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THE ECONOMICS OF TECHNOLOGICAL PROGRESS AND ENDOGENOUS GROWTH
IN OPEN ECONOMIES*

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1. INTRODUCTION

Is international trade an "engine of growth"? Do trade liberalization and

increased openness lead to higher rates of economic expansion? This has been one of the most controversial issues in international economics over the years. From Adam Smith and John Maynard Keynes to Hans Singer and Raul Prebisch, the debate between pro-traders and protectionists has raged over the years.

In the 1950s and 1960s, the vision that trade restrictions and protectionism lead to higher growth rates took hold among many policymakers, particularly in Latin America. In the form of import-substitution strategies, trade restrictions proliferated. More recently, in the 1980s and 1990s, there has been a rising perception among the public, policymakers and many academics that the question of whether or not trade leads to greater economic growth should be answered affirmatively. The proliferation of free trade zones, trade liberalization initiatives, and the successful completion of the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) are testimony to the rising faith in trade as an engine of growth. Yet, there is a vocal and influential minority which continues to assert that trade liberalization is deleterious for growth. For instance, economist Lance Taylor, of the New School for Social Research, affirms that there are "no great benefits (plus some loss) in following open trade and capital market strategies ... development strategies oriented internally may be a wise choice towards the century's end."¹

As the debate on the issue of how trade and growth are connected continues, economic research on the topic accumulates. New ideas about how trade and growth are interconnected emerge, refueling the controversy. This paper presents a summary of the key economic mechanisms postulated in recent years about how openness is linked --or not linked-- to increased rates of growth of domestic output.

A simple correlation of openness with income growth rates in a cross section of countries does not show a clear directional pattern. Figure 1, for example, plots nominal levels of protection (as measured by nominal tariff rates)

¹ Taylor (1991), p. 141.

versus output growth for a sample of European countries in the nineteenth century. These data do not result in a statistically significant relationship between protectionism and economic growth; if anything, the figure appears to indicate a positive connection between protectionism and growth².

Unfortunately, such casual empiricism is misleading. In examining the simple correlation between protectionism and growth, other factors that influence economic expansion are ignored. Since these other factors may be related to both trade and growth, they may generate a spurious relationship between the two variables. In order to examine more adequately the connection between trade and growth, a multivariate analysis is required. Such an analysis can then be used to examine how protectionism affects economic growth, holding other variables constant.

The existing empirical literature studying in a more rigorous way the connection between openness and growth overwhelmingly suggests that increased trade or reduced protectionism are linked to greater economic growth. For instance, in a recent paper, Sebastian Edwards finds that: "after taking into account the roles of capital accumulation, growth in the labor force, and technological gap, countries with higher degrees of trade intervention tend to

FIGURE 1

THE SIMPLE CORRELATION BETWEEN ECONOMIC GROWTH AND PROTECTIONISM IN THE NINETEENTH CENTURY

² On the basis of this data, Bairoch (1972) has made the argument that income growth is positively affected by protectionism; see, however, the different interpretation made by Capie (1994).

Source: Forrest Capie, *Tariffs and Growth* (Manchester: Manchester University Press, 1994), Table 2, p. 41.

grow, on average, slower than countries with lower trade restrictions.³

Similarly, Barro (1995) included tariff rates in a regression analysis of variables explaining economic growth in a cross-section of countries, finding that "the estimated coefficient is significantly negative," and concluding that: "This result brings out another channel through which distortions of markets can reduce the growth rate."⁴

Even when a negative empirical relationship between protectionism and economic growth has been established, holding other things constant, there is

³ S. Edwards, "Openness, Outward Orientation, Trade Liberalization and Economic performance in Developing Nations," NBER Working Paper No. 2908, March 1989, p. 51. In another paper, Edwards has surveyed the empirical literature on trade and growth; see S. Edwards, "Openness, Trade Liberalization and Growth in Developing Countries," *Journal of Economic Literature*, Vol. 31, September 1993.

⁴ Barro (1995), p. 438; see also Lee (1993).

still an ambiguity arising from the fact that correlation does not necessarily imply causality. As a growing literature on the political economy of protectionism indicates, reduced growth may generate a reaction against international trade, resulting in the imposition of tariffs and reduced openness. In this case, the causality goes from reduced growth to reduced trade, not the other way around.⁵ One is, therefore, motivated to look explicitly at the various ways through which openness causes growth. Further empirical analysis would then be dictated on testing whether these particular connections are empirically valid.

What are the mechanisms through which trade affects economic growth? The modern theory of economic growth suggests that, although increased supplies of factors of production such as physical capital and labor, account for a substantial portion of growth, it is technological change that explains most of the increased productivity of the labor force and, therefore, income per-capita. As Paul Krugman has aptly summarized the issue: "Mere increases in inputs without an increase in the efficiency with which those inputs are used, must run into diminishing returns; input-driven growth is inevitably limited. How, then, have today's advanced nations been able to achieve sustained growth in percapita income over the past 150 years? The answer is that technological advances have led to a continual increase in total factor productivity --a continued rise in national income for each unit of input."⁶

In order to investigate how trade affects growth, one must focus on how openness influences technological change. This paper provides a survey of the effects of trade on growth by examining the various ways through which openness affects technical change.

Our approach follows the recent literature on endogenous growth theory in

⁵ A discussion of this, and other issues, relating to the connection between trade and growth are explored by Bhagwati (1988), chapter 1.

⁶ Krugman (1994), p. 68.

assuming that technological change is not exogenous but affected instead by a myriad of economic parameters. Openness, of course, is one of these parameters. Commercial policy, for example, which restricts trade, can influence technological change by influencing domestic rivalry and competition, reallocating resources among sectors and industries in the economy, and fostering or discouraging domestic research and development. Note that the interest of this analysis is not to predict technological change, a matter which may be problematic, but instead to explain better some of the forces that influence it. As Zvi Griliches has noted: "Given the fundamental uncertainties entailed in the creative act, in invention, and in innovation, there is no reason to expect the fit of our models to be high or for the true residual to disappear. We should, however, be able to explain it better *ex post* even if we cannot predict it."⁷

The impact of trade on economic growth can be examined within two time frames: medium term and long-run.⁸ Within a medium-term context, trade alters growth over a certain period of time but the impact is only temporary disappearing after a while. In a long-run growth context, however, the focus is on how trade alters the economy's growth rate in the long-run. In the latter case, the interest is not on how trade influences technical change and growth in the short-run or during a transition period. Rather, the focus is on how trade shifts the economy's steady state growth rate.

In this paper, we start by considering the impact of trade on medium-term growth. Later sections then focus attention on long-run growth. The next section begins the discussion by reviewing how endogenous growth theory fits into the historical analysis of growth accounting.

2. ENDOGENOUS TECHNOLOGICAL CHANGE AND ECONOMIC GROWTH

⁷Griliches (1994), p. 18.

⁸ This distinction has been made by Richard Baldwin in a number of papers; see Baldwin (1992) and (1994).

Based on Solow (1956, 1957), growth accounting seeks to explain the growth rate of aggregate output into various components, mainly the growth of factor supplies --usually capital and labor-- and technological progress. The discussion begins with a standard neoclassical production function:

$$Y(t) = A(t) F[K(t), L(t)], \quad (1)$$

where $Y(t)$ refers to domestic output at time t , $A(t)$, defined as total factor productivity, denotes an index that relates to the technological level of the economy or its stock of knowledge, $K(t)$ is the amount of capital services, and $L(t)$ is the labor input. Taking proportional changes in both sides of the equation yields:

$$\dot{Y}/Y = \dot{A}/A + \left(\frac{KA F_K}{Y} \right) \dot{K}/K + \left(\frac{LA F_L}{Y} \right) \dot{L}/L, \quad (2)$$

with dots representing time derivatives ($\dot{A} = dA/dt$), and F_K and F_L denoting the partial derivatives of the production function, F , with respect to capital and labor, respectively. Equation (1) shows that output growth can be explained by the rate of technological progress or by the growth of capital and labor inputs employed in production.

On the assumptions of perfect competition in factor markets and constant returns to scale, then the marginal value product of capital, $P_Y F_K$, equals the rental rate on capital, r (with P_Y denoting the price of output, Y), and the marginal value product of labor, $P_Y F_L$, equals the wage rate, W . In addition, the sum of the share of capital in costs of production, $\mathbf{1}_k = rK/P_Y Y$, and the share of labor, $\mathbf{1}_L = WL/P_Y Y$, add up to one. Incorporating these relationships and definitions into equation (2) results in:

$$\dot{Y}/Y = \dot{A}/A + (1 - \mathbf{1}_L) \dot{K}/K + \mathbf{1}_L \dot{L}/L, \quad (3)$$

In order to measure the relative roles played by input growth and technological change in explaining output growth, one would have to measure the various

components of equation (3). Usually, the technological change growth, \dot{A}/A , is difficult to measure. As a result, Solow (1957) and others proceeded to compute available information on the growth of output and inputs, imputing the role of technological change as a residual. This is easily seen from equation (3) by rearranging terms so that:

$$\dot{A}/A = \dot{Y}/Y - [(1-\alpha)\dot{K}/K + \alpha\dot{L}/L]. \quad (4)$$

This provides an imputation of how much technological change accounts for growth, based upon information available on output and input growth.

In his classic paper on this issue, Solow (1957) obtained the technological change, as measured by the residual, explains 87.5 percent of the increase in gross output per man-hour in the U.S. during the period of 190 through 1949. For the post-war period, recent estimates put technical change as accounting for 49 percent of the increase in total factor productivity in the U.S. from 1948 to 1985. A similar calculation for France yields 76 percent, 78 percent for Germany, 55 percent for Japan and 73 percent for the United Kingdom.⁹

A myriad of other studies has confirmed the significance of the residual in accounting for a large share of long-run growth.¹⁰ In the medium-term, though, many countries have sustained high rates of growth in income per-capita through extended accumulation of capital per worker. In the case of the fast-growing Singapore, for example, Alwyn Young has suggested that its expansion since the 1960s has been totally due to increases in the supplies of capital and labor, as conventionally measured.¹¹ In assessing these results, though, one should consider that technological changes are often linked to increases in the

⁹ Boskin and Lau (1992), p. 47.

¹⁰ For a recent survey, see Barro and Sala-i-Martin (1995), chapter 10.

¹¹ See Young (1992).

stock of capital or labor. Laboratories producing the latest new inventions, for example, may use highly sophisticated equipment, and a variety of workers may be employed in such ventures. Similarly, new technology may be embodied in new machines. So, in part, physical capital accumulation is determined by technological developments, with changes in A and in K in the earlier equations intimately linked to each other.¹²

Growth accounting has been a useful tool in identifying the significant role played by the residual in explaining long-run growth. However, one needs to go further in specifying the economic forces that determine the residual. Technological change, for example, constitutes a large chunk of what is symbolically referred to as \dot{A}/A in equation (4), but how is the rate of technical change determined? Some authors, for instance, have focused on the role played by research and development expenditures in determining innovation [see Griliches (1994)]. Others have emphasized the local availability of human capital in fostering technological change [see Romer (1991) and Lucas (1993)]. Yet others have focused on learning externalities [see Stokey (1988), Young (1991), and Lucas (1993)]. And some recent literature has looked at the impact of cities and urban agglomeration on medium-term productivity growth [see Rivera-Batiz (1988a, 1988b, 1994), Eaton and Eckstein (1993), Hanson (1994), and Rauch (1995)]. What these approaches have in common is that they endogenize technological change, looking at the forces that increase or decrease the rate of technical progress in the economy. In terms of equation (1), A is an endogenous variable, determined by economic forces.

The next section provides a model of endogenous technological change showing how trade influences total factor productivity and medium-term growth.

3. RIVALRY, TRADE, AND TECHNOLOGICAL CHANGE

¹² An argument made by Lucas (1993) in reply to Young.

In examining the reasons why some firms have higher rates of innovation and are more competitive than others in different countries, one factor emerges as critical: the extent of rivalry and competition faced by firms is a key determinant of their innovative activities. Insofar as openness and international competition increase rivalry and competition among domestic firms, innovation will be stimulated and growth will rise. By contrast, protectionism and policies that restrict trade would result in reduced innovation and a slowdown of growth. As Michael E. Porter concludes in his far-ranging study of innovation and competition: "Competitive advantage emerges from pressure, challenge, and adversity, rarely from an easy life. Pressure and adversity are powerful motivators for change and innovation... Complacency and an inward focus often explain why nations lose competitive advantage. Lack of pressure and challenge means that firms fail to look constantly for and interpret new buyer needs, new technologies, and new processes... Protection, in its various forms, insulates domestic firms from the pressure of international competition"¹³

The economist F.M. Scherer has noted that "even the most casual observer cannot escape noticing the invigorating effect rivalry commonly has on industrial firms' research and development efforts."¹⁴ In this section, we develop a simple model showing how international trade, by increasing rivalry and competition induces firms to engage in greater research and development (R&D) thus leading to technological progress.

Consider an economy of the type examined by Krugman (1990), specialized in the production of slightly differentiated goods in a market structure of monopolistic competition. We first assume that the economy is operating under autarky, determining its equilibrium in the absence of trade. The effects of opening the economy to international trade are then discussed. Consumers exhibit the following Dixit-Stiglitz utility function:

¹³ Porter (1990), pp. 170-171 and 665.

¹⁴ Scherer (1986), p. 83.

$$U = \left[\sum_{k=1}^n C_k^\alpha \right]^{1/\alpha} \quad (5)$$

where C_k is the quantity consumed of each differentiated good produced in the economy, k is an index for denoting each differentiated product, with $k = 1, \dots, n$, and α is a parameter with a numerical value between zero and one. Note that α is related to the strength of tastes toward product diversity: as α increases towards 1, the products in the industry become less differentiated and product variety loses its value.

Consumers maximize profits subject to a budget constraint, given by:

$$I_0 = \sum_{k=1}^n P_k C_k, \quad (6)$$

where P_k is the price of commodity k and I_0 is the income of consumers. Maximization of equation (5) subject to (6) leads to the following first order condition:

$$C_k = \left[\frac{I_0}{P_k U^\alpha} \right]^{1/(1-\alpha)}, \quad (7)$$

whose price elasticity, ϵ_k is given by:

$$\epsilon_k = \frac{1}{1 - \alpha[1 - 1/n]} \quad (8)$$

This elasticity is always greater than one and rises with the number of firms operating in the economy. This embodies the fact that a larger number of firms causes each single producer to lose some of its influence on aggregate demand, its monopoly power, making the market more competitive. Each firm faces this increased rivalry or competition through an increase in the price elasticity of demand for its own (differentiated) product.¹⁵

¹⁵ In the present framework, how much ϵ_k can increase is bounded by the form of the utility function, which determines the elasticity of substitution between any two given products in the economy. As n rises to 4, ϵ_k approaches the value

Each firm requires the use of unskilled labor in production, given by:

$$L_k = \mu_k + \beta X_k, \quad (9)$$

where L_k is the unskilled labor used by firm k , X_k denotes the output of each firm, the parameter β represents the amount of variable labor per unit of output and μ represents a fixed amount of labor, giving rise to fixed costs of production. Unskilled labor is hired at a wage rate denoted by W .

In addition to unskilled labor, each firm uses skilled labor, H , in activities relating to research and development (R&D). This labor is hired at a wage rate W_H , and is associated with a supply of R&D which is denoted by A . The amount of R&D produced by each unit of skilled labor (the productivity of human capital in research and development activities) is denoted by λ . The amount of skilled labor used by a firm is then:

$$H_k = \lambda A_k \quad (10)$$

The use of human capital in research and development activities is assumed to produce a benefit for the firm in the form of reduced variable costs. More specifically, it is assumed that the fixed labor requirement, μ , is reduced according to the R&D undertaken by the firm, according to:

$$\mu_k = \mu_0 A_k^{-\eta} \quad (11)$$

where the parameter η is related to the productivity of research and development in reducing costs in the firm.¹⁶

Each firm maximizes profits, which --using equations (9), (10) and (11)-- are given by:

$$B_k = P_k X_k - W \beta X_k - W \mu_0 A_k^{-\eta} - W_H \lambda A_k \quad (12)$$

of: $1/(1-\eta)$.

¹⁶ This type of R&D function has been used by Dasgupta (1986) and Dasgupta and Stiglitz (1980).

The first order conditions for profit maximization, for the choice variables, X_k and A_k , respectively, are:

$$P_k = [1, \epsilon_k / (\epsilon_k - 1)] \beta W \quad (13)$$

and

$$A_k = \left[\frac{\mu_0 W}{W_H N} \right]^{1/(1+\mu)} \quad (14)$$

Equation (13) shows that price is a markup above marginal cost (βW), where the markup is related to the elasticity of demand facing a producer. Using equation (8), one can transform equation (13) into:

$$P_k = (1/F)^{-1} \beta W \quad (15)$$

where $F = 1 - 1/n$. Note that the price markup declines when the number of producers rises in the market. This is the mechanism through which increased rivalry benefits consumers in the economy: by reducing the extent to which price is above marginal cost.

Equation (14) shows that R&D activities are positively related to the cost of unskilled labor (since the higher this cost, the greater the fixed costs of the firm and, therefore, the larger the benefits of spending on R&D). The R&D engaged by each firm is negatively related to the price of human capital, W_H , since R&D activities require expenditures on skilled labor. Finally, R&D is related to the productivity of R&D in reducing costs (μ_0) and the productivity of human capital in generating knowledge in the economy (N).

For simplicity, a symmetric equilibrium will be examined here. All firms are thus assumed to face the same cost and demand parameters. Free entry into the industry guarantees zero profits, from which the equilibrium output of each firm is determined (by setting equation (12) equal to zero and substituting the values of P_k and A_k in equations (14) and (15)). The result is:

$$X_k = \left(\frac{1}{F} (1+\mu_0) \mu_0 \right) A_k^{-\mu_0} \quad (16)$$

$$(1-F)\beta$$

The employment of unskilled labor on the part of each firm is then specified by substituting the expression for X_k into equation (9), yielding:

$$L_k = \frac{1 + F''}{1 - F} \mu_0 A_k^{-\alpha} \quad (17)$$

On the symmetry assumption, aggregating over all firms in the economy, the equality of unskilled labor demand, nL_k , with the economy-wide endowment of unskilled labor, \bar{L} , yields:

$$\bar{L} = n \frac{1 + F''}{1 - F} \mu_0 A_k^{-\alpha} \quad (18)$$

where use has been made of equation (17).

Since \bar{L} is exogenous, equation (18) has two endogenous variables n and A_k . Observe also that the number of firms enters in equation (18) directly through n but also through F , which is a rising function of n ($dF/dn > 0$). Taking into account these nuances, some algebraic manipulation of the total differential of equation (18) leads to the conclusion that the equation establishes a positive connection between the number of firms, n , and the amount of R&D of each firm, A_k . The economic intuition behind this result is that, as the number of domestic firms rises, with other things held constant, the demand for unskilled labor increases. This augments the wage rate received by unskilled workers and increases the marginal benefits of R&D, whose purpose is precisely to reduce the costs of unskilled labor for the firm. As the marginal benefits of additional units of R&D shift upwards, with the marginal cost of R&D held constant (the price of skilled labor, W_H , held fixed), an increase in the amount of R&D, A_k , would occur. This positive linkage between the number of domestic firms and the amount of R&D each firm engages in, A_k , is represented by the AA curve in Figure 2.

An additional constraint is imposed by the fixed supply of skilled labor

in the economy, \bar{H} . The economy-wide equality of demand for and supply of skilled labor is:

$$nA_k = \bar{H} \quad (19)$$

Equation (19) gives a tradeoff between the number of domestic firms in the economy and the volume of R&D of each firm. An increase in the number of firms with other things held constant, increases the demand for skilled labor. With a fixed endowment of human capital, to sustain equilibrium in the skilled labor market, each firm would have to reduce its demand for skilled labor. This implies that the R&D activities of each firm would decline, reducing A_k . This tradeoff is reflected by the downward-sloping BB curve in Figure 2.

Equations (18) and (19) implicitly define the equilibrium number of firms in the economy under autarky, n^* , as well as the expenditures on R&D and the accumulation of knowledge, A_k^* . In Figure 2, this equilibrium occurs at point E, where the AA and BB curves intersect.

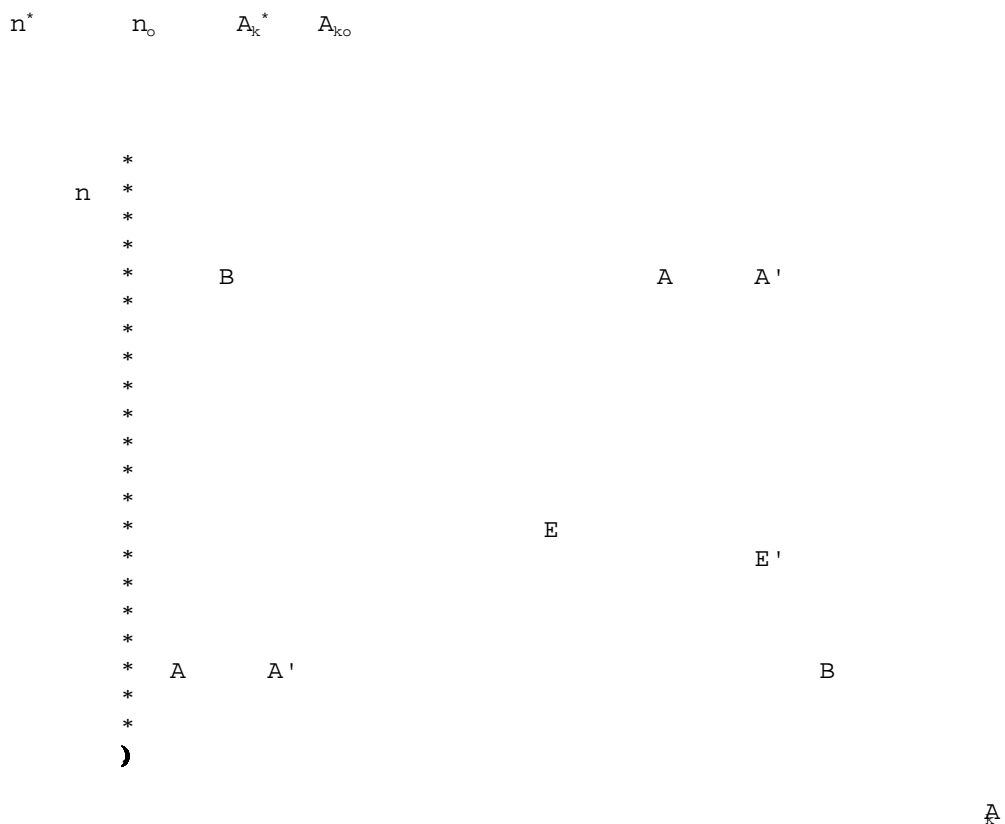
Up to this point we have considered an economy under autarky. What is the impact of international trade in this context? The simplest setting to consider is one where the two economies are identical. Both countries would then have the same number and type of consumers, equal factor endowments, identical technology, and so on. When the two economies trade, intraindustry trade will emerge. Since all products are differentiated from each other, consumers will wish to purchase not only the domestic varieties but also the foreign varieties. This increases the number of products consumed in each country. Each economy, however, would spend the same fraction of income on domestic and foreign products and therefore, there would be balanced trade.

In terms of the equilibrium at point E in Figure 1, the first thing to notice is that the domestic skilled labor market equilibrium condition (equation (19)) remains unchanged and, therefore, the BB curve remains unaltered. On the other hand, the AA curve, which is determined by the unskilled labor market equilibrium, is changed by trade. Equation (18) shows the algebraic depiction of

the domestic unskilled labor market equilibrium. The only item of equation (19) that is altered by trade is the variable F , which determines the price markup charged by firms above marginal cost. Under autarky, F depends on the number of domestic firms, n . Under free trade, however, F is related to the total number of firms in the market, not just domestic firms. With a greater set of

FIGURE 2

DOMESTIC EQUILIBRIUM UNDER AUTARKY AND FREE TRADE



competitors in the now global market, there is more rivalry and this is reflected in a reduced price markup above marginal cost. Algebraically, the variable F rises with trade, narrowing the gap between P and βW (marginal cost).

In terms of Figure 2, an increase in F shifts the AA curve to $A'A'$. The outcome is that domestic equilibrium is achieved at point E' . The opening of trade is thus associated, first of all, with a drop in the number of domestic firms from n^* to n_0 . Although the total number of competitors in the domestic market rises with trade due to the access to foreign products, the increased competition lowers price markups and induces some domestic firms to exit the market. At the same time, Figure 2 indicates that trade is associated with increased R&D expenditures per firm, A . The increased R&D per firm is a reaction to the rivalry generated by foreign competition. As the number of competitors rises and price markups decline above marginal cost, the mirror image of this phenomenon is an increase in the real wage of unskilled labor, W/P_k . This higher real cost of unskilled labor increases the marginal benefit of R&D expenditures, thus leading each firm to demand more human capital. The increased use of skilled labor per firm then results in technical improvements that lower costs.

In this model, trade is associated with technological change and therefore, economic growth. What is the impact of this growth on domestic economic welfare and how does it compare with traditional trade models under monopolistic competition (such as Krugman (1990))? The utility derived by domestic consumers is given by equation (5). On the symmetric equilibrium assumption, all C_k 's in equation (5) are identical and, therefore:

$$U = n^{(1-1)/1} n C_k \quad (20)$$

But from the income constraint, $n C_k = I/P_k$, where $I = W\bar{L} + W_H\bar{H}$. Substitution into equation (20) results in:

$$U = n^{(1-1)/1} [(W/P_k)\bar{L} + (W_H/P_k)\bar{H}] \quad (21)$$

Equation (21) shows that domestic utility rises by means of three mechanisms: (1) the number of differentiated products consumed rises from n to $2n_0$ due to the availability of foreign varieties; (2) as the number of producers increases, the real wage rate of unskilled labor, W/P_x , also increases (this is the mirror image of the reduction in price markups suffered by producers); and (3) as R&D per firm rises, the demand for skilled labor increases, which, given a fixed stock of human capital, leads to a hike in the real wage rate of skilled labor, W/P_s .

Utilizing expressions derived earlier, equation (21) becomes:

$$U = n^{(1-1/\beta)} F / \beta [L + (NA_k^{1+\mu} / \mu_0) H] \quad (22)$$

Algebraically, this shows three mechanisms through which utility is increased: through n directly, by rising F , and by augmenting A_k . Note that in the simplified models in the previous literature [such as Krugman (1990)], there is no investment in R&D and the last two mechanisms would not arise.

The present model incorporates gains from trade related to the increased domestic productivity that foreign competition induces through increased rivalry and competition. This increases domestic total factor productivity and therefore, economic growth. The impact of trade on growth described in this section, however, is medium-term. It would disappear over time, as the economy settles at the new equilibrium, algebraically described by point E' in Figure 2.¹⁷ The next section focuses on the effects of trade on long-run growth.

4. TRADE, TECHNOLOGICAL CHANGE AND LONG-RUN GROWTH

In examining the impact of trade on long-run growth, it is useful to review first some of the key forces associated with innovation and long-run growth, as

¹⁷ Medium-term growth effects may last a long time. If the economy does not move immediately from autarky to free trade, but it does so gradually eliminating trade restrictions over time, the growth effects can be long-lasting.

they have been postulated in the literature.

Studies of innovation and technological change suggest that the invention and development of new goods and new inputs constitute one of the major sources of modern economic growth. Insofar as international trade stimulates the creation of new goods and inputs, long-run growth will rise. However, as the recent literature on trade and endogenous growth makes clear, there are mechanisms through which increased trade may actually discourage innovation and thus reduce growth.

Human capital is one of the key resources used in innovative activities. The amount of human capital dedicated to innovation in an economy is closely linked to technological change. Increased international trade can severely constrain innovation and growth if it tends to generate wide sectoral shifts that reduce the use of scarce human capital in research and development activities. Such is the case, for example, if trade raises the production of manufacturing industries intensive in the use of human capital. The increased demand and employment of skilled labor within the production activities of these industries would drive human capital away from research and development, reducing innovation and growth.

These *sectoral effects* constitute a potentially pernicious impact of trade on growth for some countries. Their importance is directly related to the economy's endowment of human capital relative to that of other inputs, and whether comparative advantage dictates that human capital-intensive sectors expand or contract under trade. It is possible that trade liberalization and economic integration with the rest of the world can reduce growth. As Gene Grossman and Elhanan Helpman have noted: "A country that imports human-capital-intensive goods finds that international integration reduces derived demand for human capital and thereby lowers the cost of innovation. In such a country the indirect effect of trade also is to encourage growth. But trade may impede growth in a country that exports human capital-intensive goods because the exportables

sector draws human capital away from research activities.¹⁸

Sectoral effects imply that increased trade or economic integration can raise or lower economic growth.¹⁹ There are, however, other mechanisms through which trade can influence technical change and growth. A pre-condition for most innovative activity is a body of knowledge and ideas upon which new concepts emerge. Very few innovations totally break with the past. Most are based on existing ideas.

Insofar as international trade fosters the transmission of knowledge and ideas across any two countries, the additional information now available in each economy will tend to spur technological change and growth. As Northwestern University's historian, Joel Mokyr has noted in relation to some historic periods of innovation and growth: "When two previously unconnected civilizations establish contact, technical information is exchanged that may yield potential economic gains to both...Technologically creative societies started off as borrowers and typically soon turned into the generators and then the exporters of technology. In the seventeenth century, England was regarded as a backward society that depended on foreigners for its engineering and textile industries; by the nineteenth century, the directions were reversed. Modern day East Asia finds itself in the same position."²⁰

Within this context, restrictions on international trade which reduce flow of technological information across borders are associated not only with the distortionary losses examined exhaustively in the trade literature but also with negative effects on technical change and long-run growth. As David Mowery and Nathan Rosenberg have noted in reference to the United States: "efforts to

¹⁸ Grossman and Helpman (1991), p. 170. In another paper, Rivera-Batiz and Xie (1992) show that integration in goods restricts growth in the high-growth region and speeds it up in the low-growth region.

¹⁹ For a summary of the various effects of economic integration on medium and long-term growth, public finance, and regional development, see Rivera-Batiz and Ginsberg (1993).

²⁰ Mokyr (1990), p.188-189.

restrict the international flow of basic scientific and technological information and research...will impoverish U.S. citizens...²¹

Although international trade can greatly increase the local stock of information available in an economy, this is a necessary but not a sufficient condition for growth. The impact on economic growth may be limited if the domestic innovation system is not able to handle the new knowledge. Such is the case if key local resources are not available that can gainfully use the new information generated by openness. The next section presents a simple model of endogenous growth incorporating the role played by national innovation systems on growth.

5. NATIONAL INNOVATION SYSTEMS AND LONG-RUN ECONOMIC GROWTH

A national system of innovation is the network of institutions that support the initiation, modification and diffusion of new technologies.²² More specifically, a national innovation system includes "home-based suppliers and related industries in those products, components, machines, or services that are specialized and/or integral to the process of innovation in the industry."²³ This section will show how the state of development of national innovation systems influences technological change and growth. The economy considered is a closed economy. The implications regarding the impact of trade on domestic growth are examined in the next section.

To simplify the analysis, the model used is a straightforward extension of Romer-type endogenous growth models.²⁴ We consider an economy whose aggregate production function is given by:

²¹ Mowery and Rosenberg (1989), p. 292.

²² Cantwell (1992), p. 166.

²³ Porter (1994), p. 453.

²⁴ See Romer (1990).

$$Y = H_y^\alpha L_u^\beta \prod_{i=1}^A X(i)^F \quad (23)$$

where Y is output of final, consumer goods, H_y represents the use of human capital in the production of consumer goods, L_u denotes the amount of unskilled labor used in production, and $X(i)$ is the amount of an intermediate or capital good i used in final goods production, where there are A of these intermediate goods, all slightly differentiated from each other. It is assumed that $\alpha + \beta + F = 1$.

Given the symmetric way in which capital goods enter the production function, and the similarity of their cost, and therefore supply, functions --to be established below-- the amount of each service that industry will purchase is identical. As a result, the aggregate quantity demanded of each capital good will be $X(i) = X_c$. The total demand for capital goods is then given by: $X = nX_c$. Equation (23) can therefore be transformed into:

$$Y = A^{1-F} H_y^\alpha L_u^\beta X_c^F \quad (24)$$

Equation (24) states that final goods production is related to the quantities of labor, capital and producer services demanded and to the number of capital goods used, A . That the number of capital goods used by industry has an effect on output independent of that of their quantity demanded is an outcome of the form of the sub-production function for capital goods and reflects the presence of specialization economies in the use of intermediate goods. Note that the form of (24) is such that it can be interpreted as representing a standard Cobb-Douglas production function with inputs given by human capital, unskilled labor and physical capital, with a shift parameter equal to $A^{(1-F)}$. As noted earlier, most growth theory previously assumed that this shift parameter was exogenously determined [see Solow (1956)]. In endogenous growth theory, though, A represents the equilibrium number of capital goods produced in the economy and is the

endogenous.

Profits in the final goods sector, \mathbf{B} , are given by:

$$\mathbf{B} = P_Y H_Y L_u^\beta \sum_{i=1}^A X(i)^F - W L_u - W_H H_Y - \sum_{i=1}^A P(i) X(i) \quad (25)$$

where W is the wage rate for unskilled labor, W_H is the wage or return received by human capital, $P(i)$ represents the rental cost of each "real" capital good i used in final goods production, and P_Y is the price of final goods. The latter is normalized to equal 1.

From the first order conditions for profit maximization, the following expressions can be derived:

$$H_Y = Y/W_H \quad (26)$$

$$L_u = \beta Y/W \quad (27)$$

and

$$P(i) = (1 - \beta) H_Y L_u^\beta X(i)^{-\beta} \quad (28)$$

These implicitly define the final goods demands for unskilled labor, human capital and each capital good.

What determines the number and output of capital goods? The production of a capital good by a firm or entrepreneur requires some investment funds (venture capital) plus owning a design for the capital good. The investment funds come from the savings decisions of consumers. As in the Solow model, out of total output, a certain fraction, C , is consumed and a fraction S is saved, where $S = dK/dt$ represents the investment funds available to firms at a rate of interest, r . It is assumed that the amount of financial capital required by each capital goods firm, $K(i)$, varies with output:

$$K(i) = \mu X(i) \quad (29)$$

where μ is a fixed parameter denoting the venture capital per output required by

firm i . The cost of borrowing financial capital for each firm is the $rK(i) = r\mu X(i)$.

In addition to the investment funds, in order to produce a capital good, a firm has to purchase a design or blueprint for the capital good. These designs are produced, in turn, by a research and development sector composed of various types of specialized human capital, all of them operating within the environment of a national innovation system. It is assumed that there are N different types of specialized human capital in the research sector of the economy. The production function for the research and development sector is postulated to be:

$$\dot{A} = dA/dt = * \left(\sum_{j=1}^N H_j \right)^{1/\lambda} A \quad (30)$$

where H_j represents the amount of each specialized type of human capital used in innovation activities (involving engineering, design, legal services, etc.), λ is a parameter between zero and one to be interpreted shortly, and $*$ is a parameter reflecting the productivity of the domestic research and development sector in creating new product designs out of the stock of knowledge, A available to it.

On the simplifying assumption that the amounts of each specialized type of human capital used in the national innovation system are equal to each other then, equation (30) becomes:

$$\dot{A} = dA/dt = * N^{(1-\lambda)/\lambda} H_A A \quad (31)$$

where $H_A = \sum H_j$. Equation (31) states that the number of new capital goods designed over any given time period is related to: (1) the total amount of human capital used in the research and development sector, H_A , (2) the productivity of that human capital in designing new products out of the existing knowledge, $*$, (3) the existing body of knowledge, as reflected in the number of existing product designs, A , (4) and the number of different types of specialized human capital in the research and development sector, N .

The status of the national innovation system of a country determines the

values of λ and N in equation (31). High values of λ are related to highly productive innovation systems. Low-yielding national innovation environments would have small values of λ . If, for instance, the innovation system in a country is rooted in old, declining technological paradigms, then its productivity in using the available knowledge to develop new ideas will decline and the λ parameter will be smaller. Even though new knowledge may be flowing into the economy at a fast rate (increasing A very quickly), the development of new products will lag because of the inability of the local innovators to take the new ideas and design new capital goods based on them. This may occur if, for instance, new technologies are being developed abroad, which reflect either new industrial innovations or otherwise new areas of scientific discovery. In this case, as John Cantwell has observed: "with the emergence of a new paradigm technological leadership tends to move away from a society whose institutions were particularly geared towards problem-solving activity within the confines of the previously-prevailing paradigm."²⁵

The degree of specialization among a country's skilled labor force may also influence its rate of technological change. Urban historian Jane Jacobs, among many others, has noted that one of the key factors behind the economic growth associated with urbanization historically has been the great diversity of the specialized labor services in the cities. As she notes: "Graphics consultants, stationery engravers and designers, specialists in the ventilation of buildings, lighting consultants, and advertising agents are some examples. They simultaneously serve other local organizations providing producers' goods and services, exporters, and enterprises supplying consumer goods and services to local people."²⁶ The specialized labor allows inventions of all types to be more easily designed, engineered and marketed.

Equations (30) and (31) incorporate the productivity of specialized skilled labor in generating innovation by adopting a Dixit-Stiglitz-Ethier production function which relates the number of new products developed in any given time

²⁵ Cantwell (1992), p. 166.

²⁶ Jacobs (1969), p. 195.

period to the array of specialized types of labor available domestically, N . The exponent, α , measures the extent of specialization economies in the use of skilled labor for innovation purposes. The stronger the specialization economies, the closer the value of α to zero, and the greater the impact of increased division of skilled labor on the rate of technical change. On the other hand, as α approaches 1, specialization loses its value and the role played by N in equation (31) tends to disappear.

Within the present model, the extent of specialization among skilled workers is assumed to be exogenous. A recent literature on economic geography, however, endogenizes this variable.²⁷ By increasing the extent of the market, urban agglomeration allows a greater division of labor, leading to a more diversified labor force. It is precisely the availability of such a diversified labor force that boosts innovative activities and stimulates economic growth.²⁸

Equation (31) retains the traditional role played by increased human capital on technical change, but its impact on technological change is mediated by the economy's innovation system. Note also that the production of new designs is augmented by the total level of knowledge in the economy, other things the same. Such knowledge is reflected in equation (31) by the total number of designs, A . This is so because of the non-excludable nature of technology. Everybody has access to the designs and blueprints involved in producing all capital goods. This information is freely-available.

In order to produce a capital good i , a firm must make an investment, $K(i)$ plus buy a design for the capital good as supplied by the research and development sector. This gives the firm the right to produce using the design. The profits of each firm producing capital goods is then:

$$B(i) = P(i)X(i) - r_p X(i) \quad (32)$$

Making use of equation (28), the first order condition for profit maximization

²⁷ See Rivera-Batiz (1988a) and (1988b), and Krugman (1991). A model of economic growth based on the growth of cities is presented in Rivera-Batiz (1994). This model determines the division of skilled labor endogenously.

²⁸ See Glaeser and Mare (1994) and Rauch (1991).

for producer i leads to:

$$P(i) = r\mu / (1 - \beta) \quad (33)$$

Since the marginal cost of producing a capital good is $r\mu$, equation (33) suggests that the price of capital good i is at a markup above marginal cost.

Substituting the equilibrium price in equation (33) into the profit equation in (32) yields:

$$B(i) = (\alpha + \beta)P(i)X(i) \quad (34)$$

These would be the production profits of each capital goods firm during a given time period. From these profits, each firm must pay for the price of the design it must purchase in order to produce the capital good i . Denoting the price of a design by P_A , then potential entrants into the capital goods market drive the present value of the profits from selling the capital good to equal the price of a design, or:

$$P_A = B(i)/r = (\alpha + \beta)P(i)X(i)/r = (\alpha + \beta)(1 - \beta)H_Y^\alpha L_u^\beta X(i)^{1 - \alpha - \beta} / r \quad (35)$$

This determines the price of a design.

Human capital is used in the production of final goods and in the research and development sector. If the supply of human capital in the economy is fixed at H , then:

$$H = H_A + H_Y \quad (36)$$

If the human capital market is competitive, the wage rate for human capital in the two sectors --final goods and research/development-- must be equalized. The marginal product of human capital in the production of designs (in the research and development sector) is:

$$\dot{dA}/dH_A = \alpha N^{(1-\alpha)/\alpha} A \quad (37)$$

And if the price of a design is denoted by P_A , then the wage rate received by human capital in the research sector is equal to the marginal value product of

human capital in that sector:

$$W_H = P_A * AN^{(1-\alpha)}, \quad (38)$$

From equation (26), the marginal product of human capital in the final good sector is:

$$W_H = \alpha A H_Y^{\alpha-1} L_U^\beta X(i)^{1-\alpha-\beta} \quad (39)$$

Equating (38) and (39) results in:

$$P_A * AN^{(1-\alpha)} = \alpha A H_Y^{\alpha-1} L_U^\beta X(i)^{1-\alpha-\beta} \quad (40)$$

And substituting the expression for P_A in equation (35) into (40) results in:

$$H_Y = [\alpha / N^{(1-\alpha)}, (1-\alpha-\beta)(\alpha+\beta)] r \quad (41)$$

Equation (41) shows that the higher the interest rate, the greater the amount of human capital allocated to final goods. The reason is that, as r rises, the present value of the profits generated by producing a capital good declines. This pushes down the price of a design and, therefore, the value of the marginal product of human capital in the research sector. As a consequence, human capital shifts out of research and into final goods production.

Using the full employment equation (36):

$$\begin{aligned} H_A &= H - H_Y \\ &= H - [\alpha / N^{(1-\alpha)}, (1-\alpha-\beta)(\alpha+\beta)] r \end{aligned} \quad (42)$$

If the economy is at a steady state, its rate of growth, g , will be:

$$g = \dot{Y}/Y = \dot{A}/A = \alpha N^{(1-\alpha)}, H_A = \alpha N^{(1-\alpha)}, H - [\alpha / (1-\alpha-\beta)(\alpha+\beta)] r = \alpha N^{(1-\alpha)}, H - J r \quad (43)$$

where $J = [\alpha / (1-\alpha-\beta)(\alpha+\beta)]$ is a constant.

In order to complete the model, the interest rate must be determined. This requires modeling the consumption/savings decision of households. Following Romer (1990), it is assumed that consumers maximize the utility derived from an infinite stream of consumption beginning at time $t=0$, discounted to the present:

$$U_0 = \int_0^{\infty} e^{-\rho t} C(t)^{1-N} dt \quad (44)$$

where the utility function is assumed to be of the constant elasticity type:

$$U(J) = \frac{C(J)^{1-N}}{1-N} \quad (45)$$

Maximization of utility subject to the budget constraint then leads to:

$$\frac{\dot{C}}{C} = r - 1 - N \quad (46)$$

If the economy is at a steady state, its rate of growth, g , will be:

$$g = \frac{\dot{Y}}{Y} = \frac{\dot{C}}{C} = (r-1)/N \quad (47)$$

Combining equations (43) and (47) results in the economy's steady state growth rate:

$$g = \frac{N^{(1-\alpha)/H} - 1}{N+1} \quad (48)$$

In addition, the equilibrium interest rate is given by:

$$r = \frac{1 + N^{(1-\alpha)/H}}{N+1} \quad (49)$$

Equation (48) shows the long-run growth of the economy under autarky. Note that, the higher the stock of human capital, the greater the growth rate. By allowing greater human capital employment in research and development, economies with higher endowments of skilled labor will grow faster. This, of course, is the traditional explanation for high rates of growth in many countries. As Gay

Saxonhouse notes of Japan: "Throughout the past century, relative to these other economies [other industrialized nations], Japan, while uniquely poorly endowed with natural resources, has also been well endowed with a high-quality labor force and with unusually thrifty households. These distinctive Japanese circumstances may go a long way toward explaining its superior economic growth performance..."²⁹

Still, cross-country differences in human capital endowments fail to explain a substantial portion of growth differentials.³⁰ In the model developed in this paper, the impact of human capital on the growth rate is mediated by the status of the national innovation system. The more developed the innovation system of an economy, the greater its long-run growth rate, given the aggregate endowment of human capital. This is reflected in higher values of λ^* and N , as discussed earlier.

What is the impact of trade on long-run economic growth in the present model? The next section examines this issue.

6. THE IMPACT OF INTERNATIONAL TRADE ON ENDOGENOUS GROWTH

Suppose that, within the framework developed in the previous section, two identical economies are originally under autarky and suddenly engage in free trade. What is the impact on economic growth?³¹

In this framework, there is production of only one, homogeneous final good. We are therefore precluded from examining international trade in final goods which requires at least two differentiated products. However, the impact of trade in intermediate goods (trade in the capital goods) and in ideas (the flow of designs or blueprints) can be examined in great detail. This simplifies the analysis by excluding the sectoral effects noted earlier. It would be

²⁹ Saxonhouse (1993), p. 150.

³⁰ See Lucas (1993).

³¹ This is the type of experiment carried out by Rivera-Batiz and Romo (1992).

straightforward, though, to extend the model to a two-sector economy. Within that context, the issues raised by the present model would also apply, though the overall impact on growth would depend on how production is altered across sectors and the relative intensity of human capital utilization in each sector.

For purposes of the analysis, we assume that under autarky the two economies considered are producing capital goods which are totally different from each other. A rationale for this assumption is that technological change tends to be localized. Innovations follow particular paradigms which may take divergent paths in different countries, even if those countries have identical factor endowments and consumer tastes. Countries isolated from each other are likely to follow different paths of invention.

When trade occurs, each country has now available the ideas and knowledge of the other, as represented by the stock of blueprints, A . The greater body of knowledge (twice as much as before) increases the rate of invention and therefore, growth would rise in both economies. In fact, the steady state growth rate under free trade would be given by:

$$g = \frac{2N^{(1-\alpha)H} - 1}{N + 1} \quad (50)$$

The effects of trade on growth can be severely limited by the extent to which the national innovation system can in fact utilize effectively the new information and knowledge in the production of new ideas. It may be that the specialized human capital required to use effectively the new ideas and knowledge is not locally available. Symbolically, the value of N in equation (50) mediates the extent to which the foreign ideas have an impact on domestic innovative activities. If N is small, openness will result in a very small growth improvement. At the same time, if N is large, the impact on growth could be substantial. The same applies to other aspects of the local innovative atmosphere: the more limited their ability to develop new products with the newly-available ideas, the smaller the impact of trade on growth.

Whatever the impact of the increased flows of ideas and technology across borders on long-run growth, the present model suggests a definite positive impact

of trade on medium-term growth. The Dixit-Stiglitz-Ethier technology emphasized by endogenous growth models is one where the availability of additional types of capital goods increases productivity. As the two economies trade with each other, final goods producers find it profitable to expand the use of capital goods by adopting those produced abroad. If the two economies are identical, then there is a doubling of the number of capital goods and this has a positive impact on total factor productivity in each country. Indeed, the effect on aggregate production is:

$$Y_1/Y_0 = 2^{+\beta} \quad (51)$$

where Y_1 represents output under free trade and Y_0 is the output under autarky. Medium-term growth is thus augmented by trade by making available a wider variety of capital goods in production.

7. SUMMARY AND CONCLUSIONS

Is international trade an "engine of growth"? The existing empirical literature studying in a rigorous way the connection between openness and growth overwhelmingly suggests that increased trade or reduced protectionism are linked to greater economic growth. However, when one studies the mechanisms through which trade affects economic growth, good reasons emerge to suspect that, while openness and trade may stimulate economic expansion in some countries, it could reduce growth in others.

What are the mechanisms through which trade affects economic growth? The modern theory of economic growth suggests that increased supplies of factors of production such as physical capital and labor account for a substantial portion of growth, but that it is technological change that explains most of the increased productivity of the labor force and, therefore, income per-capita. In order to investigate how trade affects growth, one must focus on how openness influences technological change.

Openness can influence technological change in many ways. This paper has focused on several key mechanisms through which trade and innovation are related.

Firstly, by increasing domestic rivalry and competition, trade can induce domestic producers to increase their R&D activities, augmenting innovation and raising medium-term growth. In examining the reasons why some firms have higher rates of innovation and are more competitive than others in different countries, one factor emerges as critical: the extent of rivalry and competition faced by firms is a key determinant of their innovative activities. Insofar as openness and international competition increase rivalry and competition among domestic firms, innovation will be stimulated and growth will rise. By contrast, protectionism and policies that restrict trade would result in reduced innovation and a slowdown of growth.

Secondly, trade can affect growth by reallocating resources among sectors and industries in the economy, thus fostering or discouraging domestic research and development. For instance, human capital is one of the key resources used in innovative activities. The amount of human capital dedicated to innovation in an economy is closely linked to technological change. Increased international trade can severely constrain innovation and growth if it tends to generate wide sectoral shifts that reduce the use of scarce human capital in research and development activities. Such is the case, for example, if trade raises the production of manufacturing industries intensive in the use of human capital. The increased demand and employment of skilled labor within the production activities of these industries would drive human capital away from research and development, reducing innovation and growth.

Thirdly, insofar as international trade fosters the transmission of knowledge and ideas across any two countries, the additional information now available in each economy will tend to spur technological change and growth. Within this context, restrictions on international trade which reduce flows of technological information across borders are associated not only with the distortionary losses examined exhaustively in the trade literature but also with negative effects on technical change and long-run growth.

Although international trade can greatly increase the local stock of information available in an economy, this is a necessary but not a sufficient condition for growth. The impact on economic growth may be limited if the

domestic innovation system is not able to handle productively the new knowledge. Such is the case if key local resources are not available that can gainfully use the new information generated by openness. Substantial supplies of specialized labor services are required to engage in the research and development involved in the creation of new goods. Such supplies may be absent in slow-growing economies. By contrast, economies with a diversity of specialized, highly skilled, workers available for the research and development of new goods (possibly located within proximity of each other, in cities) are likely to grow faster. Under these conditions, trade is more likely to stimulate higher rates of long-run growth.

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