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⁴⁰ Merton Dagut (Witwatersrand University), Monica Ferreira (University of Cape Town), and Valerie Möller are the key participants from South Africa.

⁴¹ A. Case and A. Deaton, "Large Cash Transfers to the Elderly in South Africa," *Economic Journal*, 108, No. 450 (September 1998), pp. 1330–61.

Research Summaries

Technology and the Global Economy

Jonathan Eaton*

Since at least the eighteenth century, much of the world has experienced ongoing gains in the standard of living, a process that Simon Kuznets labeled "Modern Economic Growth." Economists have long sought to understand the forces behind this phenomenon. Accumulation of physical capital provided a simple and natural explanation. But Robert Solow's fundamental work in the late 1950s showed that capital accumulation could account for less than half of the growth in U.S. income per capita. Solow suggested that ongoing improvements in technology might tell the rest of the story. While subsequent work refined Solow's analysis, it did little to upset the basic conclusion that capital accumulation provides a very incom-

plete explanation for why countries grow.

While interest in growth waned in the 1970s, the last decade and a half has seen a resurgence of research on why incomes rise over time, and why some countries are richer than others. There are now a number of elegant *theories* of how technological progress drives growth. But in turning the spotlight to technology rather than to investment, Solow made the job of *quantifying* the sources of growth, and assessing how policies affect growth, much harder.

At the heart of the problem is measurement. We have imperfect, but usable, ways to measure resources diverted from other uses toward investment in capital. We can also gauge (much more roughly) how much capital is on hand. Such measures give us some handle on capital's contribution to growth over time and to differences in incomes across countries. But technology presents the empirical economist with a much more elusive concept. We do not observe people coming up with new ideas, and we cannot systematically trace how these ideas shape the process of production over time and space.

A number of basic questions, however, hinge on understanding how innovations occur, and how these innovations raise income levels around the world. For example: Do countries rely, for the most part, on their own innovations, or are the gains from innovation largely shared? Where does most innovation occur, and where are these innovations most rapidly put into practice? To the extent that the benefits of innovation seep across borders, do these gains spread through the exchange of products embodying these innovations, or through the diffusion of the ideas themselves?

The answers to these questions are of intrinsic interest, but they are also at the heart of any evaluation of the myriad government policies that affect innovation. For instance: What are the benefits and costs of tougher patent protection, and how are they shared across countries? Does a country recover the costs of giving research expenditures favorable tax treatment, or are the benefits largely dissipated through the diffusion of innovations abroad? What are the gains from coordinating research policies internationally? To what

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extent does greater openness spread the benefits of technical progress?

Sam Kortum and I are engaged in a research project that attempts to shed light on these issues. Our framework builds on recent advances in growth theory and trade theory. We take this theoretical framework to a number of sources of data. We look not only at productivity across countries and over time; we also use data on research effort, patenting, education, and bilateral trade.

Our research so far has pursued four broad sets of issues: 1) quantifying the contributions of innovation and diffusion to world growth, 2) explaining differences in research effort across countries, 3) analyzing the effects of national technology policies in an international context, and 4) assessing the role of trade in disseminating the benefits of technological advances between countries. I discuss our results on each category, and then turn to work-in-progress.

World Growth and the International Diffusion of Technology

In a series of papers, Kortum and I have sought to trace productivity improvements in different countries to the countries that generated the innovations behind those improvements.¹ Because they do nearly all of the world's research, countries that are members of the Organization for Economic Cooperation and Development (OECD) are our focus.

We use output per worker as a measure of the extent to which countries use innovations. Over the past two decades, OECD countries have tended to grow at very similar rates, maintaining fairly stable relative productivity levels. This observation is consistent with a world in which countries draw on a common pool of inventions, with more productive countries either taking advantage of more of these ideas, or implement-

ing them more quickly. It also suggests that not much can be learned about growth by relating the growth rates of different countries to various characteristics. Countries differ much more systematically in their relative income levels than in their growth rates.

To try to get some handle on where innovative activity occurs, we turn to various measures of research effort. Such data include research expenditure (private or overall) and research scientists and engineers (private sector or overall). Whichever number one looks at, the message is that most research is performed in just three countries: the United States, Germany, and Japan. (France and the United Kingdom follow, not very closely, behind.) Not only do these countries devote more resources toward R and D in absolute terms, but they also devote a larger fraction of their resources toward R and D than any but a handful of small, though technically advanced, countries including Sweden and Switzerland.

Hence research activity is quite concentrated, but a number of countries that do relatively little research enjoy high levels of productivity. For example, by most measures, productivity levels in France and Germany are very similar, but Germany does about twice as much research, both absolutely and relative to size. Such observations suggest that a large number of countries make use of innovations from a small number that concentrate on research.

Standard measures thus can give us some insight into who is benefiting from innovations and who is doing fairly straightforward research. But it is trickier to infer whose innovations countries are tapping. For this purpose, we turn to data on international patenting.

One feature of the international patenting system is that an inventor, in order to obtain patent protection in any particular country, has to take

out the patent there. Applying for a patent is costly, and most inventions are patented in only one country. So an inventor, in deciding to patent an invention in a particular country, probably expects that the invention has some chance of being used there. For example, the number of patents that French inventors take out in Japan might suggest something about how much technology is flowing from France to Japan. French inventors would have little reason to apply for a patent in Japan unless they thought it had a good shot at being used there sooner or later. Of course other factors would affect the decision as well, such as the cost of patenting in Japan, the size of the market there, and the quality of protection that the Japanese patent system provides a French inventor. Thus, inferring the extent of technology diffusion from the patenting data requires taking these other factors into account.

What patterns do we observe in international patenting? First, countries that put the most resources into inventive activity in fact do patent most broadly. The United States, Japan, and Germany dominate patenting by foreigners in other OECD countries. Second, larger countries are much more popular destinations for patent applications, suggesting that inventors in fact find the bother of applying for a patent much more worthwhile when the market in which they are seeking protection is large. Third, for similar reasons, higher costs of patenting (application fees, translation costs, and legal fees) tend to deter patenting. (Patenting in Japan is particularly expensive for foreigners.) Fourth, inventors are more likely to patent an invention at home than anywhere else. Fifth, inventors are more likely to take out patents in nearby countries than in countries far away. Japan, for example, is the largest foreign patenter in the United States and, after the United States, in

Canada. But in many European countries, West Germany beats out Japan.

The data themselves provide a lot of insight about what is going on. But getting a more precise picture of how innovation and diffusion drive world growth requires embedding these data into a framework that accounts for how markets allocate resources between current production and innovation, and how innovators decide where to patent their inventions. For this purpose we use a multicountry model of innovation and diffusion that incorporates these phenomena.

A key goal is to assess the contribution that different countries are making to growth around the world. Among other things, our approach allocates technical progress in each country, its "Solow residual," to the countries whose innovations drive it. We learn that the United States, Japan, and Germany are overwhelmingly the major sources of innovation in the world economy: More than half the growth of the countries we consider derives from innovations from these three countries. While the extent of international diffusion is substantial, it is not complete. Innovations appear to be about two-thirds as potent abroad as they are at home, and each country makes its greatest contribution to growth at home.

Why Some Countries Do Much More Research than Others

On average, countries in Europe do less research than the United States or Japan, not only in absolute terms but also relative to their size and resources. Moreover, countries within Europe vary enormously in the share of resources they devote toward research and in terms of how much patenting they do at home and abroad.

Eva Gutierrez, Sam Kortum, and I adapt our framework to evaluate

alternative explanations for such cross-country differences in research effort.² One possibility is that these differences reflect specialization in goods that are more or less research-intensive. Switzerland, for example, might do a lot of research because of its large pharmaceutical industry, and pharmaceuticals are research-intensive. This explanation holds, of course, only if the research needs to be done where the inventions are used. However, we find that countries that do a lot of research tend to do it across the board, in all industries. Hence cross-country differences in research effort seems to say more about differences in the countries themselves than in the goods that they produce.

It may be that some countries are simply better at doing research than others, or else that some countries provide greater rewards to doing research. We find that the second explanation seems to have much more to do with why many smaller European countries do so little research. Because of their small size and the difficulty of appropriating returns to inventions abroad, firms in these countries turn to other activities.

What Policy Can Do

Since patenting is a major component of our empirical analysis, a natural question is what patent protection contributes to innovation and growth. In fact, our results indicate that the current patent system provides only modest protection from imitation. On the one hand, even if an idea is not patented, it may take a while for someone to figure out how to copy it. On the other hand, patents eventually expire, and even an active patent does not provide an ironclad guarantee that an idea won't be stolen. Imitation is often hard to detect, and enforcing the patent can be costly. These difficulties are especially formidable for patents held abroad.

Indeed, we find that eliminating patent protection entirely would reduce world incomes by fairly small amounts. At the same time, a patent system that provides much tougher protection than the current one could do much to stimulate growth.

Most policies toward technology are pursued nationally. But as long as ideas cross borders, national policies have global effects. Consequently, there are many reasons to think that countries might benefit from coordinating and harmonizing technology policy. Gutierrez, Kortum, and I consider various aspects of technology policy in Europe. We find that there is enormous scope for free riding. Many policies that would benefit Europe as a whole generate such large cross-border externalities that they are not worthwhile at the national level. We find, for example, that tougher patent protection within the European Union (EU) would raise incomes everywhere, but the increase outside the EU is even greater. The reason is that non-EU countries benefit from the stimulus to research but do not have to bear the cost of the more pervasive monopoly power that tougher protection entails. Our results suggest that the payoff to providing European inventors a common market for their ideas is potentially quite large.

Technology and Trade

To what extent does trade bring the fruits of technological progress to foreign shores? The idea that trade can be explained by technology has its origins with David Ricardo. But the Ricardian model has resisted generalization to many countries and the incorporation of trade barriers—two extensions needed for any serious empirical analysis.

It turns out, however, that in our model of innovation these extensions are quite straightforward. Kortum and I extend our framework to ana-

lyze bilateral trade in manufactures among a sample of OECD countries.³

Among other things, we examine how the competing forces of technology and geography shape production and trade patterns in manufacturing. When transport costs are very high, countries with large internal markets tend to attract manufacturing, since inputs tend to be much cheaper there. As transport costs fall, large countries lose their edge to countries with better technology for producing manufactures regardless of their size. For example, we estimate that a drop in transport costs from their current levels will tend to shift manufacturing from Germany to Denmark, which will then find its relative isolation less of a handicap.

We also consider the classic question of the gains from trade in manufactures among our sample of countries. A dramatic finding is the extent to which they remain unexploited: at their current levels, trade barriers keep countries much closer to a world of autarky than to a world in which manufactured goods could be moved costlessly across borders.

Given the size of current trade barriers, to what extent can trade spread the benefits of technological progress through the exchange of goods embodying innovations? We find that

barriers are too high for trade to serve as the major conduit for the spread of new technology except, in some cases, to small countries very near the source of innovation. These results suggest that the benefits of innovation spread primarily through the transmission of the ideas themselves, rather than through the export of goods embodying them.

What's Next

Our work on the topics discussed so far is largely complete, but we regard it mainly as a platform from which to launch investigations of many additional questions. Right now we are exploring three fronts.

One project examines at a sectoral level the technology and trade issues that we have raised here. In particular, to what extent do countries carve out a comparative advantage in particular manufacturing activities through research efforts? A second project seeks to complete the link between our model of innovation and international trade: we explore the extent to which openness to trade fosters innovation and growth. Finally, Kortum and I have teamed up with Andy Bernard and Brad Jensen to connect our work, which focuses on aggregate measures of trade and innova-

tion, with their work on the productivity and export behavior of individual U.S. firms and establishments. It turns out that our methodology provides a simple way to link aggregate with plant-level data. One of our goals is to understand the connection between factors that affect trade at the aggregate level and what happens to individual plants. For example, we can relate the implications of greater openness for plant closings and for the fraction of remaining plants that export.

These completed and ongoing projects all involve linking economic theory to data about the world economy. A common goal is to provide a clearer quantitative picture of the role of technology in the global economy.

¹ J. Eaton and S. Kortum, "International Technology Diffusion," *International Economic Review*, 40, no. 3 (May 1999), pp. 1-33; "Trade in Ideas: Patenting and Productivity in the OECD," *Journal of International Economics*, 40 (May 1996), pp. 251-78; "Engines of Growth in the World Economy," *Japan and the World Economy*, 9 (1997), pp. 235-59.

² J. Eaton, E. Gutierrez, and S. Kortum, "European Technology Policy," *Economic Policy*, 27 (October 1998), pp. 405-38.

³ J. Eaton and S. Kortum, "Technology, Geography, and Trade" (originally published as "Technology and Bilateral Trade," *NBER Working Paper No. 6253*, November 1997).

