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TRADE, INNOVATION, AND GROWTH

by

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Recent papers by Paul Romer (1986, 1990) and Robert Lucas (1988) have reminded us that when investment takes place in an economic environment with increasing returns to scale, the marginal product of capital need not decline over time to the level of the discount rate. Then the incentive to accumulate capital may persist indefinitely, and long-run growth in per capita income can be sustained. These simple observations have revitalized the theory of economic growth. Research attention has focused primarily on the processes of accumulation of knowledge capital, in part because the public good aspects of knowledge as information naturally create increasing returns to scale in many contexts. There has been an attempt to understand the determinants of long-run growth based on investment in human capital and in new technologies.

The advances in growth theory enable us to address rigorously many issues that have long been central to international economics. For example, to what extent and in what ways might international trade serve as an "engine of growth"? Do international exchanges naturally enhance the growth performance of individual trading countries? And what economic policies are especially conducive to high levels of welfare in a growing, open economy?

Growth theorists also stand to gain from recognizing how the international economic environment impinges upon the incentives that firms in specific countries have to invest in the creation of knowledge. Several features of the global economy seem especially important for understanding growth performance. First, familiar notions of comparative advantage may determine to what extent particular countries are led to specialize in the creation of knowledge and in the production of goods that make intensive use of human capital and new technologies. Second, the large scale of the world economy provides great opportunities for the exploitation of research successes and so may enhance the incentives that firms have to invest in the generation of new technologies. Third, in a world of rapid and cheap communication, ideas and information spread quickly across international borders. Countries stand to benefit from the spillovers generated by investments in knowledge in trade partner countries, but also may lose from the lack of ability to appropriate all of the benefits from their own investments. Finally, participation in international capital markets provides an expanded set of opportunities for financing investments in all forms of capital, including knowledge capital. These various aspects of the international trade environment have featured prominently in our own work on innovation and growth in the open economy. In the next section we describe common elements of our research approach. Then, in Section II, we introduce a highly simplified model of trade, knowledge accumulation, and growth, and use it to expound some of our recent findings.

I. Modeling Endogenous Innovation

Many growth theorists raised in the neoclassical, Solovian tradition took technological progress to be an exogenous and fortuitous process. Several common features distinguish recent efforts to endogenize innovation within general equilibrium models of long-run growth. Foremost among these are, first, a rigorous accounting of the resources used up in creating new knowledge, and second, explicit consideration of the profit motive that drives private investment in R&D. In these matters, the new theory draws on modeling approaches developed by industrial organization economists.

Industrial R&D may be aimed at cost reduction, product innovation, or quality improvements. Recent research has incorporated all of these forms of technological progress into analyses of long-run innovation and growth. In our own work on product innovation (1989a,b, 1990; see also Romer, 1990) we assume that an entrepreneur must develop the design for a new, differentiated product before it can be produced. This requires that resources be devoted to R&D. We treat R&D as an ordinary economic activity, specifying a technology that relates inputs (primary factors of production) to outputs (blueprints for new products). In Grossman and Helpman (1989c,d) and Grossman (1989), we model the process of quality upgrading as a set of concurrent, industry-specific patent races, each aimed at developing the next generation of product.[1] In this case, a standard production function links the input of resources to the entrepreneur's instantaneous probability of achieving a research breakthrough. In either case, the cost of R&D depends both on technological considerations and on market conditions, the latter because factor prices are determined as usual in the general equilibrium.

Throughout our work, we have adopted a Schumpeterian perspective. Research successes generate some limited degree of market power, and so create profit opportunities. These potential profits justify the expenditures on R&D. When a new product is developed that substitutes imperfectly for existing brands, the innovator can establish a market niche and charge a price above marginal cost in the ensuing oligopolistic competition. Similarly, when an existing product is improved, the new industry leader can price above the cost of production and still find consumers willing to buy his superior, state-of-the-art product. In either case, the innovator earns a stream of profits that may last indefinitely, or for a limited period of time.

We model the R&D process as being one with free entry. Entrepreneurs may establish research labs whenever the incentive to do so is present. Then, in an equilibrium with an active R&D sector, the expected returns to this activity must just be "normal"; i.e., they must reflect the opportunity cost of capital and compensate for any undiversifiable risks. We have used this "no-arbitrage" condition to link the interest rate determined on capital markets to the rate of profit enjoyed by successful innovators and to the probability that an existing profit stream will be eroded or eliminated due to imitation or further innovation by rivals. By adopting this perspective, we are able to investigate several channels through which international trade and trade policies may affect the incentives that a firm in some country has to engage in R&D. For example, the existence of foreign competitors may shorten the likely duration of any profit opportunity if foreign firms can engage in reverse engineering or target the product in question for further improvement. And a trade barrier influences rates of profit for home and foreign firms, and also alters factor prices and so the cost of R&D in the general equilibrium.

Our modeling of R&D incorporates in all cases some of the spillovers that we believe to be inherent to the process of knowledge generation. As is well known, technology bears many of the characteristics of a public good. Knowledge as a commodity is non-rivalrous; that is, several parties may put the same information to use simultaneously at no extra cost. Also, it may be difficult in many instances to define and enforce property rights perfectly, so that parties cannot exclude the use by others of the knowledge that they may have created. In particular, an industrial innovator will have difficulty preventing others from taking advantage of the more general forms of scientific and engineering knowledge that are generated in the course of developing some specific product or process. As Romer (1990) has emphasized, these spillovers may cause aggregate investment in knowledge to exhibit non-decreasing returns to scale and so allow innovation to be a sustainable process in the long-run.

The exact form that the spillovers take may vary in different applications and for different types of industrial research. We have so far adopted two different modeling approaches. In our papers on product innovation, we follow Romer (1990) in assuming that each research project generates not only a patentable blueprint for its perpetrator, but also a non-appropriable contribution to the stock of general knowledge capital. We treat knowledge capital as a (public) input into R&D, so that at any point in time fewer resources are needed to invent a new variety of product the greater is the state of scientific understanding. In our papers on quality upgrading, we assume that research labs can enter the race for the next generation technology even if they have not succeeded in bringing out the current generation product. Implicitly, we distinguish the knowledge needed to manufacture a good (or the legality of doing so under patent rights protection) from the knowledge needed to try to invent a better product. We assume that production know-how is private and appropriable, while improvement know-how lies in the public domain.

An issue that arises in international applications concerns the spillovers of knowledge across international borders. Such spillovers undoubtedly are an important source of growth for newly industrializing countries. Knowledge also flows between firms at the research frontier in many high-technology industries. Our approach allows us to entertain alternative assumptions about the form and nature of the international diffusion of knowledge capital. For example, in our 1990 paper, we admit the possibility that general scientific knowledge flows costlessly between advanced countries, but that transnational diffusion involves longer lags than diffusion within national boundaries. In modeling technological progress in developing countries, we suppose in our 1989a and 1989c papers that imitation is a process like innovation, requiring not only an inventory of potentially imitable product designs, but also the input of local resources into research-like activities that enable foreign production techniques to be assimilated.

II. Determinants of Long-Run Growth

In order to exposit some of our findings it proves convenient to develop a very simple, indeed almost trivial, model of trade, knowledge accumulation and endogenous growth. The model bases growth on learning-by-doing in a single, knowledge-generating sector. It therefore neglects several important elements that are central to the approach described in Section I. In particular, there is no separate R&D activity and no resources are devoted exclusively to the task of generating new knowledge. Moreover, knowledge accumulation is not guided by the profits that accrue to the owners of new or superior technologies. Still, the simple economy here shares two features with the more complex economies described in Section I. First, the growth rate is proximately determined by the equilibrium allocation of resources to a knowledge-creating activity; here the sector that generates learning-by-doing benefits plays the role of the R&D sector in our other papers. Second, spillovers play a critical role in making long-run growth sustainable. Due to these similarities, the simple model can serve a useful pedagogic role.

Consider then a two-sector, two-factor economy. Let the factors, land and labor, be available in fixed supplies, T and L. Output in sector i is given by a constant-returns-to-scale, neoclassical production function

$$X^i = KF^i(T^i, L^i)\ , \qquad i=1,2, \tag{1}$$

where T^i and L^i are employments of land and labor, respectively, in sector i, and K (for "knowledge") represents the instantaneous stock of knowledge capital, a public input. Knowledge accumulates as a by-product of manufacturing experience in one of the sectors, say sector 1. These learning-by-doing benefits, which augment productivity in both sectors, are wholly external to the individual firms that generate them. We suppose that

$$\dot{K} = bX^1 \ . \tag{2}$$

Finally, consumers maximize any homothetic, intertemporal utility function.

Let us begin with a small economy that trades the two goods at exogenous relative prices, $p \equiv p_1/p_2$. Suppose for the moment that it enjoys no knowledge spillovers from abroad. Each small firm in sector 1 ignores its (non-appropriable) contribution to future knowledge, and so maximizes instantaneous profit. Clearly the equilibrium allocation of resources is the same as for a static, competitive economy with production functions F^i and total factor supplies T and L; that is, the marginal rate of transformation between goods 1 and 2 is set equal to p. Then $\dot{X}^i = F^i(T^i,L^i)bX^1$, and output in each sector grows at the constant rate $g = bF^1(T^1,L^1)$.

Suppose now that the supply of one of the factors were to increase. Several authors have found a positive relationship between the size of the resource base and the rate of growth. Here, the Rybczynski Theorem implies that an increase in the supply of the resource used intensively in the knowledge-generating sector speeds growth, but an increase in the supply of the resource used intensively in the production of good 2 slows growth. We found similar results in our 1989d paper and in Grossman (1989). There, R&D and the production of high-technology goods act like a joint activity in the free-trade equilibrium, and it is the factor intensity of the composite activity that matters for predicting the effect of factor accumulation on the rate of growth.

Next consider the effects of trade policy. Here, protection of sector 1 shifts resources into the knowledge-creating activity and so speeds the rate of growth. Protection of sector 2 has the opposite effects on resource allocation and growth. More generally, we found two distinct influences that trade policy has on the growth rate. First, protecting some sector augments the derived demand of that sector for the output of the R&D activity. Put differently, the return to a research success generally will rise when the sector in which the technology is applied is promoted via trade policy. But second, there will be an influence that operates through factor markets, similar to the one that applies in the simple model here. If the government protects a production sector that competes with R&D for resources, then the cost of R&D will rise and the allocation of resources to this activity may shrink. In our 1989b paper, where human capital is devoted to inventing new, non-traded, intermediate products, we found that promotion of the human capital-intensive final good via trade policy is detrimental to growth, while promotion of the labor-intensive good is conducive to growth. The former sector is a general equilibrium substitute for R&D, while the latter is a general equilibrium complement. In Grossman (1989), protection of the high-technology sector via trade policy causes skilled labor to shift from research to manufacturing and so retards innovation in the policy active country.

The welfare economics of our simple economy are equally transparent. The allocation of resources to sector 1 is sub-optimal, because this activity generates a spillover benefit that private agents do not take into account. A first-best policy subsidizes output in this sector, while commercial policy represents a second-best government intervention. These welfare-improving policies raise the growth rate. But the optimal growth rate may fall well short of the maximal rate, and policies that cause an excessive allocation of resources to knowledge creation can reduce welfare.

The welfare analysis of a Schumpeterian economy with an explicit R&D activity shares some of these features, but involves further complexities. There exists in such economies a second distortion besides that due to the spillovers generated in the creation of knowledge. This distortion arises from the non-competitive pricing of innovative products by successful entrepreneurs. It leads to an undersupply of the volume -- as opposed to the number -- of innovative products. We show in our 1989b paper that equilibrium growth is nonetheless too slow in our particular specification of product innovation (based on the familiar Dixit-Stiglitz formulation), but our 1989c paper demonstrates that the equilibrium allocation of resources to R&D may be excessive when research generates quality improvements (see also Aghion and Howitt, 1989). In the former case, an appropriate subsidy to R&D always raises welfare, while in the latter case a tax on R&D may be desirable. Moreover, in these richer economic environments, even if the growth rate is too slow, a trade policy that encourages growth may fail to provide second-best welfare benefits. A trade policy that increases the rate of growth toward the first-best level may lower welfare if it at the same time reduces the level of output of the non-competitively priced commodities (see Grossman and Helpman, 1989b).

Equation (2) points to the potential role of international spillovers in the growth process, and suggests another mechanism by which commodity trade might influence growth. The simplest specification would make technological progress ($\dot{K}$) a function of <u>world</u> output of good 1. Then the home country would automatically enjoy the benefits of knowledge created abroad. But this specification probably is not descriptive of a large portion of the international diffusion of technology that actually takes place. Often it is necessary for local firms to invest resources in order to capture spillover benefits from abroad. In our models of the product life cycle, we suppose that products initially developed in the industrialized "North" later become candidates for (costly) imitation by the semi-industrialized "South". We use this formulation to study the growth effects of North-South trade. Our 1989a paper provides an example where such trade must speed growth in both regions; product imitation by the South raises the North's incentive to innovate, because firms in the North earn greater profits during their period of monopoly production. Even though imitation spells the eventual end to their profit stream, the expected present value of the returns to any innovation are increased by trade. While this result does not generalize to all specifications (see our 1989c paper), it does suggest that the link between the rate of technological diffusion (as influenced, for example, by policies regarding the protection of foreign intellectual property) and the equilibrium rate of innovation and growth is more subtle than might appear at first glance.

Let us consider now a two-country world economy, each with production functions as in (1) and with technological progress in (2) depending upon world output of good 1. Suppose that the home country were to subsidize output of this good or promote the industry by means of a trade policy. Resources in this country would shift into sector 1, which <u>ceterus paribus</u> would accelerate growth in the world economy. But in the foreign country the opposite resource movements would take place. The contribution of the foreign country to knowledge accumulation would decline. The net effect on technological progress and hence world growth would depend upon the balance of these offsetting influences. This balance, in turn, would depend in part upon which of the two countries enjoyed comparative advantage in the production of the X^1.

In our 1990 paper and in Grossman (1989) we studied the effects of trade and industrial policies on the long-run rate of growth in the world economy. We considered policies introduced by a single country in situations where learning externalities from R&D are international in scope. Our findings were quite similar to those for the simple economy here. If a country with comparative advantage in undertaking R&D were to subsidize research, the world growth rate would accelerate. But if a similar subsidy were to be introduced by the country that is relatively better at manufacturing rather than innovating, the world growth rate <u>may</u> decline. Similarly, protective trade policy will raise long-run rates of growth when undertaken in a country with comparative disadvantage in R&D, but will have the opposite effect on growth when implemented by a country with comparative advantage in R&D. Since we find that trade protection shifts resources from research into manufacturing in the policy active country, and in the opposite direction in the policy inactive country, our findings are understandable in the light of the results for the simple model of this paper.

III. Concluding Remarks

Casual observation and more systematic empirical research suggest that countries that have adopted an outward oriented development strategy have grown faster and achieved a higher level of economic well being than those that have chosen a more protectionist trade stance. The evidence on the efficacy of explicit policies to promote exports, including various forms of industrial targeting, is not yet conclusive. The approach to modeling endogenous innovation and endogenous human capital formation that has been proposed here may provide a means for improving our understanding of the connection between the international trade environment including the trade policy regime and long-run growth performance. It seems clear that the less developed countries <u>potentially</u> stand the most to gain from their international relationships, since in principle these countries can draw upon the large stock of knowledge capital already accumulated in the industrialized world. But it is equally clear from the poor growth experience of some of these countries that the technology flows are anything but automatic. We need to learn much more about the mechanisms by which knowledge and technology diffuse across international borders (including, for example, the role of multinational corporations in this regard), and the incentives that impinge upon the equilibrium rate of technology transfer.

Footnotes

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[1]This approach draws on Phillipe Aghion and Peter Howitt (1989).

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