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ECONOMIC INTEGRATION AND ENDOGENOUS GROWTH*

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Abstract

In a world with two similar, developed economies, economic integration can cause a permanent increase in the worldwide rate of growth. Starting from a position of isolation, closer integration can be achieved by increasing trade in goods or by increasing flows of ideas. We consider two models with different specifications of the research and development sector that is the source of growth. Either form of integration can increase the long-run rate of growth if it encourages the worldwide exploitation of increasing returns to scale in the research and development sector.

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I. Introduction

Many economists believe that increased economic integration between the developed economies of the world has tended to increase the long-run rate of economic growth. If they were asked to make an intuitive prediction, they would suggest that prospects for growth would be permanently diminished if a barrier were erected that impeded the flow of all goods, ideas, and people between Asia, Europe, and North America. Yet it would be difficult for any of us to offer a rigorous model that has been (or even could be) calibrated to data and that could justify this belief.

We know what some of the basic elements of such a growth model would be. Historical analysis (e.g. Rosenberg [1980]) shows that the creation and transmission of ideas have been extremely important in the development of modern standards of living. Theoretical arguments dating from Adam Smith's analysis of the pin factory have emphasized the potential importance of fixed costs and the extent of the market. There is a long tradition in trade theory of using models with Marshallian external effects to approach questions about increasing returns. More recently, static models with fixed costs and international specialization have been proposed that come closer to Smith's description of the sources of the gains from trade. (Dixit and Norman [1980], Ethier [1982], Krugman [1979,1981], Lancaster[1980]). There are also dynamic models with fixed costs and differentiated products in which output grows toward a fixed steady state level (Grossman and Helpman [1989a]).

Recent models of endogenous growth have used these ideas to study the effects that trade can have on the long-run rate of growth. (See for example the theoretical papers by Dinopoulos, Oehmke, and Segerstrom [1990], Feenstra [1990], Grossman and Helpman [1989b,1989c,1989d,1989e,1990], Krugman [1990, Chapter 11], Lucas [1988], Romer [1990], Segerstrom, Anat, and Dinopoulos [1990], and Young [1990]. Backus, Kehoe, and Kehoe [1990] present both theoretical models and cross country empirical evidence that bears on their models.) These models permit a distinction between a one shot gain (i.e. a level effect) and a permanent change in the growth rate (i.e. a growth effect) that is extremely important in making an order of magnitude estimate of the benefits of economic integration. Conventional attempts to quantify the effects of integration using the neoclassical growth model often suggest that the gains from integration are small. If these estimates were calculated in the context of an endogenous growth model, integration might be found to be much more important.

The papers written so far have already demonstrated, however, that the growth effects of trade restrictions are very complicated in the most general case. Gene Grossman and Elhanan Helpman [1989b,1989c,1989e,1990] have been particularly explicit about the fact that no universally applicable conclusions can be drawn. There are some models in which trade restrictions can slow down the worldwide rate of growth. There are others in which they can speed up the worldwide rate of growth.

To provide some intuition for the conjecture described in the beginning, that trade between the advanced countries does foster growth, we narrow the focus in this paper. We do not consider the general case of trade between countries with different endowments and technologies. Instead, we focus on the pure scale effects of integration. To set aside the other "comparative advantage" effects that trade induces in multisector trade models, we consider integration only between countries or regions that are similar. Therefore, we do not address the kinds of questions that are relevant for modeling the effects that trade between a poor LDC and a developed country can have on the worldwide rate of growth.

In the early stages of our analysis of integration and growth, it became clear that the theoretical treatment of ideas has a decisive effect on the conclusions one draws. In many of the existing models, flows of ideas cannot be separated from flows of goods. In others, flows of ideas are exogenously limited by national boundaries regardless of the trade regime. In either of these cases, economic integration can only refer to flows of goods along cargo networks. We consider a broader notion of integration, one that assigns an effect to flows of ideas along communication networks.

Flows of ideas deserve attention comparable to that devoted to flows of goods, for public policy can influence international communications and information flows to the same extent that it influences goods flows. Governments often subsidize language training and study abroad. Tax policies directly affect the incentive to station company employees in foreign nations. Immigration and visa policies directly limit the movement of people. Telecommunications networks are either run by government agencies or controlled by regulators. Some governments restrict direct foreign investment, which presumably is important in the international transmission of ideas. Others have made the acquisition of commercial and technical information a high priority task for their intelligence agencies.

Although these are the only ones we consider, it should be clear that flows of goods and flows of ideas are not the only elements in economic integration. Under some assumptions about nominal variables and the operation of financial markets, economic integration will also depend on monetary and institutional arrangements. The growth models we consider are too simple to consider these effects. It should also be clear that economic integration is not synonymous with political integration. Firms in Windsor, Ontario may be more closely integrated into markets in the United States than they are to markets in the neighboring province of Quebec. Moreover, the notion of full economic integration does not entail the abolition of citizenship distinctions that have taken place in Germany's reunification.

The structure of the paper is as follows. Section II lays out the basic features of the production structure on which all arguments rely. It describes preferences, endowments, and the nature of equilibrium under the two specifications of R&D. Section III describes the equilibrium for both models in the closed economy and complete integration cases, and illustrates the scale effects that are present. Section IV presents the three main thought experiments concerning partial integration. Sections V and VI describe the general lessons that can be learned about the relation between the scale of the market and growth and discuss limitations of the models, extensions, and the relation to other models of endogenous growth.

II. Specification of the Models

A. Functional forms and decentralization in the manufacturing sector

The specification of the production technology for the manufacturing sector is taken from Romer [1990]. Manufacturing output is a function of human capital H, labor L, and a set $x(i)$ of capital goods indexed by the variable i. To avoid complications arising from integer constraints, the index i is modeled as a continuous variable. Technological progress is represented by the invention of new types of capital goods.

There are two types of manufacturing activities: production of consumption goods and production of the physical units of the types of capital goods that have already been invented. A third activity, research and development (R&D), creates designs for new types of capital goods. This activity is discussed in next section.

Both manufacturing activities use the same production function. Let $x(i)$ denote the stock of capital of type i that is used in production and let A be the index of the most recently invented good. By the definition of A, $x(i) = 0$ for all $i>A$. Output Y is assumed to take the form

$$Y(H, L, x(\cdot)) = H^{\alpha} L^{\beta} \int_0^A x(i)^{1-\alpha-\beta}\, di. \tag{1}$$

Since the production function for manufacturing consumption goods is the same as that for manufacturing units of any type of existing capital, the relative prices of consumption goods and all types of existing capital goods are fixed by the technology. For simplicity, we choose units so that all of these relative prices are 1. Fixed prices imply that the aggregate capital stock $K = \int_0^A x(i)\, di$ is well defined, as is aggregate output Y.

In this specification, one unit of any capital good can be produced if one unit of consumption goods is foregone. This does not mean that consumption goods are directly converted into capital goods. Rather, the inputs needed to produce one unit of consumption are shifted from the production of consumption goods into the production of a capital good. Since inputs are used in the same proportions, it is easy to infer the allocation of inputs between the different production activities from the level of output of those activities. Because all of the outputs here have the same production function, the consumption sector and all of the sectors producing the different capital goods can be collapsed into a single sector. We can therefore represent total manufacturing output as a function of the total stock of inputs used in the combined manufacturing sectors and can describe the division of inputs between sectors by the constraint $Y = C + \dot{K}$. For one of the models of R&D described in the next section, we can use this same observation to combine the research sector and the aggregate manufacturing sector into a single sector describing all output in the economy. In the other model, the R&D and manufacturing sectors must be kept separate.

There are many equivalent institutional structures that can support a decentralized equilibrium in manufacturing. For instance, the holder of a patent on good j could become a manufacturer, producing and selling good j. Alternatively, the patent holder could license the design to other manufacturers for a fee. Formally, it is useful to separate the manufacturing decision from the monopoly pricing decision of the patent holder, so we assume that patent holders contract out manufacturing to separate firms. It is also easier to assume that the patent holder collects rent on its capital goods rather than selling them. For analytical convenience, we therefore describe the institutional arrangements in the following, slightly artificial way. First, there are many firms that rent capital goods $x(i)$ from the patent holders, hire unskilled labor L, and employ skilled human capital H to produce manufactured goods. Each of these firms can produce consumption goods for sale to consumers. It can also produce one of the capital goods on contract for the holder of the patent. All of the manufacturing firms have the production function given in equation (1), which is homogeneous of degree one. They are price takers and earn zero profit. Manufacturing output is taken as the numeraire.

The firm that holds the patent on good j bids out the production of the actual capital good to a specific manufacturer. It purchases physical units of the good for the competitive price, by normalization equal to 1. The patent holder then rents out the units to all manufacturing firms at the profit maximizing monopoly rental rate. It can do this because patent law prohibits any firm from manufacturing a capital good without the consent of the patent holder. The patent is a tradeable asset with a price P_A that is equal to the present discounted value of the stream of monopoly rent minus the cost of the machines. It is easy to verify that this set of institutional arrangements is equivalent to other arrangements. For example, the equivalent licensing fee for each unit of capital sold by a licensee is the present value of the stream of monopoly rent on one machine minus the unit cost of manufacturing it.

B. Functional forms and decentralization in R&D

We consider two specifications of the technology for R&D that permit easy analytic solutions. Each specification captures different features of the world, and neither alone gives a complete description of R&D. We use both of them because they help us isolate the exact sense in which economic integration can influence long-run growth. As the examples in the next section shows, it would be easy to come to misleading conclusions about integration and growth if one generalized from a single example.

The first specification of the technology for producing designs for new capital goods assumes that human capital and knowledge are the only inputs that influence the output of designs:

$$\dot{A} = \delta H A. \tag{2}$$

Here H denotes the stock of human capital used in research. The stock of existing designs A is a measure of general scientific and engineering knowledge as well as practical know-how that accumulated as previous design problems were solved. (See Romer [1990] for additional discussion of this specification.) New designs build on this knowledge, so we refer to this type of R&D process as the knowledge–driven specification of R&D. This specification imposes a sharp factor intensity difference between R&D and manufacturing. Neither unskilled labor nor physical capital have any value in R&D. Because of this difference, the resulting model must be analyzed using a two sector framework.

A useful polar case is a technology for R&D that uses the same inputs as the manufacturing technology, in the same proportions. If H, L, and x_i denote inputs used in R&D and B denotes a constant scale factor, output of designs can be written as

$$\dot{A} = BH^{\alpha}L^{\beta}\int_0^A x(i)^{1-\alpha-\beta}\, di. \tag{3}$$

This specification says that human capital, unskilled labor, and capital goods (such as personal computers or oscilloscopes) are productive in research. But in contrast to the previous specification, knowledge *per se* has no productive value. Access to the designs for all previous goods, and familiarity with the ideas and know-how that they represent, does not aid the creation of new designs. We refer to this as the lab equipment specification of R&D.

As noted above, the growth model with a knowledge–driven specification for R&D has an unavoidable two sector structure. The production possibility frontier in the space of designs and manufactured goods takes on the usual curved shape. In the lab equipment model, the production functions of the goods and R&D sectors are the same, so the production possibility frontier is a straight line. If the output of goods is reduced by one unit and the inputs released are transferred to the R&D sector, they yield B patents. Thus the price P_A of a patent in terms of goods is determined on the technology side, $P_A = \frac{1}{B}$. Since capital goods and consumption goods have the same production technology, we integrated them into a single manufacturing sector in the last section. In the lab equipment model we can go further, and aggregate manufacturing and research into a single sector. Let H, L, and $x(i)$ denote the entire stock of inputs available in the economy at date t. Then we can express the value of total output $C + \dot{K} + \dot{A}/B$ in terms of the total stock of inputs,

$$(4) \qquad C+\dot{K}+\dot{A}/B = H^{\alpha}L^{\beta}\int_0^A x(i)^{1-\alpha-\beta}\,di.$$

The model's symmetry implies that $x(i) = x(j)$ for all i and j less than A. We can therefore substitute $K/A = x(i)$ in equation (4) to obtain a reduced form expression for total output in terms of H, K, L, and A:

$$(5) \qquad \begin{aligned} C+\dot{K}+\dot{A}/B &= H^{\alpha}L^{\beta}A(K/A)^{1-\alpha-\beta} \\ &= H^{\alpha}L^{\beta}K^{1-\alpha-\beta}A^{\alpha+\beta}. \end{aligned}$$

The knowledge-driven and lab equipment specifications of the R&D sector lead to different assumptions about how equilibrium in the R&D sector is decentralized. In the knowledge-driven model, output of designs is homogeneous of degree 2. By Euler's theorem, it is not possible for both of the inputs A and H to be paid their marginal product. We make the assumption that A receives no compensation. Holders of patents on previous designs have no technological or legal means of preventing designers of new goods from using the ideas implicit in the existing designs. The stock of A that can be put to use, with no compensation, by any individual researcher is therefore the entire stock of knowledge about previous designs, provided that there exists a communication network that makes this information available. The equilibrium is one with knowledge spillovers or external effects in the R&D sector (but not in the manufacturing sector.) In this case, we can describe research as if it were done by independent researchers who use their human capital to produce designs, which they subsequently sell.

In the lab equipment model, output of designs is the same, homogeneous-of-degree-one production function as in the manufacturing sector. As is the case for the manufacturing sector, the equilibrium is one in which patents convey market power but in which there are no other entry restrictions. There are no external effects and no knowledge spillovers. There is free entry into both R&D and manufacturing. The only restriction is that no one can manufacture capital of type i without the consent of the holder of the patent on good i. In this case, we conceive of R&D as being undertaken by separate firms that hire inputs, produce patentable designs, and sell them for a price P_A.

III. Balanced Growth and Integration

The description of the technology given so far represents output as a function of the inputs H, L, K, and A, and specifies the evolution equations for K and A. To facilitate the simple balanced growth analysis that we undertake, the stocks of L and H are each taken as given. Increases in either L or H could be accommodated if we undertook the more complicated task of solving a nonlinear system of differential equations with growth rates that vary over time.

The calculation of a balanced growth equilibrium for each of the two specifications of the R&D technology can be summarized in terms of two linear relations between the rate of growth and the interest rate that hold along a balanced growth path. One relation comes from the conditions of equilibrium in production and the other from preferences.

As shown in the Appendix and as illustrated in Figure I, the interest rate implied by equilibrium in the production sector is decreasing in the rate of growth of output for the knowledge-driven model:

$$r_{\text{technology}} = \frac{\delta H - g}{\Lambda}. \tag{6}$$

The term in the denominator depends only on the production function parameters, $\Lambda = \alpha(\alpha+\beta)^{-1}(1-\alpha-\beta)^{-1}$.

The corresponding expression for the interest rate from the lab equipment model is shown in the Appendix to be a function of the production parameters and the stock of H and L. It does not, however, depend on the rate of growth:

$$r_{\text{technology}} = \Gamma H^{\alpha} L^{\beta}, \tag{7}$$

where Γ is defined by $\Gamma = B^{\alpha+\beta}(\alpha+\beta)^{\alpha+\beta}(1-\alpha-\beta)^{2-\alpha-\beta}$.

In the knowledge-driven specification, the negative relation between the interest rate and the growth rate arises because an increase in the interest rate reduces the demand for capital goods. The calculations in the Appendix show that an increase in the interest rate reduces the number of units of each capital good that are rented, and thereby reduces

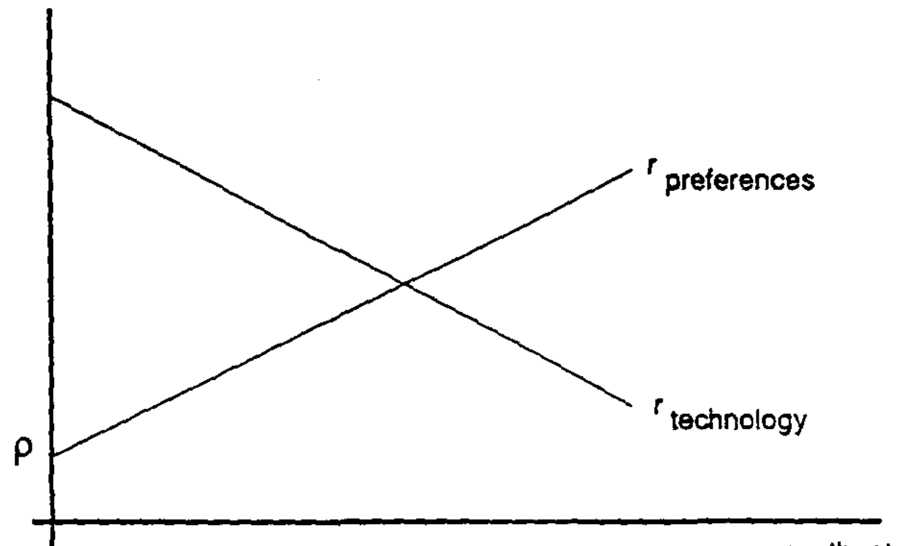

Figure I: Determination of r and g in the knowledge-driven specification

the value of a patent. According to the curved production possibility frontier between designs and manufactured goods, the reduction in the price of the patented design causes a shift in human capital out of the production of new designs and into the production of manufactured goods. This shift slows down the creation of technology and thereby slows growth. In the lab equipment model, only a single value of the interest rate is consistent with production of both goods and designs. The relative price of patents and final goods is fixed, so the interest rate is technologically determined.

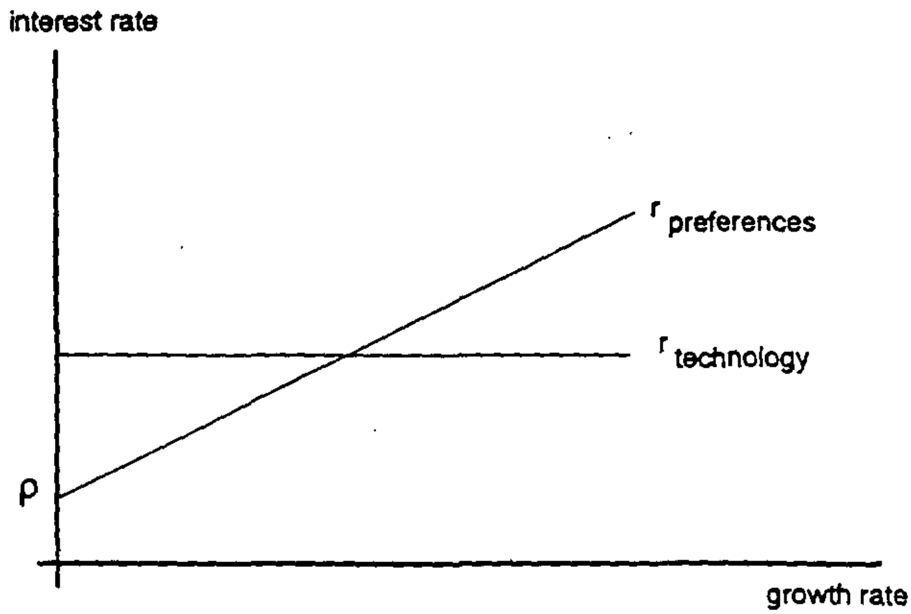

Figure II: Determination of r and g in the lab equipment specification

It remains to specify the preferences that provide the other balanced growth relation between the interest rate and the rate of growth. The simplest formulation to work with is Ramsey preferences with constant elasticity utility,

$$U = \int_0^\infty \frac{C^{1-\sigma}}{1-\sigma} e^{-\rho t}\, dt, \quad \sigma \in [0,\infty).$$

Under balanced growth, the rate of growth of consumption must be equal to the rate of growth of output. Thus, for any fixed rate of growth $g=\dot{C}/C$, we can calculate the implied interest rate from the consumer's first order conditions for intertemporal optimization:

(8) $$r_{\text{preferences}} = \rho+\sigma g.$$

These preferences yield a positive relation between the interest rate and the growth rate because when consumption is growing more rapidly, current consumption is more valuable compared with future consumption, so the marginal rate of substitution between present and future consumption is higher. Consumers would therefore be willing to borrow at higher interest rates.

There is a parameter restriction that is necessary to ensure that the growth rate is not larger than the interest rate. If it is, present values will not be finite and the integral that defines utility will diverge. In terms of Figures I and II, the restriction is that the intersection of the two curves must lie above the 45 degree line. This will always be true if σ is greater than or equal to 1, since in this case, the $r_{\text{preferences}}$ curve always lies above the 45 degree line. If σ is less than 1, the $r_{\text{technology}}$ curve must not lie too far up and to the right.

Because the rate of growth under each specification is determined by the intersection of two straight lines, it can be calculated directly from the relation between r and g determined on the preference side, equation (8), and the relation between r and g determined by the technology, either equation (6) or (7). The balanced rate of growth for a closed economy under the knowledge-driven model of the research sector is

(9) $$g = \left[\frac{\delta H-\Lambda\rho}{\Lambda\sigma+1}\right].$$

The balanced rate of growth for the lab equipment model is

$$g = \frac{\Gamma H^{\alpha} L^{\beta} - \rho}{\sigma}. \tag{10}$$

Both of these models have a dependence on scale that is crucial to the analysis of the effects of trade. To see this, consider two economies that have identical endowments of H and L. In the long run, these economies will have the same stocks of accumulated inputs as well, so that scale effects offer the only lasting source of gains from trade and economic integration.

Suppose that the two economies are physically contiguous, yet are totally isolated from each other by an impenetrable barrier that impedes the flow of goods, people, and ideas. If these economies evolve under isolation, the balanced rate of growth in each is characterized by Figures I and II and calculated in equations (9) and (10). Now suppose that the barrier is removed, so that the economies are completely integrated into a single economy. The change from two economies with endowments H and L to one economy with stocks $2H$ and $2L$ causes an upward shift in the $r_{\text{technology}}$ curve in both figures. Both the rate of growth and the interest rate increase after complete economic integration takes place, regardless of the specification of the technology for R&D. In both models (even the knowledge-driven model with no knowledge spillovers), the rate of growth is too low compared to the rate that would be selected by a social planner.[1] As a result, one

[1]For the knowledge-driven model, this is shown in Romer [1990]. For an early version of the lab equipment model, this is shown in Romer [1987]. See Barro and Sala i Martin [1990] for a discussion of the optimality of the no intervention equilibrium and of tax and subsidy policies that can achieve the socially optimal balanced rate of growth in a variety of endogenous growth models.

would expect integration to be welfare improving. A full welfare analysis, however, would require explicit consideration of the dynamics along the transition path.

With this discussion as background, the examples in next section are designed to address three questions. First, can free trade in goods between countries induce the same increase in the balanced growth rate as complete integration into a single economy? If not, can the free movement of goods, combined with the free movement of ideas, reproduce the rate of growth under full integration? And finally, what is the underlying explanation for the dependence of the growth rate on the extent of the market?

IV. Trade in goods and flows of ideas

In this section we conduct a series of thought experiments about partial integration. In the first two experiments, we focus on the knowledge-driven specification for R&D because it permits a sharp distinction between flows of goods and flows of ideas. In the third, we consider the lab equipment specification in which ideas have no direct effect on production.

In the analysis of the knowledge-driven specification, we start with two identical, completely isolated economies that are growing at the balanced growth rate. We first allow for trade in goods, but continue to restrict the flow of ideas. To emphasize the distinction between goods and ideas, we assume that trade in goods does not induce any transmission of ideas. For example, we assume that is it impossible to reverse engineer an imported good to learn the secrets of its design. Under these assumptions, we show that trade in goods has no effect on the long-run rate of growth. Then in the second experiment, we calculate the additional effect of opening communications networks and permitting flows of ideas. We show that allowing flows of ideas results in a permanently higher growth rate.

In the third experiment, we consider the effects of opening trade in goods under the lab equipment specification. In this case, trade in goods alone causes the same permanent increase in the rate of growth as complete integration. Since ideas *per se* have no effect on production, the creation of communications networks has no additional effect.

A. Flows of goods with no flows of ideas in the knowledge-driven model

In all of the experiments considered here, the form of trade between the two countries is very simple. By symmetry, there are no opportunities for intertemporal trade along a balanced growth path, hence no international lending. Because there is a only a single final consumption good, the only trades that take place are exchanges of capital goods produced in one country for capital goods produced in the other.

With the knowledge-driven model of research, it is straightforward to show that opening trade in goods has no permanent effect on the rate of growth. In balanced growth, the rate of growth of output is equal to the rate of growth of A, $\dot{A}/A = \delta H_A$, which is determined by the split of human capital $H=H_Y+H_A$ between the manufacturing sector and the research sector. Opening trade in goods has two offsetting effects on wages for human capital in these two sectors. Before trade is opened, the number of different types of machines that are used in the manufacturing sector must equal the number that have been designed and produced domestically. Along the new balanced growth path after trade is opened, the number of types of machines used in each country approaches twice the number that have been produced and designed domestically. In their pursuit of monopoly rents, researchers in the two countries will specialize in the production of different types of designs and avoid redundancy, so the worldwide stock of designs will ultimately be twice as large as the stock that has been produced in either country.

With trade in the specialized capital goods, domestic manufacturers can take advantage of foreign designs and vice versa. Ultimately, the level $\bar{x}$ at which each durable is used in each country will return to the level that obtained under isolation. From equation (1) it follows that the increase in A doubles the marginal product of human capital in the manufacturing sector, increasing it from $\frac{\partial Y}{\partial H} = \alpha H^{\alpha-1} L^{\beta} \bar{x}^{1-\alpha-\beta} A$ to $\frac{\partial Y}{\partial H} = \alpha H^{\alpha-1} L^{\beta} \bar{x}^{1-\alpha-\beta}(2A)$.

For the research sector, opening of trade implies that the market for any newly designed good is twice as large as it was in the absence of trade. This doubles the price of the patents and raises the return to investing human capital in research from $P_A \delta A$ to $2P_A \delta A$. Since the return to human capital doubles in both of the competing sectors, free trade in goods does not affect the split of human capital between manufacturing and research. Hence, it does not change the balanced rate of economic growth or the interest rate. In terms of Figure I, opening trade in goods does not change the position of either the $r_{\text{preferences}}$ locus or the $r_{\text{technology}}$ locus.

This result does not imply that free trade in goods has no effect on output or welfare. Consider, for example, the extreme case in which two isolated economies start from completely nonintersecting sets of capital goods A and A^* that have the same measure. Before trade in goods, the home country will use capital at the level $\bar{x}$ for A types of capital goods and the foreign country will use capital at the same level $\bar{x}$ for A different types of capital goods. If existing capital is freely mobile, each country will immediately exchange half of its capital stock for half of the capital stock of the other country when trade in capital goods is allowed. Each will then be using capital at the level $\bar{x}/2$ on a set of capital goods of measure $A+A$. (Over time, the level of usage will climb back to $\bar{x}$ as capital accumulation takes place because the level of x is determined by r and g, and on the new balanced growth path these are the same as before.) From the form of production in manufacturing given in equation (1), it follows that immediately after trade is opened, output in each country jumps by a factor of $2^{1-\alpha-\beta}$. This is analogous to the kind of level effect one encounters in the neoclassical model and in static models of trade with differentiated inputs in production, (e.g. Ethier [1982].) In the specific model outlined here, free trade in goods can affect the level of output and can therefore affect welfare, but it does not affect long-run growth rates.

If the two different economies start from a position with exactly overlapping sets of goods prior to the opening of trade, the timing of the effect on output is different, but the ultimate effect is the same. The level of output at future dates will differ from what it would have been without trade in goods and will generally be higher. But once the transitory effects have died out, the underlying growth rate will be same as it was prior to the opening of trade in the capital goods.

B. Flows of information in the knowledge–driven model of research

This second example shows that greater flows of ideas can permanently increase the rate of growth in the knowledge–driven model of research. Once we allow for flows of information, we must make some assumption about international protection of intellectual property rights. In each country, we have assumed that patents protect any designs produced domestically. Once ideas and designs created abroad become available, the government could try to expropriate the monopoly rents that would accrue to the foreigners by refusing to uphold their patents. To simplify the discussion here, we assume that neither government engages in this practice. A patent in one country is fully respected in the other. (For a discussion of incomplete protection of intellectual property rights, see Rivera–Batiz and Romer [1990].)

Consider the two identical economies with the knowledge–driven specification of the research sector described in the first experiment. Trade in goods has already been allowed, and this creates the incentive for researchers to specialize in different designs. Over time the sets of designs that are in use in the two countries will be almost entirely distinct, so the worldwide stock of knowledge approaches twice the stock of designs in either country. In the absence of communications links, this means that researchers in each country will ultimately be using only one half of the worldwide stock of knowledge. In the domestic country, the rate of growth of A is given by $\dot{A} = \delta H_A A$. In the foreign country, it is given by $\dot{A}^* = \delta H_A^* A^*$.

Now suppose that flows of ideas between the two countries are permitted. Research in each country now depends on the total worldwide stock of ideas as contained in the union of A and A^*. If the ideas in each country are completely nonintersecting, the effective stock of knowledge that could be used in research after communication opens would be twice as large as it was before: $\dot{A} = \dot{A}^* = \delta H_A(A+A^*) = 2\delta H_A A$. Even if the allocation of $H = H_Y + H_A$ between manufacturing and research did not change, the rate of growth of A would double. But the increase in the set of ideas available for use in research increases the productivity of human capital in research and has no effect on its productivity in manufacturing. This change in relative productivity induces a shift of human capital out of manufacturing and into research. For two reasons, communication of ideas speeds up growth.

Increasing the flow of ideas has the effect of doubling the productivity of research in each country. Compared to the closed economy model, the formal effect is the same as a doubling of the research productivity parameter δ. This would shift the $r_{\text{technology}}$ curve in Figure I upward, and lead to a higher equilibrium growth rate and interest rate. The algebraic solution for the balanced growth rate of A (and therefore also of Y, C, and K) can be determined by replacing δ with 2δ in equation (9) to obtain $g = (2\delta H - \Lambda\rho)/(\sigma\Lambda + 1)$.

Doubling the value of the productivity parameter δ has exactly the same effect on the rate of growth of output and designs as a doubling of H. And according to the discussion in section II, doubling H has the same effect on growth as complete integration of the two economies into a single economy. Flows of both ideas and goods together have the same effect on the growth rate as does complete integration. Complete integration would permit permanent migration as well, but since ideas and goods are already mobile and because the ratio of H to L was assumed to be the same in the two countries, migration is not necessary to achieve productive efficiency. For symmetric economies, allowing both trade in goods and free flows of ideas is enough to reproduce the resource allocation under complete integration.

So far, we have considered the additional effect that free flows of information would have if free trade in goods were already permitted. It is useful to consider the alternative case in which flows of information are permitted but flows of goods are not. In this case, the results hinge on the degree of overlap between the set of ideas that are produced in each country.

In the absence of trade in goods, there would be no incentive for researchers in different countries to specialize in different designs either before or after flows of information are permitted. Moreover, after flows of information are opened, there would be a positive incentive for researchers in one country to copy designs from the other, and little offsetting incentives to enforce property rights. If the firm that owns the patent on good j is not permitted to sell the good in a foreign country, it has no economic stake in the decision by a foreign firm to copy good j and sell it in the foreign market. (The domestic firm would of course have both the incentive and the legal power to stop exports of the copies from the foreign country.) In the extreme case in which identical knowledge is created in each country, opening flows of information has no effect at all on production.

Alternatively, one could imagine that discovery is a random process with a high variance so that truly independent discoveries would take place in the different isolated countries. In this case, permitting the international transmission of ideas would speedup worldwide growth rates to some extent, even in the absence of trade in goods. With free communication, each researcher would be working with a larger stock of ideas than would otherwise have been the case. For example, when the first overland routes to China were opened in the Middle Ages, transportation of goods was so expensive that the economic effects of trade in goods was small. But the economic consequences of the ideas that travelers brought back (e.g. the principle behind the magnetic compass and the formula for gunpowder) were large.

C. Flows of goods in the lab equipment model of research

The two previous examples show that there is sometimes a separation between growth effects and level effects. In the first experiment, opening trade in goods had level effects but no growth effects. In the second experiment, opening flows of ideas had both a growth effect and a level effect. (Manufacturing output goes down when H shifts into research, and research output goes up.)

From the first two examples it is tempting to conclude that flows of goods will generally have level effects of the type that are familiar from neoclassical analysis and that it is only flows of ideas that have growth effects. The third example considered shows that this conclusion is wrong. The lab equipment model is constructed so that ideas *per se* have no effect on production. Hence, permitting international flows of ideas can have no economic effect. Yet we know from the discussion in section III that complete integration causes a permanent increase in the rate of growth. The experiment considered in this example shows that trade in goods is all that is needed to achieve this result.

Recall that when trade in goods is permitted in the knowledge-driven model, this increases the profits that the holder of each patent can extract because it increases the market for the good. By itself, this increase in the return to producing designs would tend to increase the production of designs, but in the knowledge-driven specification, this effect is exactly offset by the increase in the marginal productivity of human capital in manufacturing.

In the lab equipment specification, opening trade in goods would cause the same kind of increase in the profit earned at each date by the holder of a patent if the interest rate remained constant. But as was noted in section II.B, the price of the patent $P_A = 1/B$ is determined by the technology. The only way that the larger market can be reconciled with a fixed price for the patent is if the interest rate increases. A higher interest rate reduces the demand for capital goods, thereby lowering the profit earned by the monopolist at each date. The calculation in the appendix shows that the required increase in the interest rate is by a factor of $2^{\alpha+\beta}$. When two identical economies are integrated and $2H$ is substituted for H and $2L$ is substituted for L in equation (7), the same increase in r obtains. In each case, the higher interest rate leads to higher savings. From Figure II or from equation (10) it follows that this increase in the interest rate leads to the same faster rate of growth as complete integration.

V. Scale Effects and Growth

In the last example we noted one incorrect conjecture about why tighter economic integration leads to faster growth. From the knowledge-driven model one might conclude that flows of ideas are crucial to the finding that economic integration can speed up growth. But the lab equipment model shows that closer integration can speed up growth even in a model in which flows of ideas have no effect on production. A related conjecture is that knowledge spillovers are fundamental and that increasing the extent of the spillovers is how integration speeds up growth. The lab equipment model shows that this too is incorrect, for it has no knowledge spillovers.

Finally, one might conclude that it is the increasing returns to scale in the production function for designs, $\dot{A} = \delta H_A A$, that causes integration to have a growth effect in the knowledge-driven model. This conjecture seems to us to come closest to the mark, but it needs to be interpreted carefully. To see why, recall that the production function for designs in the lab equipment model, $\dot{A} = BH^{\alpha}L^{\beta}\int_0^A x(i)^{1-\alpha-\beta}\,di$, exhibits constant returns to scale as a function of H, L, and the capital goods $x(i)$. There is, nonetheless, a form of increasing returns that is present in this model. It comes from the fixed cost that must be incurred to design a new good. With integration, this fixed cost need only be incurred once. Under isolation, it must be incurred twice, once in each country.

To bring out the underlying form of increasing returns, recall from equation (5) that we can substitute $\bar{x} = K/A$ into the expression for $\dot{A}$ and write it as a function of H, L, K, and A that is homogeneous of degree $1+\alpha+\beta$: $\dot{A} = H^{\alpha}L^{\beta}K^{1-\alpha-\beta}A^{\alpha+\beta}$. Interpreted as a statement about this kind of reduced form expression, it is correct to say that both models exhibit increase returns to scale in the production of new designs as a function the stocks of basic inputs. Consequently, operating two research sectors in isolation is not as efficient as operating a single integrated research sector. To operate an integrated research sector in the knowledge-driven model, two things are required. First, one must avoid redundant effort, that is, devoting resources in one economy to rediscovering a design that already exists in the other. Trade in goods provides the incentive to avoid redundancy. Second, one must make sure that ideas discovered in one country are available for use in research in both countries. Flows of ideas along communications networks serve this function.

In the lab equipment model, trade in goods once again provides the incentive to avoid redundant effort. Beyond this, all that is needed to create a single worldwide research sector is to ensure that all types of capital equipment available worldwide are used in all research activities undertaken anywhere in the world. Since ideas do not matter in research, trade in the capital goods is all that is needed.

There is one final point worth emphasizing. Sergio Rebelo [1990] offers a general observation about multisector models that is relevant for the experiments considered here. Consider a single sector model of the form $C+\dot{K}+\dot{A} = B_0 F_0(K, A)$, where $F_0(\cdot)$ is a homogeneous of degree 1. In this example, K and A can denote any two arbitrary capital goods. If the productivity parameter B_0 increases, the balanced growth rate increases. Consider next a two sector model in which there is an essential fixed factor L that enters as an input in the homogeneous of degree 1 production function for consumption and capital of type K: $C+\dot{K} = B_1 F_1(K, A, L)$. The capital good A, however, is produced by a homogeneous of degree one function $F_2(\cdot)$ of K and A alone: $\dot{A} = B_2 F_2(K, A)$. In this case, a change in the productivity parameter B_1 has no effect on the balanced rate of growth. It has only level effects. In contrast, an increase in B_2 increases the balanced rate of growth.

The connection between Rebelo's observation and our results is as follows. We do not consider changes in technology parameters like B_1 and B_2, but we do induce changes in scale for functions that are homogeneous of some degree greater than 1. Increases in scale are analogous to increases in the productivity parameters. In the knowledge driven model, trade in goods exploits increasing returns in the sector that produces C and K, but not in the sector that produces A. It is like an increase in B_1 in Rebelo's two sector model, and induces only level effects. Flows of ideas increase productivity in the research sector that produces A, and are analogous to an increase in Rebelo's coefficient B_2. Finally, trade in goods in the lab equipment model induces a scale effect that is like an increase in B_0 in Rebelo's one sector model.

VI. Limitations of the Models and Extensions

As noted in the introduction, the analysis carried out in this paper takes the form of thought experiments for idealized cases. These experiments reveal the following general insight about the connection between economic integration and the rate of economic growth. In a model of endogenous growth, if economic integration lets two economies exploit increasing returns to scale in the equation that represents the engine of growth, integration will raise the long run rate of growth purely because it increases the extent of the market. Depending on the form of the model, this integration could take the form of trade in goods, flows of ideas, or both.

This conclusion must be tempered by a large number of qualifications. First, there is no consensus yet about whether the equation that is the engine of growth is homogeneous of some degree that is greater than 1 in the basic inputs (as it is in both of the models considered here) or instead is homogeneous of degree 1 (as it is, for example, in the papers by Rebelo [1991] and Lucas [1988].)

Second, as noted in the introduciton, we have focused on trade between economies with identical endowments and technologies to highlight the scale effects induced by economic integration. In a general two sector framework, trade between economies that have different endowments or technologies will induce allocation effects that shift resources between the two sectors in each country. For example, Grossman and Helpman [1990] show that trade between countries that have different endowments or technologies will induce shifts between the manufacturing sector and the R&D sector that can either speed up or slow down worldwide growth. If one wants to take the optimistic conclusions reached in this paper literally, they are most likely to apply to integration between similar developed regions of the world, for example between North America, Europe, and Japan.

There are many details of R&D at the micro level that have been ignored in all of the analysis. We have assumed that giving participants in the economy an incentive to avoid redundancy in research is sufficient to ensure that no redundancy takes place. We have also assumed that patents are infinitely lived and, implicitly, that the institutional structure avoids patent races. We have not considered the role of secrecy in preserving economic value for ideas. All of these restrictions are very strong. Grossman and Helpman [1989d] show how one element of the microeconomic literature on patents, the destruction of monopoly profits by new discoveries, can be included in an aggregate growth model. Other extensions will no doubt follow.

The functional forms used here cannot be literally correct. For example, in both of our models, the output of patents at any date increases in proportion to the resources devoted to R&D. This permits the solution for balanced growth paths using linear equations, but it cannot be a good description of actual research opportunities. We would expect that a doubling of research effort would lead to a less than two fold increase in R&D output, in large part because of the coordination and redundancy problems at the micro level that we have ignored. Addressing these issues would help reconcile a model in which growth rates increase linearly in H in one case, or as a power of H and L in the second, with a historical record showing that growth rates have indeed increased over time, but not by nearly as much as the functional forms used here would suggest. More precision in the definition of the input H that is most important for research would also be helpful in this regard. In terms of their effect on research output, one presumably does not literally want to equate two people holding high school degrees with one person holding a Ph.D. degree.

Perhaps the most interesting limitation of the models considered here is one that it shares with many other models: there is no description of how ideas or information affect the production of goods. Once one admits that ideas *per se* can influence research output, it is apparent that they can influence the output of goods as well. Presumably this is what learning-by-doing models try to capture with the assumption that some production parameter increases with cumulative experience: producing goods yields both goods and ideas, and the ideas raise the productivity of the other inputs. Formal models in the tradition of Arrow [1962] have not yet addressed the importance of communication networks and information flows. When the learning-by-doing models are used in international trade, it is implicitly assumed that there is a communication network that extends throughout one national economy, yet does not cross national boundaries. Little theoretical attention has been given to the analysis of policy choices that can affect the efficiency of international communication networks and to explaining historical episodes (e.g. the emergence of the textile industry in the United States and of the automobile industry in Japan) that reflect large flows of information from developed industries in one country to developing industries in another.

Given these limitations and qualifications, our only claim is to have formalized, and we hope illuminated, an effect that is potentially important. If the discovery of new ideas is central to economic growth, one should expect that increasing returns associated with the opportunity to reuse existing ideas will be present. If the increasing returns extend to the sector of the economy that generates growth, economic integration will induce scale effects that will raise the long-run rate of growth. And because of the remarkable growth of exponential functions, policies that affect long-run rates of growth can have very large cumulative effects on economic welfare. Many other effects may be present as well, but in future theoretical and empirical work, we argue that scale effects on growth that are induced by economic integration are worth watching out for.

Appendix

A. Derivation of equation (7)

In the lab equipment model, the value of total production in manufacturing and research depends only on the aggregate stocks of inputs, not on their allocation between the two sectors:

$$Y + \dot{A}/B = H^{\alpha} L^{\beta} \int_0^A x(i)^{1-\alpha-\beta}\, di.$$

Taking its supply of H and L as given, each representative firm in the manufacturing sector chooses levels of $x(i)$ to maximize profits. Consequently, the first order condition for the problem of maximizing $Y + \dot{A}/B$ minus total input cost $\int P(i)x(i)\, di$ with respect to the use of input i yields the economy wide inverse demand curve for good i. The rental rate p that results when a total of x units of the capital good are supplied is

(A.1) $$p = (1-\alpha-\beta)H^{\alpha}L^{\beta}x^{-(\alpha+\beta)}.$$

Input producers choose x to maximize the present value of monopoly rent minus the unit cost of each piece of capital, $P_A = \max\, (px/r) - x$. The first order condition that determines the number of machines $\bar{x}$ that the holder of the patent on good i rents to manufacturing firms is

(A.2) $$(1-\alpha-\beta)^2 H^{\alpha}L^{\beta}\bar{x}^{-(\alpha+\beta)}r^{-1} - 1 = 0,$$

which implies that $p/r = (1-\alpha-\beta)^{-1}$. The present discounted value of profit collected by the holder of the patent can then be simplified to

$$P_A = (p\bar{x}/r) - \bar{x} = \frac{\alpha+\beta}{1-\alpha-\beta}\bar{x}. \tag{A.3}$$

Since $P_A = 1/B$, this implies that $\bar{x} = (1-\alpha-\beta)/B(\alpha+\beta)$. Substituting this expression into equation (A.2) yields equation (7) in the text:

$$r_{\text{technology}} = B^{\alpha+\beta}(\alpha+\beta)^{\alpha+\beta}(1-\alpha-\beta)^{2-\alpha-\beta}H^{\alpha}L^{\beta}.$$

B. Derivation of equation (6).

The demand for the capital goods in this model has exactly the same form as in the lab equipment model, with the qualification that since all of the demand comes from the manufacturing sector, H must be replaced by H_Y. If we use equation (A.1) with this replacement to substitute for p in the expression for P_A, we have

$$P_A = (\alpha+\beta)\frac{p\bar{x}}{r} = \frac{\alpha+\beta}{r}(1-\alpha-\beta)H_Y^{\alpha}L^{\beta}\bar{x}^{\,1-\alpha+\beta}.$$

Equating the wages of human capital in manufacturing and research yields $P_A\delta A = \alpha H_Y^{\alpha-1}L^{\beta}A\bar{x}^{\,1-\alpha-\beta}$. Combining these expressions and solving for H_Y gives $H_Y = \frac{1}{\delta}\alpha(\alpha+\beta)^{-1}(1-\alpha-\beta)^{-1}r = \Lambda r$. Hence, $g = \delta H_A = \delta H - \delta H_Y = \delta H - \Lambda r$.

C. Trade in goods in lab equipment model is equivalent to complete integration.

If the interest rate remained constant, the value of a patent $P_A = \pi/r$ would double when trade in goods between two identical markets is introduced in this model. The monopolist that sells in two identical markets and faces constant marginal costs of production will maximize profits in each market independently and earn twice the flow of profits that would accrue from one market alone. Since the value of the patent must remain fixed at $1/B$ by the specification of the technology for producing patents, the interest rate must increase to restore equilibrium.

As shown above, maximization of profit by the monopolist implies that p/r is constant, so profit is proportional to $\bar{x}$. To offset the doubling of profit that the opening of trade would otherwise induce, r must increase by enough to make the number of units of capital supplied by the monopolist in each country fall by one half. From equation (A.2), this will happen if r increases by a factor of $2^{\alpha+\beta}$. This is same the factor increase in r that results from doubling H and L when the two countries are combined.

REFERENCES

Arrow, Kenneth J., "The Economic Implications of Learning By Doing," Review of Economic Studies XXIX (June 1962), 155–73.

Backus, David, Patrick Kehoe, and Timothy Kehoe. "In Search of Scale Effects in Trade and Growth," University of Minnesota Working paper (1990).

Barro, Robert and Xavier Sala i Martin, "Public Finance in Models of Economic Growth," National Bureau of Economic Research, Working Paper No. 3362 (1990).

Dinopoulos, Elias, James Oehmke, and Paul Segerstrom. "High Technology Industry Trade and Investment: The Role of Factor Endowments," University of Florida working paper (1990).

Dixit, Avinash and Joseph Stiglitz, "Monopolistic Competition and Optimum Product Diversity." American Economic Review LXXVI (June 1977), 297–308.

______________ and V. Norman, The Theory of International Trade, Cambridge England: Cambridge University Press (1980).

Ethier, Wilfred J. "National and International Returns to Scale in the Modern Theory of International Trade." American Economic Review LXXII (June 1982), 389–405.

Feenstra, Robert. "Trade and Uneven Growth," National Bureau of Economic Research, Working Paper No. 3276 (1990).

Grossman, Gene and Elhanan Helpman, "Product Development and International Trade," Journal of Political Economy XCVII (December 1989a), 1261–1283.

______________ and ______________, "Endogenous Product Cycles" National Bureau of Economic Research, Working Paper No. 2113 (1989b).

______________ and ______________, "Growth and Welfare in a Small Open Economy," National Bureau of Economic Research, Working Paper No. 2809 (1989c)

______________ and ______________, "Quality Ladders in the Theory of Growth," National Bureau of Economic Research, Working Paper No. 3099, (1989d).

______________ and ______________, "Quality Ladders and Product Cycles," National Bureau of Economic Research, Working Paper No. 3201 (1989e).

______________ and ______________, "Comparative Advantage and Long Run Growth" American Economic Review LXXX (September 1990), 796–815.

Helpman, Elhanan, "International Trade in the Presence of Product Differentiation, Economies of Scale, and Monopolistic Competition: A Chamberlinian-Heckscher-Olin Approach," Journal of International Economics IX (1981), 305–340.

Krugman, Paul, "Increasing Returns, Monopolistic Competition, and International Trade," Journal of International Economics IX (November 1979), 469–479.

______________, "Intraindustry Specialization and the Gains from Trade," Journal of Political Economy VXXXIX (October 1981), 959–73.

______________. Rethinking International Trade, Cambridge MA: MIT Press (1990).

Lancaster, Kevin, "Intraindustry Trade under Perfect Monopolistic Competition," Journal of International Economics X (1980), 151–75.

Lucas, Robert E. Jr., "On the Mechanics of Economic Development." Journal of Monetary Economics XXII (1988), 3–42.

Rebelo, Sergio. "Long Run Policy Analysis and Long Run Growth." Journal of Political Economy, forthcoming (1991).

Rivera-Batiz, Luis A. and Paul M. Romer. "International Trade with Endogenous Technological Change." University of Chicago, mimeo (1990).

Rosenberg, Nathan, Inside the Black Box, Cambridge England: Cambridge University Press (1980).

Romer, Paul M. "Increasing Returns and Long–Run Growth." Journal of Political Economy XCIII (October 1986), 1002–1037.

______________. "Growth Based on Increasing Returns Due to Specialization." American Economic Review LXXVII (May 1987), 56-62.

______________. "Endogenous Technological Change." Journal of Political Economy, XCXXVIII (October 1990), S71–S102.

Segerstrom, Paul, T. C. A. Anat and Elias Dinopoulos, "A Schumpeterian Model of the Product Life Cycle." American Economic Review, forthcoming (1990).

Young, Alwyn. "Learning by Doing and the Dynamic Effects of International Trade." Quarterly Journal of Economics, forthcoming (1991).