong country effects in productivity growth across industries. In countries with fast growth in aggregate most industries also exhibit faster productivity growth; see Conrad and Jorgenson (1985) and Nishimizu and Robinson (1986). 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 of that arise in characterizing equilibrium trade and growth in many endogenous growth models. Some models, like that of Rivera–Batiz and Romer (1989), predict that more openness in international trade would lead to convergence of growth rates. Others, like Young (1989), 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 of production in an industry and therefore influence its 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 to 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 the learning by doing effects operate. 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 some evidence of scale effects on growth rates. Weighting by specialization indexes, however, has little influence on our estimates.

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, at three educational levels. Although we find some evidence of intensity is related to growth, 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 and engineers in a country, total scientists and engineers engaged in R&D, and 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.

In theories with product differentiation, in which growth may be generated by any of our three 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 differentiated products designed to capture this phenomenon. We find that growth is related to both of these measures and to scale.

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/research and development, and product differentiation. 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 either as 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 goods.

Learning by doing. The potential of learning by doing to account for economic growth was first recognized by Arrow (1962). Recent studies of its role in theories of growth and trade include Boldrin and Scheinkman (1988), Clemhout and Wan (1970), Lucas (1988), Stokey (1988), and Young (1989). The micro evidence has a long history. Wright's (1936) 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 (1990). 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 (1988) formalizes this idea and shows that it can lead to sustained growth in the aggregate.

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

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

Here Y_{it} is total real output 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

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

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

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

which implies that the growth rate in per capita output is

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

Notice the scale effect: If two countries have identical capital–labor ratios and the 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

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

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

$$A_{it+1} = A_{it} (1 + \Sigma_{j=1}^{I} \beta_{ij} Y_{jt})^{\rho}. \tag{2.6}$$

Defining variables as above, the per capita growth rate is

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

Once again the scale effect is obvious.

Human capital/research and development. Uzawa (1965), Lucas (1988), and Stokey (1990) have proposed human capital accumulation as a possible explanation of sustained growth. There are obvious external effects: 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) $$Y_t = \gamma\,(N_{1t}\,h_t)^{1-\alpha}\,K_t^{\alpha}.$$

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

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

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) $$A_t = N_{2t}$$

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

The per capita growth rate of output is

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

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 in the production function itself. Following Lucas (1988), we define

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

Lucas defines A_t, again the spillover term, as

$$A_t = h_t; \tag{2.14}$$

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) — that is, with $\delta = 0$ — the per capita growth rate becomes

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

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.

It is worth pointing out that it is spillovers affecting production rather than accumulation that drives the distinction between these two formulations. We could 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

$$A_t = N_{1t}\, h_t, \tag{2.16}$$

and the per capita growth rate would be

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

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} above as being the proportion of labor devoted to R&D, then we can interpret the above 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. 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 (1970), as well as many of the references in the next paragraph.

Product differentiation. Our final model is based on new product development and product differentiation. As in Stokey (1988) and Young (1989), learning by doing leads to the development of new or improved products. Final output is produced according to the production function

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

There is a continuum of differentiated capital goods, with $X_t(i)$ denoting the quantity of capital goods of type i, $0 \leq i < \infty$. The parameter ρ is positive, allowing output even if there is no input of some capital goods. This type of production function, originally proposed by Ethier (1982) as a reinterpretation of the utility function of Dixit and Stiglitz (1977), 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 (1989), Dinopoulos, Oehmke, and Segerstrom (1989), Glomm (1989), Grossman and Helpman (1989a, 1989b, 1989c), Rivera–Batiz and Romer (1989), Romer (1986, 1987, 1990), and Schmitz (1989). Stokey (1990) uses it to study the effects of human capital accumulation.

Growth arises from an increase in the number of available capital goods. In period t, only capital 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 products,

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

The resource constraint on capital goods is

$$\int_0^{A_t} X_t(i) \, di = K_t. \tag{2.20}$$

If the production functions for capital goods are identical, then the most efficient allocation of resources results in equal amounts of all goods that are produced being 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 1986, 1990). Let $X_t(i) = \overline{X}_t$, $0 \leq i \leq A_t$. Using (2.14), we obtain

$$\bar{X}_t = K_t/A_t, \tag{2.21}$$

which implies

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

The growth rate of output per worker is

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

If we assume, in addition, that the capital stock grows at the same rate as output, then growth is simply a function of the scale of production:

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

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 the first model 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 that production 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 second model, 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 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 products 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 differentiated products. When there is less than perfectly free trade in differentiated products, 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 (1988) and Young (1989), learning by doing leads to pure scale effects: countries with larger industries grow faster. We look for this below in the data. In Table 1 we list the variables used in the study, starting with annual growth rates of per capita GDP. As in Barro (1989), Romer (1989), and others, the per capita GDP series is from the Summers–Heston (1988) dataset, described in greater detail by Kravis, Heston, and Summers (1982), which adjusts national products for differences in purchasing power. Note that growth rates are measured as percentages; the United States, for example, grew at an average rate of 1.88 percent between 1970 and 1985. We define the remaining variables as they arise. A complete description of all of them is contained in the appendix.

The simplest example of a scale effect is for countries with larger national products to grow faster. Our learning by doing model provides two equivalent interpretations. The first is (2.4) with the country treated 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.

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:

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

Using (2.5) we can write this as

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

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

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

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 examine the relation between growth and specialization–based measures of scale with several measures of specialization, constructed from national product accounts and trade statistics at several levels of disaggregation. The presumption is that the categories in the data correspond to those in the theory. The first dataset is the United Nations'

National Income and Product Accounts (Table 4.2 from the 1989 computer tape), which provides a breakdown of GDP across nine industrial categories and a further decomposition of manufacturing into nine subcategories. This allows us to compute two specialization indexes, one for total industry and another for manufacturing. From these we compute scale variables by multiplying the specialization indexes by GDP and manufacturing, respectively. Both the indexes and GDP are for 1970, and we relate them to growth from 1970 to 1985.

The relation between growth and aggregate GDP is reported in the first column of Table 2. Each column 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 slight evidence of a scale effect, in the sense that the coefficient is positive and larger than its standard error. 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 x log 100) percent per year. This difference in size corresponds, for example, to a comparison of the United States and New Zealand, or Nigeria and Lesotho. When the scale refers to manufacturing, or when scale variables are modified by specialization indexes, we find no evidence that scale is related to growth.

Part (b) of the table reports similar statistics from regressions with ancillary variables from Barro's (1989) dataset: an indicator of political stability, a dummy variable for oil exporting countries, and a dummy variable for sub–Saharan Africa. We chose variables that we thought might serve as indicators of institutional differences that lie outside our theory. Certainly factor endowments, which the oil variable is intended to measure, are not part of our theory. Keep in mind, however, that only differences that the learning equation (2.2), or changes in the production function (2.1), are related to growth in the theory. Stationary differences in endowments, for example, that enter the production function cancel in the determination of the growth rate (2.4). Thus the importance of the oil probably stems from the enormous change in its relative price in our sample period. Use of sub–Saharan Africa is a little more contentious. The case for including this variable is that it captures unmeasured institutional differences, say, or drastic changes in climate. The case against is that this variable is closely correlated with scale, which we want to examine directly.

The African dummy is by far the most important ancillary variable; without it the the estimated scale effect with ancillary variables is very similar to the estimate in the simple regression. The countries of sub–Saharan Africa both grow more slowly and have smaller scales of industry than the rest of our sample. The question is whether we want to attribute this difference in growth to scale or to other, unmeasured, properties of these countries. In the absence of more concrete information about what these other properties are, we prefer the scale interpretation.

The remainder of the table uses specialization indexes from one– and three–digit export data from the United Nations' *Yearbook of International Trade Statistics.* One motivation 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 1977) and that productivity growth is faster in tradeables than nontraded goods (Marston 1987). 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. Another motivation 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. Then a specialization index for exports equals an index for production. To be specific, the relevant relation between growth and scale is

$$g(y_t) = \beta Y_t \Sigma_{i=1}^{I} (X_{it}/X_t)^2, \tag{3.4}$$

where X_{it} is exports of product i and X_t is total exports. We compute this over all one– and three–digit products, and over the subset of manufacturing goods. 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. The index has been used previously by Michaely (1984, Chapter 4) in another context. The relevant trade data are collected by the United Nations.

Despite their motivation, scale variables based on export data do not account for cross–country differences in growth rates of per capita GDP. The relevant regressions are reported in columns 5 through 8 of Table 2. In short, the evidence for scale effects at the level of aggregate GDP is weak.

In Table 3 we repeat the investigation with manufacturing. The dependent variable is the growth rate of manufacturing output per employee from 1970 to 1985, taken from the World Bank's *World Tables.* The scale variables are 1970 manufacturing output, with and without specialization indexes. Here the data is kinder 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, column one, has a heteroskedasticity–consistent t–statistic of 5.4. The coefficient estimate, 0.897, indicates that a hundredfold increase in the scale of manufacturing is associated with a 4.1 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. Note, too that the scale effects do not disappear when we add ancillary variables. We find, instead, that the sub–Saharan Africa variable no longer has a significant effect on growth once scale is taken into account. Once again, however, the specialization indexes add little to the relation. It appears, both here and more generally, that cross–country differences in scale are enormous relative to differences in specialization, so the latter has little influence on the regressions.

4. The Scale of Human Capital

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

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

In contrast, when the spillovers enter the production process directly, as in Lucas (1988) and our equations (2.15) and (2.17), there are no scale effects. For this reason we look at both scale and level 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*. In Table 4 we relate annual per capita growth rates from 1970 to 1985 to student and teacher inputs in or near 1970. Each is measured for three levels of education, primary, secondary, and university. In the table we report three measures for both students and teachers. For students, level 1 refers to the number enrolled, levels 1&2 refers to a weighted sum of first and second level students, and levels 1–3 refers to a weighted sum of all three levels. We construct the weights by assuming that a secondary education has a marginal value of twice that of a primary education, and 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) + 3 secondary, for levels 1&2, and (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 4 we report estimates of a semi–log linear version of (4.1), with growth rates regressed on the logarithms of scale and intensity variables. As in the previous section, we report estimates from simple regressions and regressions that include three ancillary variables. With respect to the simple regressions 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. The numbers for column three imply that a hundredfold increase in the number of effective students, holding intensity fixed, is associated with a 0.62 (= 0.134 x 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) x log 2] percent faster growth. Our finding of intensity effects for education conforms with Barro (1989), who finds that primary and secondary *enrollment rates* help to account for growth.

Once more we find that the ancillary variables, especially the sub–Saharan African dummy, lower the precision of these estimates. With respect to magnitude, the estimates from the simple and ancillary regressions in column three imply comparable scale effects, but intensity effects that differ in sign. Regressions not reported here reveal, however, that if we use only the oil and political stability variables in the ancillary regressions, the precision of both scale and intensity coefficients is actually improved.

5. The Scale of Science and Research Activity

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 a narrower view of research and development, like the numbers of scientists and engineers and expenditures on research and development.

Once more the data are taken from UNESCO *Statistical Yearbooks* as described in the appendix. We measure, specifically, total numbers of scientists and engineers; scientists, engineers, and technicians; scientists and engineers engaged in R&D; and 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 product and trade data. We note, for example, that the United States, which has ten times the population of Canada but is in other respects very similar, has only three 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 are important differences in the definitions of these categories across countries. Nevertheless, the data are available for a broad range of countries and we think that they may contain useful information for our study.

Our findings are reported in Table 5. We see, for the most part, no strong relation between growth and either the scale or intensity of R&D activity. The strongest effect statistically is for scientists and engineers in R&D. The intensity coefficient for this variable implies that doubling research intensity in a country of given population size is associated with an annual growth rate 0.23 percent higher. On the whole the evidence is too weak to draw strong conclusions about either scale or intensity effects.

6. 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 is the introduction of new products, then trade plays a more central role: a country can grow faster if it is able to import differentiated products 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 (1975) index of intra–industry trade and an intra–industry import index of our own construction.

The Grubel–Lloyd index is

$$(6.1) \qquad \text{Grubel–Lloyd Index} = \frac{\Sigma_{i=1}^{I} \{X_i + M_i - |X_i - M_i|\}}{X + M},$$

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 three–digit SITC trade data reported in the United Nations' *Yearbook of International Trade Statistics.* Both indexes 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 three–digit level reflects trade in finely differentiated products. Thus trade in category 711, nonelectrical machinery, 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.

In Table 6 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 columns the relation is positive. The best results are obtained using the growth rate of manufacturing output per worker as the dependent variable. In the last column the index has a t–statistic of 2.74 in the simple regression and a t–statistic of 2.04 in the regression that includes ancillary variables. Notice that the scale of manufacturing also has a significantly positive effect in each of these two regressions.

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,

$$(6.2) \qquad \alpha_i = \frac{\Sigma_{j=1}^{J} \; (X_i^j + M_i^j - | X_i^j - M_i^j |)}{\Sigma_{j=1}^{J} \; (X_i^j + M_i^j)},$$

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 to construct a measure of imports of differentiated products:

$$(6.3) \qquad \text{Intra–Industry Import Index} = \Sigma_{i=1}^{I} \; \alpha_i \, M_i^j / Y^j;$$

where Y is GDP or manufacturing output, 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 7 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 –0.269. This is in accord with our theory where small countries can partially escape the trap of small scale by importing differentiated products; 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 column three imply that a hundredfold increase in the scale of manufacturing, everything else being equal, is assocated with a 4.8 percent increase in the growth rate in manufacturing output per worker.

7. Discussion

In our investigation of the relation between growth and the scale of production in Section 3 (Tables 2 and 3), our 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. Similarly, our theory relating intra–industry trade industries and scale to growth does better in Section 6 (Tables 6 and 7) when restricted to manufacturing than it does with all products. 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 regressions in Table 4, which relates to human capital accumulation, and those in Table 5, which relates 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. Table 8 reports some of the results. Notice that in every case, both in the simple regression and the regression with ancillary variables, 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 all industries. 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. Very incomplete data in the 1982 UNESCO *Statistical Yearbook* (Table 5.10) 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: 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 Table 9, we repeat some regressions in Tables 4, 5, and 8, substituting either the growth rate of population or the growth rate of employment in manufacturing, as approximate, for the scale variable. The results here are very unfavorable for this variant of our theory. The coefficients of population growth are all negative, often significantly. Indeed, in regressions not reported here we repeated all the possible regressions related to Tables 4, 5, and 8 and have found that the coefficient of population growth is always negative.

The striking results of our investigation are undoubtedly those related to manufacturing scale and the intra–industry trade indexes. 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. Such an alternative theory is worth studying further. It is worth noting, however, that this theory 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 output per worker and productivity growth is only 0.108, however, while that between the log of total output and productivity growth is 0.571. (Table 10 in the Appendix contains the simple correlations of many of the key variables.)

8. Final Thoughts

We have looked for national scale effects on growth in cross section relations. We have based our search on theories of growth with learning by doing, human capital formation, research and development, and product differentiation. Another class of theories, including papers by Jones and Manuelli (1990) and King, Plosser, and Rebelo (1988), bases growth on physical capital accumulation with convex technologies. This class does not predict scale effects on growth rates, and has not been pursued in the paper.

Our use of cross–country data analysis is, as Stern (1989) notes, unfortunately vulnerable to unmeasured heterogeneity of environmental factors across countries. This is abundantly clear in Section 4, where the effects of human capital accumulation measures are evident in simple regressions but largely disappear when we introduce a dummy variable for sub–Saharan African countries. We suspect further progress will have to supplement cross–section analysis with data at a more microeconomic level.

References

Aghion, P., and P. Howitt, "A Model of Growth Through Creative Destruction," unpublished manuscript, Massachusetts Institute of Technology, 1989.

Argote, L., and D. Epple, "Learning Curves in Manufacturing," *Science*, 247 (1990), 920–924.

Arrow, K. J., "The Economic Implications of Learning by Doing," *Review of Economic Studies*, 24 (1962), 155–73.

Barro, R., "Economic Growth in a Cross Section of Countries," NBER Working Paper 3120, 1989.

Boldrin, M., and J. A. Scheinkman, "Learning–By–Doing, International Trade and Growth: A Note," in P. W. Anderson, K. J. Arrow, and D. Pines, eds., *The Economy as an Evolving, Complex System*, (Reading, MA: Addison–Wesley, 1988).

Chenery, H., S. Robinson, and M. Syrquin, *Industrialization and Growth*, (New York: Oxford University Press, 1986).

Chipman, J., "Induced Technical Change and Patterns of International Trade," in R. Vernon, ed., *The Technology Factor in International Trade*, (New York: Columbia University Press for the NBER, 1970).

Christensen, L. R., D. Cummings, and D. W. Jorgenson, "Relative Productivity Levels, 1947–1973: An International Comparison," *European Economic Review*, 16 (1981), 61–94.

Clemhout, S., and H. Y. Wan, "Learning–by–Doing and Infant Industry Protection," *Review of Economic Studies*, 37 (1970), 33–56.

Conrad, K., and D. W. Jorgenson, "Sectoral Productivity Gaps Between the United States, Japan and Germany, 1960–1979," in H. Giersch, ed., *Probleme und Perspektiven der weltwirschaflichen Entwicklung*, (Berlin: Dunker and Humblot, 1985), 335–347.

Deardorff, A., "Testing Trade Theories and Predicting Trade Flows," in R. W. Jones and P. B. Kenen, *Handbook of International Economics, volume 1*, (New York: Elsevier, 1984).

De Long, J. B., and L. H. Summers, "Equipment Investment, Relative Prices, and Economic Growth," presented at the NBER Conference on Economic Growth, Vail, April 1990.

Dinopoulos, E., J. F. Oehmke, and P. S. Segerstrom, "High–Technology–Industry Trade and Commercial Policy," unpublished manuscript, Michigan State University, 1989.

Dixit, A. K., and J. Stiglitz, "Monopolistic Competition and Optimum Product Diversity," *American Economic Review*, 67 (1977) 297–308.

Edwards, S., "Openness, Outward Orientation, Trade Liberalization, and Economic Performance in Developing Countries," NBER Working Paper 2908, 1989.

Ethier, W. L., "National and International Returns to Scale in the Modern Theory of International Trade," *American Economic Review*, 72 (1982), 389–405.

Ghemawat, P., "Building Strategy on the Experience Curve," *Harvard Business Review*, 63 (1985), 143–49.

Glomm, G., "Variety, Growth, and Trade," unpublished manuscript, University of Virginia, 1988.

Grossman, G. M., and E. Helpman, "Comparative Advantage and Long–Run Growth," NBER Working Paper 2809, 1988.

Grossman, G. M., and E. Helpman, "Product Development and International Trade," *Journal of Political Economy*, 97 (1989a), 1261–83.

Grossman, G. M., and E. Helpman, "Quality Ladders and Product Cycles," unpublished manuscript, Princeton University, 1989b.

Grossman, G. M, and E. Helpman, "Quality Ladders in the Theory of Growth," unpublished manuscript, Princeton University, 1989c.

Grubel, H., and P. J. Lloyd, *Intra–Industry Trade*, (London: Macmillan, 1975).

Helpman, E., "Increasing Returns, Imperfect Markets, and Trade Theory," in R. W. Jones and P.B. Kenen, eds., *Handbook of International Economics,* volume 1, (New York: Elsevier, 1984).

Helpman, E., and P. Krugman, *Market Structure and Foreign Trade: Increasing Returns, Imperfect Competition, and the International Economy*, (Cambridge: MIT Press, 1985).

Hufbauer, G., "The Impact of National Characteristics and Technology on the Commodity Composition of Trade in Manufactured Goods," in R. Vernon, ed., *The Technology Factor in International Trade*, (New York: Columbia University Press for the NBER, 1970).

Jones, L. and R. Manuelli, "A Convex Model of Equilibrium Growth," *Journal of Political Economy*, forthcoming 1990.

Jorgenson, D. W., and M. Nishimizu, "U.S. and Japanese Economic Growth, 1952–1974: An International Comparison," *Economic Journal*, 88 (December 1978), 707–726.

Jovanovic, B., and G. MacDonald, "Competitive Diffusion," University of Rochester Center for Economic Research, Working Paper 160, 1988.

King, R. G., C. I. Plosser, and S. T. Rebelo, "Production, Growth, and Business Cycles," *Journal of Monetary Economics*, 21 (1988), 195–232.

Kormendi, R., and P. Meguire, "Macroeconomic Determinants of Growth: Cross–Country Evidence," *Journal of Monetary Economics*, 16 (1985), 141–163.

Kravis, I., A. Heston, and R. Summers, *World Product and Income: International Comparisons of Real Gross Product*, (Baltimore: Johns Hopkins University Press for the World Bank, 1982).

Krugman, P., "The Narrow Moving Band, the Dutch Disease, and the Competitive Consequences of Mrs. Thatcher," *Journal of Development Economics*, 27 (1987), 41–55; reprinted in Krugman, *Rethinking International Trade*, (Cambridge: MIT Press, 1990).

Kuznets, S., *Modern Economic Growth*. (New Haven: Yale University Press, 1966).

Leamer, E., *Sources of International Comparative Advantage: Theory and Evidence*, (Cambridge: MIT Press, 1984).

Lucas, R. E., "On the Mechanics of Economic Development," *Journal of Monetary Economics*, 22 (1988), 3–42.

Marshall, A., *Principles of Economics*. (London: Macmillan, 1890).

Marston, R.C., "Real Exchange Rates and Productivity Growth in the United States and Japan," in S. W. Arndt and J. D. Richardson, eds., *Real–Financial Linkages Among Open Economies*, (Cambridge, MA: MIT Press, 1987), 71–96.

Michaely, M., "Exports and Growth: An Empirical Investigation," *Journal of Development Economics*, 1 (1977), 49–53.

Michaely, M., *Trade, Income Levels, and Dependence*, (New York: Elsevier, 1984).

Murphy, K., A. Shleifer, and R. Vishny, "Industrialization and the Big Push," *Journal of Political Economy*, 97 (1989), 1003–26.

Nishimizu, M., and S. Robinson, "Productivity Growth in Manufacturing," in H. Chenery, S. Robinson, and M. Syrquin, *Industrialization and Growth*, (New York: Oxford University Press, 1986).

Ohlin, B., *Interregional and International Trade*. (Cambridge MA: Harvard, 1933).

Parente, S., "Economic Institutions and External Factors: Implications for the Replacement of Inferior Technologies," unpublished manuscript, Economic Analysis Group, U.S. Department of Justice, 1989.

Rivera–Batiz, L., and P. Romer, "International Trade with Endogenous Technological Change," unpublished manuscript, University of Chicago, 1989.

Romer, P. M., "Increasing Returns, Specialization, and External Economies: Growth as Described by Allyn Young," unpublished manuscript, University of Chicago, 1986.

Romer, P. M., "Growth Based on Increasing Returns Due to Specialization," *American Economic Review*, 77 (1987), 56–62.

Romer, P. M., "Human Capital and Growth: Theory and Evidence," NBER Working Paper 3173, 1989a.

Romer, P. M., "What Determines the Rate of Growth and Technological Change," World Bank, Policy, Planning, and Research Working Paper WPS 279, September 1989b.

Romer, P. M., "Endogenous Technological Change," *Journal of Political Economy*, forthcoming 1990.

Rosenstein–Rodan, P., "Problems of Industrialization in Eastern and Southeastern Europe," *Economic Journal*, 53 (1943), 202–212.

Schmitz, J., "Imitation, Entrepreneurship, and Long–Run Growth," *Journal of Political Economy*, 97 (1989), 721–39

Smith, A., *The Wealth of Nations.* (London: Strahan and Cadell, 1776; reprinted by Penguin, 1986).

Stern, N., "The Economics of Development: A Survey," *Economic Journal*, 99 (1989), 597–685.

Stokey, N. L., "Learning by Doing and the Introduction of New Goods," *Journal of Political Economy*, 96 (1988), 701–17.

Stokey, N. L., "Human Capital, Product Quality, and Growth," unpublished manuscript, Northwestern University, 1990.

Summers, R., and A. Heston, "A New Set of International Comparisons of Real Product and Price Levels," *Review of Income and Wealth*, 34 (1988), 1–25.

Tamura, R., "Efficient Equilibrium Convergence and the Effects of Heterogeneity on Aggregate Growth in an Endogenous Growth Model," unpublished manuscript, University of Iowa, June 1990.

United Nations, *Yearbook of International Trade Statistics, Volume 1: Trade by Country.* (New York: United Nations, 1988).

United Nations, *Growth of World Industry.* (New York: United Nations, 1978).

United Nations Educational, Scientific, and Cultural Organization, *Statistical Yearbook*, (UNESCO: Paris, 1970, 1982).

Uzawa, H., "Optimum Technical Change in an Aggregative Model of Economic Growth," *International Economic Review*, 6 (1965), 18–31.

World Bank, *World Development Report 1987*, (New York: Oxford University Press, 1987).

World Bank, *World Tables, 1988–89 Edition*, (Washington: World Bank, 1989).

Wright, T. P., "Factors Affecting the Cost of Airplanes," *Journal of Aeronautical Sciences*, 3 (1936), 122–28.

Young, A., "Increasing Returns and Economic Progress," *Economic Journal*, 38 (1928), 527–542.

Young, A., "Learning by Doing and the Dynamic Effects of International Trade," unpublished manuscript, Columbia University, 1989.

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 (1988), 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)/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, 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 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*, Summers and Heston (1988), 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 Summer–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.

Ancillary variables. The source is the Barro–Wolf dataset described by Barro (1989). AFRICA is a dummy variable that equals one for countries in sub–Saharan Africa, zero otherwise. OIL is a dummy that equals one for oil–exporting countries. REVOL is an index of the average number of revolutions and coups per year.

Output specialization indexes. The source is the United Nations' *National Income and Product Accounts*, Table 4.2 from the 1989 computer tape. This source provides national accounts in constant prices in local currency units by sector. There is a broad breakdown into nine categories that we use to construct the GDP specialization index. There is a further breakdown of manufacturing into nine subcategories that we used to construct the manufacturing specialization index. The formula used is equation (3.3) in the paper. The date for all series is 1970.

Export specialization indexes. The source is the 1970 data in the United Nations' *Yearbook of International Trade Statistics*, the 1989 computer tape (Table 5, rev. 1). We constructed indexes with both 1–digit and 3–digit SITC categories. One index in each case was for all categories of goods. The other was for manufacturing only, categories 5 through 8 of the 1–digit data and 500 to 899 in the 3–digit data. When fewer than 60 categories of goods were available (30 for manufacturing), we label the 3–digit index not available. The date for all series is 1970. We have experimented with using 100 categories (50 for manufacturing), 80 categories (40 for manufacturing), and 50 categories (25 for manufacturing) as alternative cut–off points for including observations. These alternatives have little effect on the results reported in the text.

Educational inputs. The source is the United Nations Educational, Scientific, and Cultural Organization's *Statistical Yearbook*, 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. Aggregates of first, second, and third levels are described in the text.

Research and development indicators. The source is the United Nations Educational, Scientific, and Cultural Organization's *Statistical Yearbook*, 1970 edition. Scientists and engineers; scientists, engineers, and technicians; and scientists and engineers in R&D are all from Table 3.1. Expenditure 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 primarily the United Nations' *Yearbook of International Trade Statistics*, the 1989 computer tape (Tables 4 and 5, rev. 1). The Grubel–Lloyd index uses formula (6.1). The trade flows are reported in U.S. dollars. From the 3 digit trade flows we computed the α's in (6.2). The intra–industry import index (6.3) for all products uses the same trade flows and Summers–Heston GDP. The intra–industry import index for manufacturing uses the same trade flows and manufacturing output constructed 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.

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 (26 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 indexes persist in the common sample.

Tables 10 and 11 report the simple correlations between the major series. Table 10 uses the maximum sample available for each pair of variables. Table 11 uses a sample of 38 countries for which all of the series are available. Notice the similarities between the two tables.

C. Intra–Industry Trade Indexes

	Grubel–Lloyd (All Products)	Grubel–Lloyd (Manufacturing)	Intra–industry Imports (All Products)	Intra–industry Imports (Manufacturing)
Algeria	0.067	0.072	0.121	1.700
Angola	0.097	0.053	NA	NA
Benin	0.137	0.142	0.109	1.174
Burkina	0.088	0.055	0.054	0.041
Cameroon	0.100	0.148	0.111	1.189
Cent. African Rep.	0.052	0.062	NA	NA
Chad	NA	0.050	NA	NA
Congo	NA	0.046	NA	0.064
Egypt	0.118	0.141	0.041	0.032
Ethopia	0.057	0.040	0.024	0.233
Gabon	NA	0.046	NA	0.070
Ivory Coast	0.079	0.140	0.116	1.608
Kenya	0.145	0.115	0.744	0.864
Liberia	0.069	0.078	0.173	3.027
Madagascar	0.117	0.096	0.088	0.078
Malawi	0.128	0.096	0.056	0.046
Mali	0.175	0.222	NA	NA
Mauritius	NA	0.130	NA	0.325
Morocco	0.943	0.094	0.073	0.060
Niger	NA	0.048	NA	0.046
Nigeria	0.036	0.018	0.026	0.557
Senegal	0.212	0.341	0.092	0.536
Somalia	0.111	0.178	NA	NA
Tanzania	0.159	0.108	0.034	0.266
Togo	0.080	0.107	NA	NA
Tunesia	0.194	0.121	0.079	0.769
Uganda	0.018	0.037	NA	NA
Zaire	0.016	0.009	0.066	1.453
Zambia	0.009	0.006	0.066	0.367
Hong Kong	0.308	0.331	NA	NA
India	0.214	0.227	0.015	0.075
Iran	0.050	0.031	0.073	0.068
Israel	0.416	0.460	0.098	0.090
Japan	0.236	0.328	0.026	0.057
Jordan	0.224	0.149	0.077	0.754
Korea	0.167	0.195	0.082	0.437
Kuwait	0.127	0.137	0.105	0.090
Malaysia	0.191	0.126	0.150	0.762
Pakistan	0.123	0.066	0.043	0.268
Philippines	0.080	0.067	0.064	0.250
Singapore	0.538	0.441	NA	NA
Thailand	0.094	0.045	0.086	0.474
Austria	0.576	0.664	0.117	0.361
Belgium	0.663	0.741	0.201	0.643

Intra–Industry Trade Indexes, (continued)

	Grubel–Lloyd (All Products)	Grubel–Lloyd (Manufacturing)	Intra–industry Imports (All Products)	Intra–industry Imports (Manufacturing)
Cyprus	0.186	0.221	0.111	0.094
Denmark	0.509	0.617	0.130	0.682
Finland	0.293	0.355	0.111	0.405
France	0.675	0.781	0.574	0.046
Germany (FRG)	0.535	0.597	0.070	0.144
Greece	0.190	0.191	0.082	0.481
Ireland	0.304	0.150	0.024	0.004
Italy	0.470	0.610	0.063	0.196
Malta	0.294	0.297	0.207	0.166
Netherlands	0.609	0.727	0.174	0.144
Norway	0.432	0.489	0.147	0.569
Sweden	0.558	0.669	0.100	0.363
Switzerland	0.512	0.564	0.151	0.129
Turkey	0.075	0.086	0.025	0.114
Barbados	0.211	0.220	0.252	2.931
Canada	0.558	0.626	0.080	0.359
Costa Rica	0.207	0.298	0.146	0.131
El Salvador	0.273	0.416	0.096	0.559
Guatemala	0.287	0.424	0.071	0.405
Honduras	0.136	0.179	0.090	0.630
Mexico	0.263	0.277	0.033	0.142
Nicaragua	0.200	0.301	0.010	0.436
Panama	0.066	0.039	0.129	0.978
Trinidad & Tobago	0.165	0.216	0.176	1.000
United States	0.490	0.567	0.018	0.064
Argentina	0.152	0.223	NA	NA
Brazil	0.166	0.190	NA	NA
Chile	0.073	0.048	0.052	0.193
Columbia	0.116	0.101	0.477	0.196
Guyana	NA	0.129	NA	0.947
Peru	0.038	0.036	0.042	0.171
Uruguay	0.077	0.086	0.028	0.024
Venezuela	0.023	0.045	0.067	0.483
Australia	0.220	0.287	0.059	0.052
Fiji	0.151	0.074	0.111	0.574
New Zealand	0.122	0.162	0.091	0.083

Table 1

Properties of the Data

Variable	Mean	St. Dev.	Minimum		Maximum		Observations
(a) Growth Rates (percent)							
GDP Per Capita, 1970-85	1.334	2.465	-5.519	(Kuwa)	8.213	(Sing)	118
Manufacturing Output Per Employee, 1970-85	-0.606	3.413	-9.683	(Bots)	5.665	(Japa)	67
(b) Scale of Industry (billions of 1980 U.S. dollars)							
GDP	57.40	196.7	0.263	(Gamb)	1939.6	(USA)	118
Manufacturing Ouptut	19.18	58.3	0.027	(Bots)	420.4	(USA)	67
Specialization-Weighted GDP	20.51	57.6	0.262	(Cypr)	361.1	(USA)	46
Specialization-Weighted Manufacturing	7.32	19.3	0.046	(Cypr)	95.1	(USA)	26
Export-Weighted GDP (1-digit SITC)	26.81	61.7	0.386	(Beni)	441.1	(USA)	63
Export-Weighted GDP (3-digit SITC)	5.86	9.83	0.092	(Malt)	54.3	(USA)	77
Export-Weighted Manufacturing (1-digit SITC)	7.57	17.1	0.074	(Cypr)	95.6	(USA)	42
Export-Weighted Manufacturing (3-digit SITC)	1.61	3.3	0.012	(Barb)	20.89	(USA)	50

Table 1 (continued)

Variable	Mean	St. Dev.	Minimum		Maximum		Observations
(c) Education (thousands of people)							
Students Level 1	2362	6293	3.48	(Oman)	57045	(Indi)	117
Students Levels 1&2	4210	11647	6.24	(Oman)	97274	(Indi)	116
Students Levels 1-3	4868	13250	67.39	(Luxe)	103081	(Indi)	107
Teachers Level 1	78	197	0.20	(Oman)	1376	(Indi)	116
Teachers Levels 1&2	186	492	0.61	(Oman)	3364	(USA)	111
Teachers Levels 1-3	242	657	2.25	(Yeme)	4638	(USA)	94
(d) Research and Development (thousands of people or bllions of 1980 U.S. dollars)							
Scientists and Engineers	500	1517	1.52	(Burk)	10294	(Indi)	50
Scientists, Engineers and Technicians	1667	5080	0.67	(Togo)	37050	(Japa)	57
Scientists & Engineers in R&D	232	806	0.12	(Bots)	5167	(USA)	47
Research and Development	2.42	894	0.002	(Maur)	58.19	(USA)	44
(e) Intra-Industry Trade							
Grubel-Lloyd Index (All Products)	0.216	0.175	0.009	(Zamb)	0.675	(Fran)	74
Grubel-Lloyd Index (Manufacturing)	0.226	0.206	0.006	(Zamb)	0.781	(Fran)	80
Intra-Industry Import Index (All Products)	0.089	0.050	0.015	(Indi)	0.252	(Barb)	64
Intra-Industry Import Index (Manufacturing)	0.474	0.587	0.004	(Irel)	3.027	(Libe)	69

Table 2

Regressions of Growth in Per Capita GDP on Scale of Industry

Scale Variable	GDP	Manufacturing	Specialization Weighted GDP	Specialization Weighted Manufacturing
Observations	118	67	46	26
(a) Simple Regressions				
Scale Coef.	0.167	0.104	0.198	0.079
(std. error)	(0.102)	(0.100)	(0.162)	(0.147)
R^2	0.016	0.011	0. 020	0.005
(b) Regressions with Ancillary Variables				
Scale Coef.	-0.045	-0.044	-0.008	-0.219
(std. error)	(0.102)	(0.086)	(0.160)	(0.102)
R^2	0.271	0.192	0.389	0.581

Scale Variable	Export Weighted GDP (1 Digit SITC)	Export Weighted GDP (3 Digit SITC)	Export Weighted Manufacturing (1 Digit SITC)	Export Weighted Manufacturing (3 Digit SITC)
Observations	63	77	42	50
(a) Simple Regressions				
Scale Coef.	0.286	0.012	0.132	0.091
(std. error)	(0.177)	(0.214)	(0.174)	(0.148)
R^2	0.034	0.000	0.010	0.006
(b) Regressions with Ancillary Variables				
Scale Coef.	-0.054	-0.137	-0.137	0.024
(std. error)	(0.183)	(0.195)	(0.192)	(0.139)
R^2	0.329	0.286	0.256	0.217

Part (a) refers to regressions of growth rates of per capital GDP 1970-85 on a constant and the logarithm of scale. Part (b) regressions also include Barro's (1989) OIL, REVOL, and AFRICA as independent variables. Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table 3

Regressions of Growth in Manufacturing Output Per Worker on Scale of Industry

Scale Variable	Manufacturing	Specialization Weighted Manufacturing	Export Weighted Manufacturing (1 Digit SITC)	Export Weighted Manufacturing (3 Digit SITC)
Observations	67	26	42	50
(a) Simple Regression				
Scale Coef.	0.897	0.701	0.895	0.712
(std. error)	(0.167)	(0.190)	(0.220)	(0.215)
R^2	0.326	0.237	0.253	0.177
(b) Regressions with Ancillary Variables				
Scale Coef.	0.750	0.370	0.655	0.615
(std. error)	(0.186)	(0.202)	(0.265)	(0.236)
R^2	0.383	0.634	0.420	0.314

Part (a) refers to regressions of growth rates in manufacturing output per worker 1970-85 on a constant and the logarithm of scale. Part (b) regressions also include Barro's (1989) OIL, REVOL, and AFRICA as independent variables. Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table 4

Regressions of Growth in Per Capita GDP on Scale and Intensity in Education

Scale Variable	Students Level 1	Students Levels 1&2	Students Levels 1-3	Teachers Level 1	Teachers Levels 1&2	Teachers Levels 1-3
Intensity Var.	Students Per Capita	Students Per Capita	Students Per Capita	Teachers Per Capita	Teachers Per Capita	Teachers Per Capita
Observations	117	116	107	116	111	94
(a) Simple Regressions						
Scale Coef.	0.121	0.103	0.134	0.115	0.120	0.175
(std. error)	(0.135)	(0.133)	(0.139)	(0.133)	(0.131)	(0.150)
Intensity Coef.	0.641	0.949	1.007	0.709	0.759	0.626
(std. error)	(0.339)	(0.378)	(0.448)	(0.332)	(0.335)	(0.372)
R^2	0.048	0.099	0.089	0.069	0.109	0.087
(b) Regressions with Ancillary Variables						
Scale Coef.	0.152	0.149	0.157	0.152	0.162	0.222
(std. error)	(0.130)	(0.130)	(0.140)	(0.130)	(0.132)	(0.156)
Intensity Coef.	-0.067	-0.061	-0.302	-0.105	-0.096	-0.357
(std. error)	(0.337)	(0.400)	(0.482)	(0.288)	(0.354)	(0.360)
R^2	0.274	0.275	0.276	0.277	0.270	0.280

Part (a) refers to regressions of growth rates of per capita GDP 1970-85 on a constant and the logarithms of scale and intensity. Part (b) regressions also include Barro's (1989) OIL, REVOL, and AFRICA as independent variables. Numbers in parentheses are keteroskedasticity--consistent standard errors.

Table 5

Regressions of Growth in Per Capita GDP on Scale and Intensity in R&D

Scale Variable	Scientists & Engineers Total	Scientists, Engineers, & Technicians Total	Scientists & Engineers in R&D Total	R&D Expenditures Total
Intensity Variable	Scientists & Engineers Per Capita	Scientists, Engineers, & Technicians Per Capita	Scientists & Engineers in R&D Per Capita	R&D Expenditures Percent of GDP
Observations	50	57	47	44
(a) Simple Regressions				
Scale Coef.	-0.084	0.248	-0.362	0.155
(std. error)	(0.234)	(0.226)	(0.195)	(0.184)
Intensity Coef.	0.262	-0.065	0.696	-0.504
(std. error)	(0.306)	(0.333)	(0.318)	(0.451)
R^2	0.015	0.047	0.081	0.034
(b) Regressions with Ancillary Variables				
Scale Coef.	0.009	0.409	-0.191	-0.085
(std. error)	(0.198)	(0.219)	(0.139)	(0.160)
Intensity Coef.	-0.254	-0.371	-0.648	-0.413
(std. error)	(0.303)	(0.326)	(0.259)	(0.400)
R^2	0.375	0.188	0.521	0.338

Part (a) refers to regressions of growth rates of per capita GDP 1970-85 on a constant and the logarithms of scale and intensity. Part (b) regressions also include Barro's (1989) OIL, REVOL, and AFRICA as independent variables. Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table 6

Regressions of Growth on Scale and the Grubel-Lloyd Index of Intra-Industry Trade

Growth Rate	GDP Per Capita	GDP Per Capita	Manufacturing Per Worker
Scale Variable	GDP	Manufacturing	Manufacturing
Grubel-Lloyd Index	All Products	Manufacturing	Manufacturing
Observations	74	49	49
(a) Simple Regressions			
Scale Coef.	0.018	-0.005	0.600
(std. error)	(0.140)	(0.141)	(0.216)
Index Coef.	1.372	0.776	1.042
(std. error)	(0.272)	(0.303)	(0.380)
R^2	0.261	0.135	0.378
(b) Regressions with Ancillary Variables			
Scale Coef.	-0.048	-0.032	0.596
(std. error)	(0.145)	(0.122)	(0.246)
Index Coef.	0.568	0.250	0.714
(std. error)	(0.304)	(0.340)	(0.350)
R^2	0.387	0.283	0.414

Part (a) refers to regressions of growth of the specified variable 1970-85 on a constant and the logarithms of the scale variable and the Grubel-Lloyd index for all products or manufacturing products, as indicated. Part (b) regressions also include Barro's (1989) OIL, REVOL, and AFRICA as independent variables. Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table 7

Regressions of Growth on Scale and the Intra-Industry Import Index

Growth Rate	GDP Per Capita	GDP Per Capita	Manufacturing Per Worker
Scale Variable	GDP	Manufacturing	Manufacturing
I.I.I. Index	All Products	Manufacturing	Manufacturing
Observations	64	45	45
(a) Simple Regressions			
Scale Coef.	0.285	0.162	1.053
(std. error)	(0.140)	(0.193)	(0.270)
Index Coef.	0.619	0.131	0.599
(std. error)	(0.369)	(0.443)	(0.742)
R^2	0.047	0.019	0.326
(b) Regressions with Ancillary Variables			
Scale Coef.	0.066	0.079	1.079
(std. error)	(0.152)	(0.179)	(0.329)
Index Coef.	0.056	0.220	0.978
(std. error)	(0.360)	(0.427)	(0.719)
R^2	0.286	0.236	0.441

Part (a) refers to regressions of growth of the specified variable 1970-85 on a constant and the logarithms of the scale variable and the intra-industry import index for all products or manufacturing products, as indicated. Part (b) regressions also include Barro's (1989) OIL, REVOL, and AFRICA as independent variables. Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table 8

Regressions of Growth in Manufacturing Output Per Worker on Scale and Intensity in Education and R&D

Scale Variable	Students Levels 1-3 Total	Teachers Levels 1-3 Total	Scientists, Engineers, & Technicians Total	R&D Expenditures Total
Intensity Variable	Students Per Capita	Teachers Per Capita	Scientists, Engineers, & Technicians Per Capita	R&D Expenditures Percent of GD
Observations	64	56	40	32
(a) Simple Regressions				
Scale Coef.	0.600	0.617	0.770	1.265
(std. error)	(0.203)	(0.188)	(0.318)	(0.279)
Intensity Coef.	2.046	1.168	0.057	-1.082
(std. error)	(0.565)	(0.400)	(0.410)	(0.651)
R^2	0.212	0.262	0.306	0.560
(b) Regressions with Ancillary Variables				
Scale Coef.	0.573	0.628	0.842	0.919
(std. error)	(0.216)	(0.215)	(0.340)	(0.313)
Intensity Coef.	0.164	0.349	-0.304	-0.659
(std. error)	(0.997)	(0.728)	(0.433)	(0.658)
R^2	0.290	0.306	0.392	0.635

Part (a) refers to regressions of growth rates in manufacturing output per worker 1970-85 on a constant and the logarithms of scale and intensity. Part (b) regressions also include Barro's (1989) OIL, REVOL, and AFRICA as independent variables. Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table 9

Regressions of Growth on Population Growth and Intensity

in Education and R&D

Growth Rate	GDP Per Capita	GDP Per Capita	Manufacturing Per Worker	Manufacturing Per Worker
Population Growth	Total Population	Total Population	Employment in Manufacturing	Employment in Manufacturing
Intensity Variable	Students Levels 1-3 Per Capita	Scientists, Engineers & Technicians Per Capita	Students Levels 1-3 Per Capita	Scientists, Engineers & Technicians Per Capita
Observations	107	57	64	40
(a) Simple Regressions				
Population Coef.	-0.825	-0.827	-0.356	-0.296
(std. error)	(0.211)	(0.401)	(0.103)	(0.166)
Intensity Coef.	0.538	0.003	1.603	0.693
(std. error)	(0.416)	(0.210)	(0.621)	(0.346)
R^2	0.200	0.132	0.251	0.266
(b) Regressions with Ancillary Variables				
Population Coef.	-0.505	0.517	-0.333	-0.238
(std. error)	(0.233)	(0.424)	(0.113)	(0.162)
Intensity Coef.	-0.316	0.016	-0.053	0.504
(std. error)	(0.461)	(0.214)	(0.995)	(0.329)
R^2	0.301	0.166	0.311	0.316

Part (a) refers to regressions of growth rates of the specified variable 1970-85 on a constant and on the growth rates of the specified population and the logarithm of intensity. Part (b) regressions also include Barro's (1989) OIL, REVOL, and AFRICA as independent variables. Numbers in parentheses are heteroskedasticity-consistent standard errors.

Table 10

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	74	64	67	53	67	80	69
2. Log of GDP/capita	0.561	118	118	74	64	67	53	67	80	69
3. Growth of GDP/capita	0.125	0.100	118	74	64	67	53	67	80	69
4. Log of Grubel-Lloyd index (all products)	0.341	0.549	0.511	74	64	48	41	48	74	64
5. Log I.I.I. index (all products)	-0.434	0.243	0.076	0.224	64	44	38	44	64	64
6. Log of manufacturing	0.978	0.544	0.103	0.361	-0.457	67	53	67	49	45
7. Log of manufacturing/worker	0.270	0.753	-0.149	0.086	0.076	0.357	53	53	42	39
8. Growth of manufacturing/worker	0.525	0.501	0.478	0.585	0.013	0.571	0.108	67	49	45
9. Log of Grubel-Lloyd index (manufacturing)	0.369	0.572	0.402	0.945	0.264	0.383	0.192	0.493	80	69
10. Log of I.I.I. index (manufacturing)	-0.262	-0.140	-0.121	-0.160	0.550	-0.648	-0.222	-0.269	-0.055	69

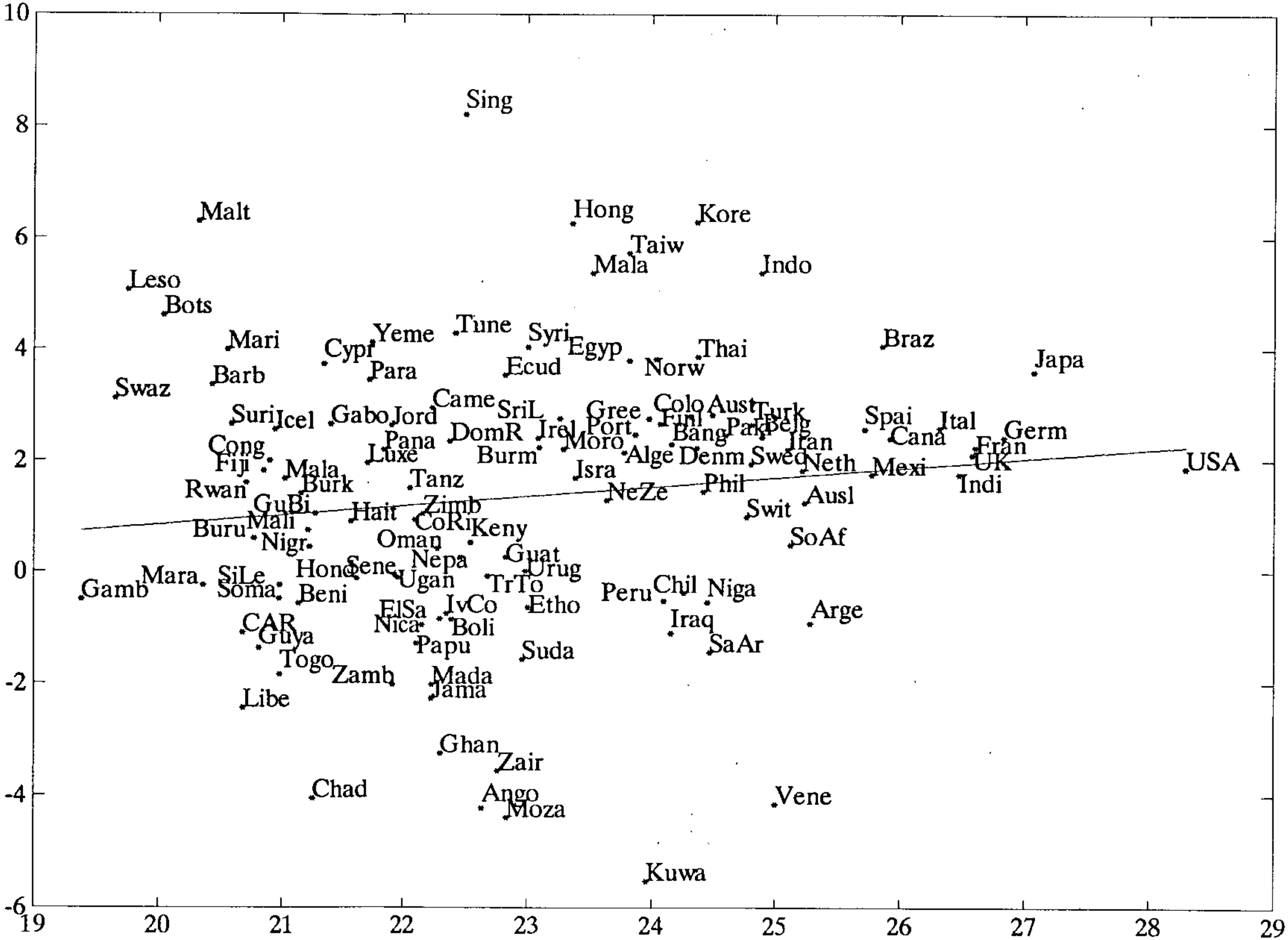
Below-diagonal elements are simple correlation coefficients between variables. Diagonal elements are number of observations in series. Above-diagonal elements are numbers of observations used in computing correlation coefficients.

Table 11

Correlations Between Variables Based on 38 Common Observations

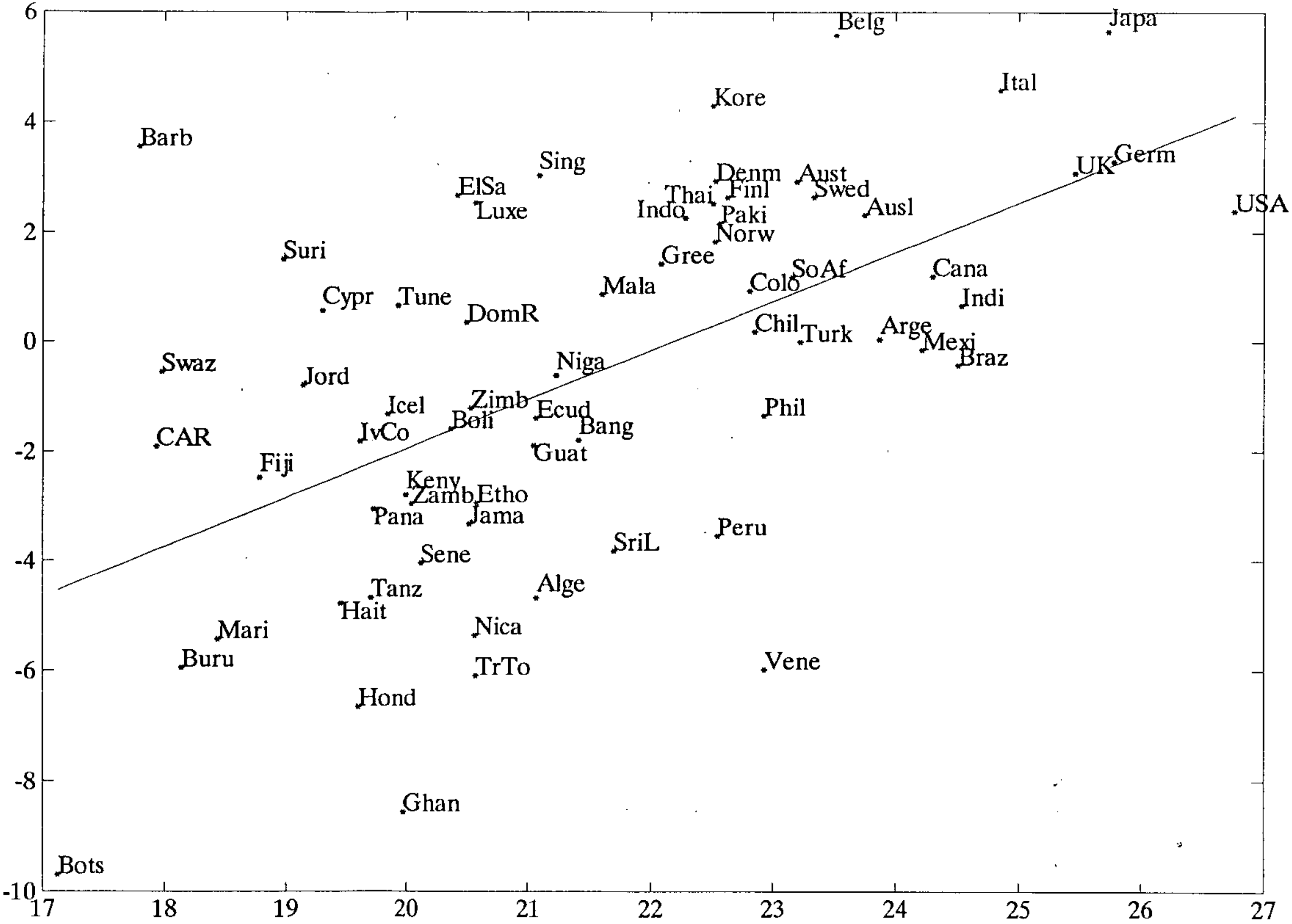
Variable	1	2	3	4	5	6	7	8	9	10
1. Log of GDP										
2. Log of GDP/capita	0.454									
3. Growth of GDP/capita	0.150	0.023								
4. Log of Grubel-Lloyd index (all products)	0.344	0.476	0.469							
5. Log I.I.I. index (all products)	-0.563	0.254	0.130	0.157						
6. Log of manufacturing	0.988	0.500	0.134	0.365	-0.533					
7. Log of manufacturing/worker	0.365	0.772	-0.295	0.081	0.076	0.428				
8. Growth of manufacturing/worker	0.472	0.377	0.635	0.591	0.003	0.496	0.020			
9. Log of Grubel-Lloyd index (manufacturing)	0.355	0.564	0.320	0.961	0.150	0.381	0.189	0.512		
10. Log of I.I.I. index (manufacturing)	-0.633	-0.138	0.002	-0.084	0.785	-0.666	-0.222	-0.261	-0.115	

FIGURE 1



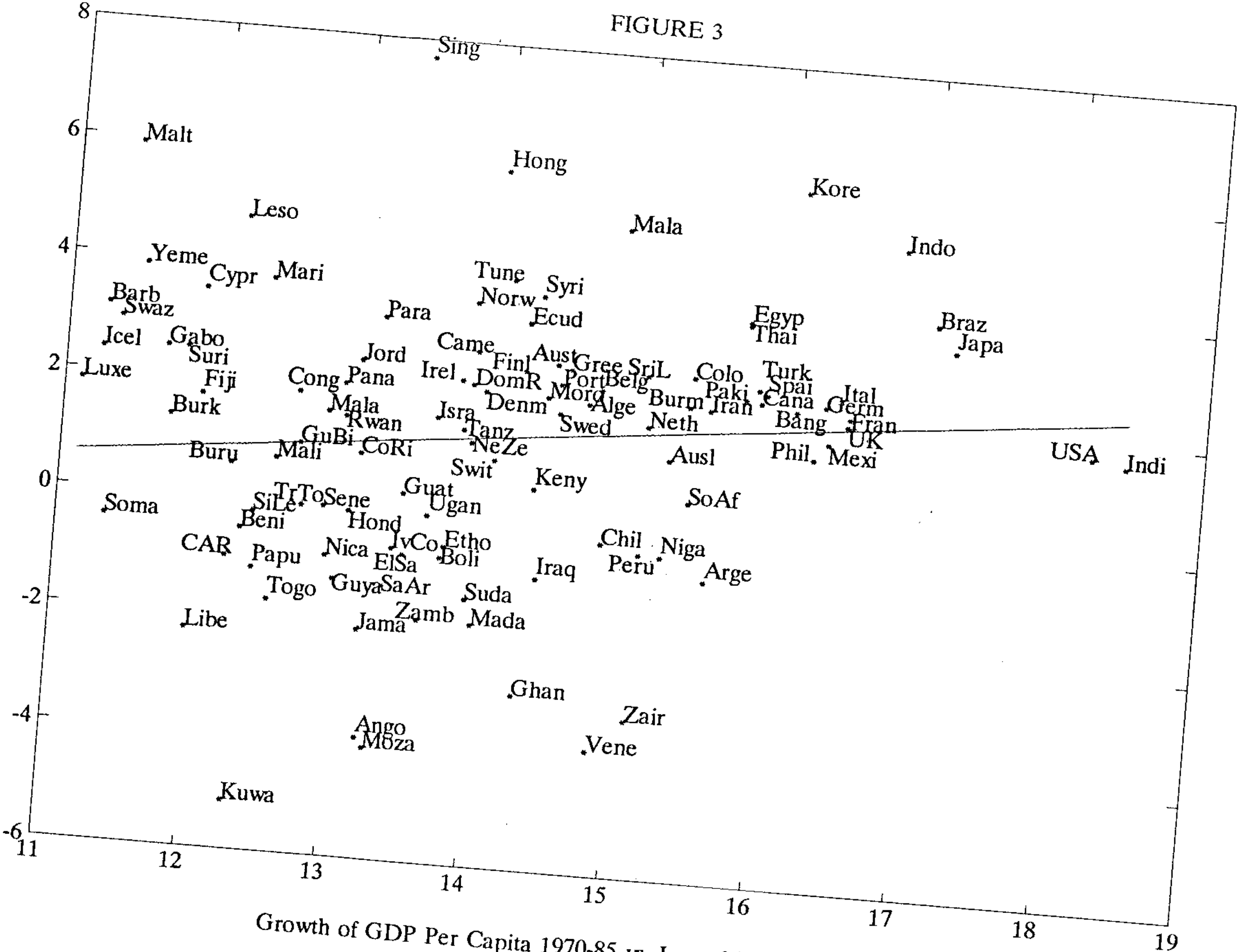
Growth of GDP Per Capita 1970-85 vs. Log of GDP

FIGURE 2



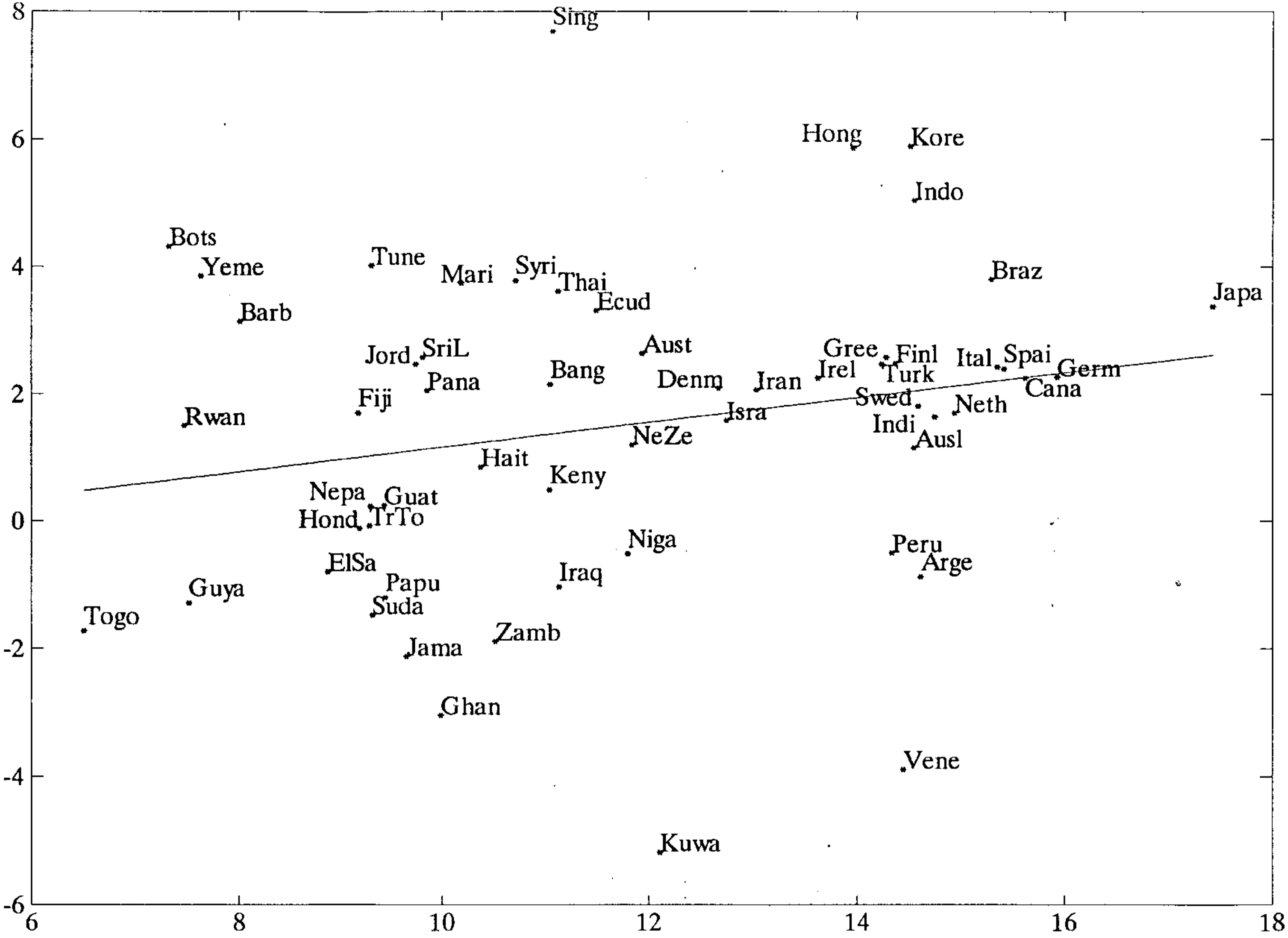
Growth of Manufacturing Output Per Worker 1970-85 vs. Log of Manufacturing

FIGURE 3



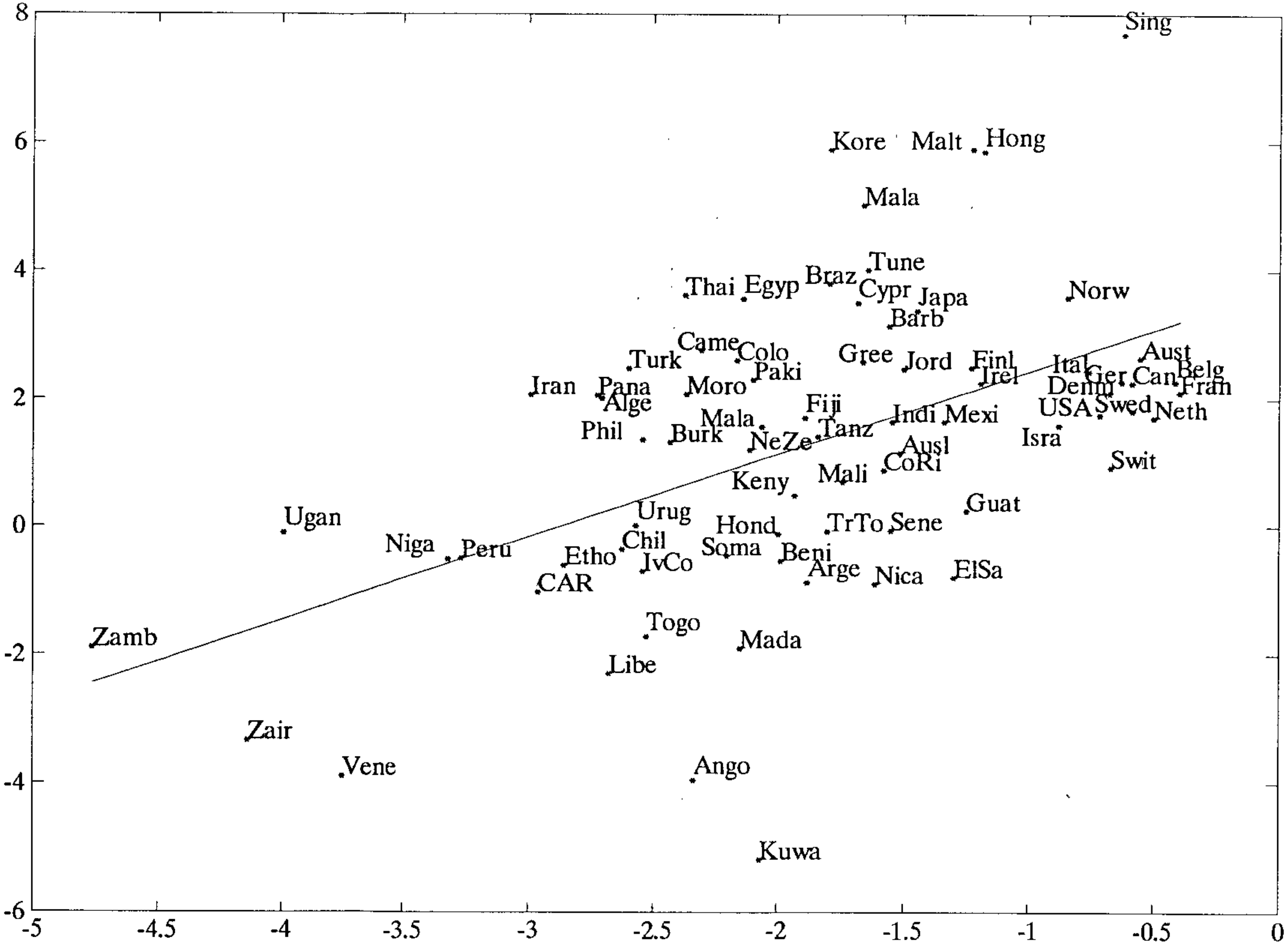
Growth of GDP Per Capita 1970-85 vs. Log of Students Levels 1-3

FIGURE 4



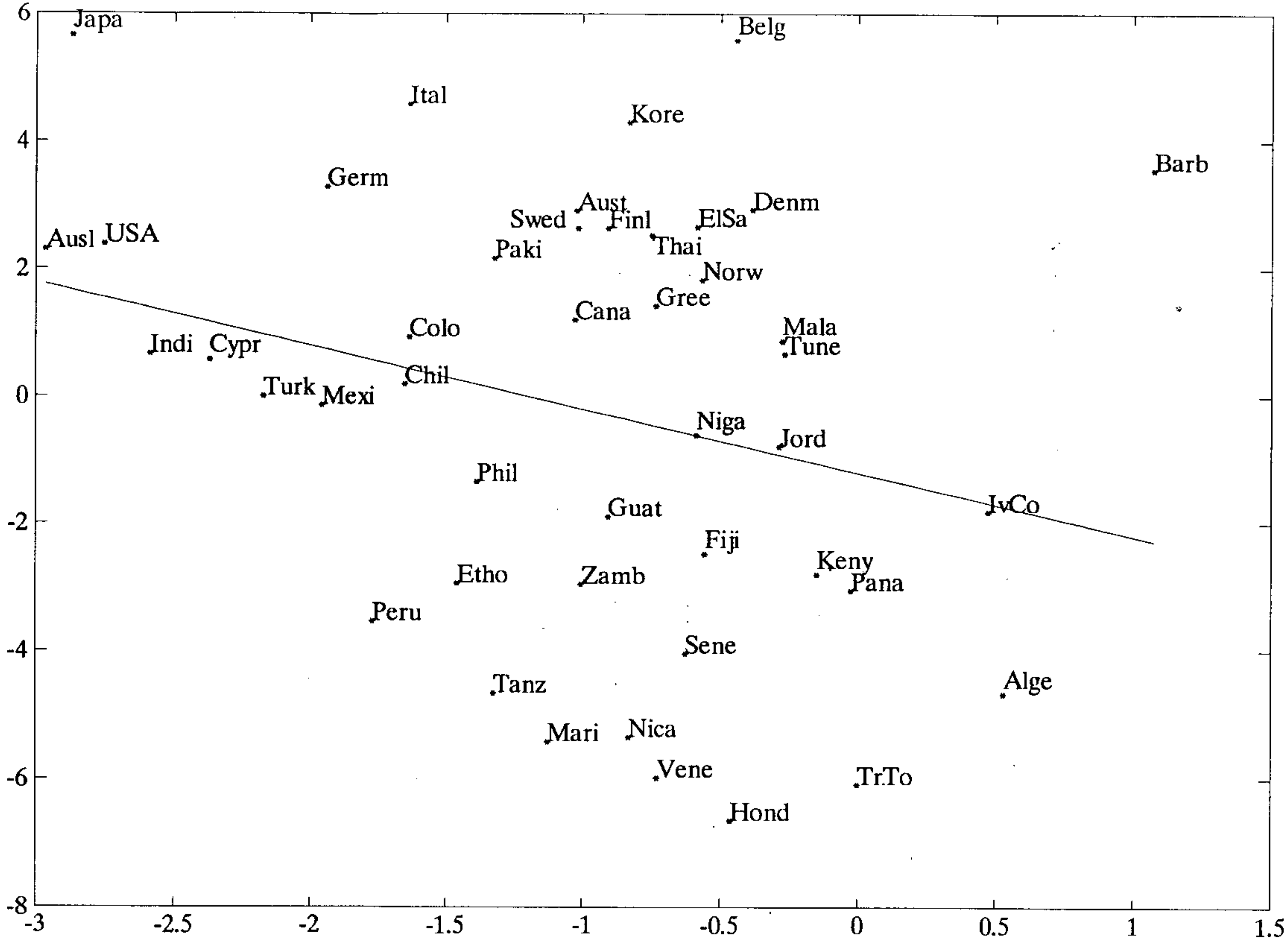
Growth of GDP Per Capita 1970-85 vs. Log of Scientists, Engineers, and Technicians

FIGURE 5



Growth of GDP Per Capita 1970-85 vs. Log of Grubel-Lloyd Index (All Products)

FIGURE 6



Growth of Manufacturing Output Per Worker 1970-85 vs. Log of Intra-Industry Import Index (Manufacturing)