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R&D AND PRODUCTIVITY: THE INTERNATIONAL CONNECTION

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ABSTRACT

Countries differ greatly in R&D spending, and these differences are particularly striking when comparing developed with developing countries. The paper examines the extent to which the benefits of R&D are concentrated in the investing countries. It is argued that significant benefits spill over to other countries in the world. The argument is supported by quantitative estimates of such cross-country effects.

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"...we may say that certainly since the second half of the nineteenth century, the major source of economic growth in the developed countries has been science-based technology – in the electrical, internal combustion, electronic, nuclear, and biological fields, among others." (Kuznets (1966, p. 10))

"No matter where these technological and social innovations emerge – and they are largely the product of the developed countries – the economic growth of any given nation depends upon their adoption. ...Given this worldwide validity and transmissibility of modern additions to knowledge, the transnational character of this stock of knowledge and the dependence on it of any single nation in the course of its modern economic growth become apparent." (Kuznets (1966, p. 287))

1 Introduction

Ninety-six percent of the world's research and development is performed in a handful of industrial countries. The remaining four percent is performed in a large number of developing countries, among them only 15 doing significant R&D.[1] This raises the question of whether the distribution of the benefits of R&D is as skewed as the distribution of expenditures.

Why should we be interested in this question? First, because research and development is an important activity. True, the industrial countries spend only between 1.5 to 3 percent of GDP on R&D. But rates of return on R&D are so high that this investment has a significant impact on output growth. Second, if the benefits of R&D are distributed across countries as unevenly as the expenditures, disparities in income per capita will tend to widen. As it happens, these disparities are large already. Income per capita in the US, for example, is twenty times higher than in many developing countries, and many more times higher than in some of the poorest countries of the world.

[1] See Coe, Helpman and Hoffmaister (1997).

Patterns of capital accumulation tend to compensate for differences in income per capita. But R&D raises productivity which in turn encourages capital accumulation. Therefore large differences in R&D benefits counteract the equalizing effects of capital accumulation. And they can trigger cumulative processes that greatly widen disparities in income per capita.[2]

2 Is R&D Important?

It is sometimes taken for granted that research and development is an important activity that drives some of the most dynamic sectors of modern economies. But this is by no means a universal attitude. Mankiw (1995), for example, has recently argued that one can understand economic growth by focusing on education and capital accumulation, disregarding the determinants of technological progress.[3] In my view, overwhelming evidence exists that inventive activities play a key role in modern economic growth. Education is of course very important, and so is capital accumulation. But they do not diminish the role of technological progress as a major force in expanding income per capita. The importance of inventive activities can be argued in three parts.

First, a large number of historical studies have examined particular inventions and innovations and the role of technological progress more generally in the long-run evolution of national economies.[4] Historical studies are particularly relevant in this context, because it is often necessary to take a long-run view of technological improvements in order to understand their impact. The steam engine, which provided a reliable source of energy, is a case in point.[5] The dynamo, which enabled flexible use of electricity in manufacturing plants, is another.[6] In both cases it took many years for the full economic impact of the new technology to work itself out. For

[2] See Grossman and Helpman (1991, chapter 8).

[3] See, however, Klenow and Rodriguez-Clare (1997) for a criticism of this position within the frame of its own premises.

[4] See, for example, Schmookler (1966), Landes (1969), Rosenberg (1982) and Mokyr (1990).

[5] See von Tunzelmann (1978).

[6] See Du Boff (1967) and David (1991).

example, forty years had passed from the invention of the dynamo until electrification substantially raised total factor productivity in US manufacturing.[7] It is therefore unfortunate that too often macroeconomic analysis loses sight of the relevant time frame for technological progress. What the detailed historical studies have taught us is that over the last two hundred years inventions and innovations played a central role in raising our standard of living.[8]

Second, studies have found high rates of return on R&D investment in the post-war period.[9] To begin with, these rates are high for individual companies. In the US, for example, the average rate of return on R&D investment is more than twice the rate of return on investment in capital equipment. In some countries it is more than twice as high.[10] But the social rate of return is higher still; spillovers across firms that operate in the same sector double the rate of return. And the rate of return rises further when measurement takes account of the spread of benefits from R&D-performing to technologically related user sectors.[11] In those instances the rates of return may exceed 100%. All in all rates of return on R&D investment appear to be consistently high.

Third, studies of national economies provide estimates of the extent to which research and development contributes to the total factor productivity of the performing countries.[12] Coe and Helpman (1995) find particularly high rates of return (e.g., 85% for small industrial countries). Their estimates most likely overstate the true rates of return, but they are not out of line with the findings of other studies that take intersectoral spillovers into account.[13,14]

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[7]See David (1991).

[8]See Rosenberg and Birdzall (1986).

[9]See Griliches (1979).

[10]See Mohnen (1992).

[11]See Terleckyj (1980), Sherer (1982), Griliches (1992) and Mohnen (1992).

[12]See Coe and Helpman (1995), Kim (1995), Engelbrecht (1996), Hejazi and Safarian (1996) and Nadiri and Kim (1996).

[13]See, for example, Terleckyj (1980) and Scherer (1982).

[14]Engelbrecht (1996) shows that these estimates are somewhat exaggerated, because they do not take into account differences in education. Park (1995) finds also lower rates of return. Finally, Nadiri and Kim (1996), who use a different approach, find much smaller rates of return for the G7

Taken together, these three parts suggest that inventive activities are very important indeed.

Having established that R&D is important, we now examine how R&D investment in one country affects other economies. For this purpose it is necessary to understand how countries interact with each other in the international marketplace and in what ways they become interdependent through these interactions, to which we turn next.

3 International Links

National economies operate in a global system. Each country depends on its trade partners for the supply of consumer goods, intermediate inputs, machines and equipment. In addition, trade partners supply a country with markets in which it can sell its products and services. And countries adopt each other's manufacturing methods, modes of organization, product design and product development.

The traditional literature emphasized gains from trade that stem from comparative-advantage-based specialization, where comparative advantage derives from technological differences or differences in factor endowments.[15] Later, economies of scale and variety choice were added to the sources of gains from trade.[16] Finally, dynamic scale economies and learning mechanisms have been incorporated into the analysis.[17] While improvements in the terms of trade raise a country's total factor productivity, the theoretical literature has emphasized four additional channels through which the productivity levels of various countries are interrelated.

First, international trade enables a country to consume products and to use inputs that were developed and perfected in other countries, which it cannot manufacture on its own. Such inputs can differ in quality from those available at home, or they can perform functions that complement domestic inputs. Second, international trade and direct foreign investment provide opportunities for cross-boarder learning in the

countries.

[15]See, for example, Dixit and Norman (1980).

[16]See Helpman and Krugman (1985).

[17]See Grossman and Helpman (1991,1995).

normal course of business, which requires no special effort or investment of resources. This sort of learning applies to manufacturing techniques, organizational methods and market conditions. In either case the acquired knowledge improves domestic productivity. Third, international trade and investment provide opportunities for a deliberate effort to imitate foreign products and methods. Imitation is widespread in developing countries. But it is not free.[18] It is, for example, quite costly to reverse-engineer a sophisticated product. Nevertheless, this is an important channel through which technology transfer takes place. Some of the fastest growing economies have relied on it extensively, such as Japan in the immediate postwar era and the newly industrializing countries of East Asia more recently. Fourth, international economic relations that provide learning opportunities reduce innovation and imitation costs, making it easier to raise total factor productivity in the future.

The theory thus suggests two broad ways in which trade and investment contribute to total factor productivity: by making available products and services that embody foreign knowledge, and by providing foreign technologies and other types of knowledge that would otherwise be unavailable or very costly to acquire. Productivity transmission channels of this sort are particularly important for developing countries, but they also play a significant role in industrial countries.[19]

To conclude, international trade and direct foreign investment have the potential to carry productivity gains via flows of goods and knowledge across national boarders. If such flows prove to be important in practice, then existing patterns of R&D investment do not produce equally skewed patterns of benefits. It is therefore of value to know the size of such international spillovers.

[18]See Mansfield, Schwartz and Wagner (1981), who find that imitation costs exceed half the value of innovation costs.

[19]According to Lockwood (1954), direct learning played an important role in Japan, when it opened up to the rest of the world in the second half of the 19th century. It also played an important role in South Korea during the early stages of its recent industrialization, as reported by the case studies in Rhee, Ross-Lauson and Purcell (1984). Finally, Irwin and Klenow (1994) find significant international spillovers in the modern semiconductor industry.

4 Productivity Growth and Stocks of Knowledge

To estimate the extent of international R&D spillovers we need to identify a variable that correctly reflects their influence. Total factor productivity (TFP) seems to be particularly suitable for this purpose. Simple measures of TFP do not adjust, however, for the quality of capital and labor, and both are important. Unfortunately, such adjustments are difficult to make, especially for large samples of countries. As a result most studies attempt to explain variations in simple measures of TFP, but include available proxies for human capital amongst the explanatory variables.

The relationship between productivity, education, trade and R&D has been studied for close to 100 countries. About one-fifth of them are industrial and the rest are developing. They vary greatly in productivity growth, R&D investment, levels of education, trade and direct foreign investment.

Table 1 shows some of these differences for three industrial countries, four developing countries, and averages for developing countries in two continents: Asia and Africa. Over a period of 20 years, from 1971 to 1990, total factor productivity increased by 10% in the US, by 30% in Ireland and by 70% in Japan. Ghana, on the other hand, suffered a decline of 6% in total factor productivity. In other words, the efficiency with which Ghana's economy was able to utilize resources declined by 6%. The fate of Zaire was even worse; its TFP declined by 36%. But two of the remaining developing countries in the table have done extremely well. Mauritius doubled its total factor productivity, while Taiwan increased its by 87%.

For the industrial countries, the table also provides rates of increase in the stock of R&D investment (i.e., a cumulative measure of how much research and development a country has done over those years). This stock has doubled in the US, more than tripled in Japan, and almost tripled in Ireland.

More generally, among the industrial countries Japan had the fastest rate of productivity growth. It also experienced the highest growth in the stock of R&D investment among the G7 economies.[20] Within a group of 77 developing countries for

[20]See Coe and Helpman (1995).

which calculations were made, about half had very small changes in total factor productivity over those years. But for about a dozen countries total factor productivity increased by more than 50%. In contrast, another dozen countries suffered serious declines in total factor productivity over the same 20 years.[21] And countries in Asia did on average much better than countries in Africa. As shown in Table 1, developing countries in Africa hardly made any productivity gains during those years while developing countries in Asia gained 31%.

Table 2 reports a measure of openness to foreign trade and a measure of human capital for the four developing countries in Table 1. The former is represented by imports of machinery and equipment from industrial countries as a share of the developing country's GDP; the latter by the secondary school enrollment ratio (the ratio of students in secondary schools to the population in the relevant age group). Evidently, Taiwan and Mauritius, which experienced a high rate of productivity growth, had both more exposure to foreign trade and a better-educated labor force, than Zaire and Ghana which suffered declines in total factor productivity.

Differences in the degree of openness and secondary school enrollment ratios exhibited in Table 2 are not particularly extreme within the sample of 77 developing countries studied by Coe, Helpman and Hoffmaister (1997). In their sample, the lowest import share of machinery and equipment was 1% for India. The highest was 38% for Singapore. While Singapore is an outlier, India is not; a number of countries had an import share of 2%. In fact, about half the countries had an import share that did not exceed 5% while only 13 had an import share larger than 10%. Considerable variation also existed in the secondary school enrollment ratio, whose sample average was 31%. While some countries, such as Jordan, had an enrollment ratio in excess of 70%, a number of African countries, such as Chad, had enrollment ratios of less than 10%.

Using this sort of data one can estimate the impact of education, trade, direct foreign investment and R&D on total factor productivity, including cross-country effects.

[21] See Coe, Helpman and Hoffmaister (1997).

5 Quantitative Assessment I

What do these estimates show? To begin with, education has a significant impact on total factor productivity. Estimates from macro data only confirm known findings from more detailed micro studies. But after controlling for education, R&D investment shows up as a potent force of productivity growth, the more so for countries that are more involved in foreign trade and investment. Countries that perform R&D reap large benefits from this investment. But a fraction of these benefits also spills over to other countries.

Table 3 reports estimates of the elasticity of TFP with respect to domestic and foreign R&D capital stocks; all the estimates are positive and significant. The elasticity with respect to foreign R&D capital is proportional to import shares, the import share of goods and services for the industrial countries and the import share of machinery and equipment for developing countries. Since developing countries engage in little R&D activity, the impact of their own R&D on TFP has not been estimated.

For the purpose of estimating these elasticities domestic R&D capital stocks were constructed by accumulating real R&D investment, allowing for depreciation.[22] Foreign R&D capital stocks where constructed as the trade-weighted average of trade partners' domestic R&D capital stocks, using import shares as weights. Evidently, the elasticities with respect to domestic R&D capital stocks are large. This elasticity also appears to be much larger in the G7 countries than in the smaller industrial countries. Elasticities with respect to foreign R&D capital stocks also appear to be large. A G7 country that has an import share of goods and services of 25% (such as Canada in 1990) has a foreign R&D elasticity of 0.075, which is about the same as the elasticity with respect to the domestic R&D capital stocks of the smaller industrial countries.[23,24] On the other hand, a developing country that has an import share of

[22]See Griliches (1979).

[23]An import share of 25% is not unusual for the industrial countries. West Germany and the UK had somewhat larger import shares in 1990 while a number of the smaller industrial countries (such as Ireland) had import shares more than twice as large.

[24]As noted before, Engelbrecht (1996, Table 1, column (iv)) finds somewhat lower elasticities for the industrial countries, after controlling for differences in education levels. His elasticities of TFP

machinery and equipment of 7% (the group's average), enjoys a TFP elasticity with respect to foreign R&D capital of close to 0.06, which is substantial.

These estimates imply that the own rate of return on R&D investment is about 120% in G7 countries and about 85% in the smaller industrial countries.[25] Since the calculation of these rates of return is sensitive to the initial stocks of R&D, however, and these stocks are very imperfectly estimated, one should treat these findings with great caution. Nevertheless, they do suggest that R&D investment is highly profitable (at the national level) in the industrial countries.

These estimates also suggest that there are substantial international R&D spillovers. In addition to the domestic rate of return, R&D investment in G7 countries produces an extra 30% return by raising TFP in the smaller industrial countries. And particularly encouraging is the finding that developing countries also gain from R&D performed in the industrial countries.

We conclude that a country's total factor productivity depends not only on how much research and development it does, but also on how much research and development is done in other countries with which it engages in trade and investment. The larger a country's exposure to the international economy, the more it gains from R&D activities in other countries.

Two channels appear to be major carriers of these cross-country benefits: international trade and direct foreign investment. At the moment, we know more about the role of trade than about the role of direct foreign investment. But ongoing research will undoubtedly provide better information on the relative importance of these transmission mechanisms.

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with respect to the domestic R&D capital stock are 0.237 for the G7 countries and 0.055 for the smaller industrial countries, while his elasticity with respect to the foreign R&D capital stock is $0.220m_{GS}$. On the other hand, Hejazi and Safarian (1996, Table 3, column (a)), who add direct foreign investment flows from the US as an additional channel of international R&D spillovers, find (for the industrial countries) similar elasticities with respect to the domestic R&D capital stock and higher elasticities with respect to the foreign R&D capital stock.

[25] See Coe and Helpman (1995).

6 Quantitative Assessment II

Elasticity estimates of the type reported in Table 3 can be evaluated in more than one way. We have so far gauged their importance by examining implied rates of return on R&D investment. Those calculations are incomplete, however, because they do not take into account a variety of changes that are induced by higher levels of R&D, such as shifts in patterns of capital accumulation and in terms of trade. An alternative way to evaluate the significance of these elasticities is to embody them in a fully fledged econometric model of the world economy and to trace out by means of this model the dynamic implications of an increase in R&D investment. This sort of evaluation has been done with the International Monetary Fund's MULTIMOD model in Bayoumi, Coe and Helpman (1996).

MULTIMOD consists of 13 linked econometric models that cover the entire globe. Bayoumi, Coe and Helpman (1996) used a version that dropped the oil-exporting developing countries. The remaining coverage consisted of one model for each one of the G7 countries, one for the remaining industrial countries, and four regional models of non-oil-exporting developing countries: in Africa, the Western Hemisphere, the Asian NIEs (Hong Kong, Korea, Singapore and Taiwan), and the remaining Asian developing countries.[26]

Some features of MULTIMOD make it particularly suitable for a long-run analysis of economic growth.[27] First, output is determined by a standard production function of labor and capital. Second, consumption is derived in a consistent way from a reasonable structure of preferences (of the Blanchard type), implying that in the long run consumption is proportional to wealth. In addition, care is taken to include in wealth the expected stream of labor and capital income, as predicted by the model. As a result expectations are self-fulfilling in the long run. Third, the investment function is derived from the theory of investment in the presence of costs of adjustment. Fourth, countries are linked via trade with endogenous adjustments of the terms of trade.

[26]See Bayoumi, Hewitt and Symansky (1995) for details.

[27]MULTIMOD has a number of Keynesian features in the short run, which appear to me to be unreliable for predictions of short-run growth.

Finally, although the developing countries face balance of payments constraints, the industrial countries do not, and the world interest rate is determined so as to equate world savings with world investment.

The IMF's version of MULTIMOD treats total factor productivity as exogenous. Bayoumi, Coe and Helpman (1996) changed this feature by incorporating into the model a set of equations that were estimated by Coe and Helpman (1995) and Coe, Helpman and Hoffmaister (1997), which provide a link between TFP, trade and domestic and foreign R&D capital stocks. These equations have R&D elasticities as reported in Table 3. Using the augmented version of MULTIMOD they traced out the dynamic response of all countries and regions to increases in R&D investment.

It takes a long time to reach a steady state in a neoclassical model, and MULTIMOD is no exception. Expansion of R&D investment, which is the main focus of our attention, takes about 80 years to reach its full impact. But the fact of the matter is that the impact is large early on and very small in the last phases of the growth process. In particular, about half of the quantitative effects are obtained after 15 years.[28] In what follows we focus on the long run.

Table 4 shows the simulated effects of an increase in R&D investment in the US of 1/2% of GDP; the new level of investment is maintained throughout. This raises US total factor productivity by 6.7%. But it also raises total factor productivity by 2.4% in the industrial countries and by 3.4% in the developing countries. So clearly, other countries stand to gain much from an expansion of US R&D. There exists, however, an additional multiplier effect. As total factor productivity rises, it becomes more profitable to invest in machines, equipment and structures. This additional investment flow raises the capital stock, thereby raising output. As a result GDP rises not only because the economy becomes more productive, but also because it invests more. The induced accumulation of capital raises output growth by about one-third of the rise in total factor productivity. Therefore output in the US rises in total by 9%, in the industrial countries by 3.3% and in the developing countries by 4.3%. Finally, consumption rises by 7.2% in the US, by 3.8% in the other

[28]See Bayoumi, Coe and Helpman (1996).

industrial countries and by 4.4% in the developing countries. Evidently, consumption rises by less than output in the US and by more than output in the other countries. This difference reflects terms-of-trade movements. As US output expands in response to larger R&D investment, its terms of trade deteriorate while the terms of trade of its trade partners improve. A comparison of the last two columns in Table 4 reveals that changes in the terms of trade have a lesser effect on the developing countries than on the industrial countries.

Table 5 shows changes in total factor productivity, output and consumption that result from a coordinated expansion of R&D by 1/2% of GDP in all industrial countries. Now the quantitative impact is very large indeed. Total factor productivity rises by 13.8% in the industrial countries and by 10.3% in the developing countries. After accounting for the induced accumulation of capital, output rises by 18.7% in the industrial countries and by 14.1% in the developing countries. Clearly, the output multipliers of R&D investment are large, with major international ramifications. And again, consumption rises by less than output in the R&D-expanding countries and by more than output in their trade partners (consumption rises by 17.3% in the industrial countries and by 15.5% in the developing countries; almost at the same rate). Now developing countries make a significantly larger consumption than output gain as a result of an improvement in their terms of trade while the industrial countries gain in consumption significantly less than in output as a result of the deterioration in their terms of trade.

7 Conclusions

It is apparent from the reported estimates that R&D is an important activity that has a major impact on the performing countries as well as on their trade partners. We may not yet have precise estimates of these impacts, both because of difficulties with available data and because of some unsettled methodological issues. But it is safe to draw a tentative conclusion, namely, that these effects are important and that there exist significant cross-country links that are driven by foreign trade and investment. Since foreign trade and investment are also important for a variety of other reasons, international productivity links that are driven by R&D make them all the more important. This means that we have reasons to be optimistic about recent trends towards a tighter integration of national economies. And it means that technological developments in industrial countries that have been perceived by many to be detrimental to the developing countries may in fact be good for them after all.

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Table 1
Rates of Growth: 1971-1990
(in percent)

	TFP	R&D Stock
US	10	100
Ireland	30	270
Japan	70	320
Zaire	-36	
Ghana	-6	
Taiwan	87	
Mauritius	100	
Africa	2	
Asia	31	

Source: Coe and Helpman (1995, Table 1) for the first three rows; Coe, Helpman and Hoffmaister (1997, Table 1) for the rest.

Table 2

Average: 1971-1990

(in percent)

	Import share	Secondary enrollment
Zaire	5	24
Ghana	4	36
Taiwan	10	47
Mauritius	8	46

Source: Coe, Helpman and Hoffmaister (1997, Table 1).

Table 3
Elasticity of TFP with Respect to R&D Stocks

	Domestic	Foreign
G7	0.234	$0.294m_{GS}$
Small Industrial	0.078	$0.294m_{GS}$
Developing		$0.837m_{ME}$

Source: Coe and Helpman (1995, Table 3, column (iii)) for the first two rows; Coe, Helpman and Hoffmaister (1997, Table 2, column (x)) for the third row.

m_{GS} represents imports of goods and services as a fraction of GDP.

m_{ME} represents imports of machinery and equipment from industrial countries as a fraction of GDP.

Table 4
US Raises R&D by 1/2% of GDP
Long-Run Rates of Growth
(in percent)

	TFP	GDP	Consumption
US	6.7	9.0	7.2
Industrial	2.4	3.3	3.8
Developing	3.4	4.3	4.4

Source: Bayoumi, Coe and Helpman (1996, Table 1, last column).

Table 5

Industrial Countries Raise R&D by 1/2% of GDP

Long-Run Rates of Growth

(in percent)

	TFP	GDP	Consumption
Industrial	13.8	18.7	17.3
Developing	10.3	14.1	15.5

Source: Bayoumi, Coe and Helpman (1996, Table 1, last column).