International Knowledge Flows and Economic Performance
An Introductory Survey of the Evidence

by

Giorgio BARBA NAVARETTI *
David TARR**

* Università degli Studi di Ancona, Centro Studi Luca d'Agliano, Fondazione Eni Enrico Mattei
** The World Bank

A growing number of departments of corporations are labelled *'Knowledge Department'* or *'Directorate for Knowledge Flows and Management'*. The World Bank's 1998/9 World Development Report is on *'Knowledge for Development'*. These are just two signs of the increasing institutional awareness of the importance of knowledge for business performance, economic growth and development.

The comparison between Ghana and South Korea is a frequently told growth tale: in 1960 income per capita was the same in both countries; today, it is seven times higher in Korea. More than the performance gap, the staggering fact is the inability of analysts to single out the causes of the gap. The accumulation of physical and human capital barely justifies a three fold difference in income per capita. A remaining $ 4,000 gap is yet to be explained. Many analysts agree that knowledge could well be the main hidden factor of production in Korea's growth (World Bank, 1999; Rodriguez-Clare, 1997).

The characteristics of knowledge as an economic good may explain why this initially neglected and now actively investigated factor of production remains relatively concealed. Knowledge is a public good with rarely enforceable property rights; it is seldom quantified or priced; it is sometimes codified, but more frequently tacit and in any case difficult or impossible to observe. All measures of knowledge are indirect, either inputs to (years of schooling, manuals) or outputs of (human capital, patents the unexplained residual in growth accounting) its accumulation.

Two elements combine in defining its likely importance for economic growth. The evidence that countries with higher income per capita also hold larger stocks of our indirect measures of inputs and outputs of knowledge and the fact that knowledge travels cheaply and fast. This symposium issue is precisely devoted to the empirical analysis of international diffusion of technological knowledge and economic performance at the micro level.

Although well established in theory and anecdotes, the link between accumulation of knowledge and growth has been tested by relatively few rigorous empirical analyses. The most quoted reference in this area is the paper by Coe and Helpman 1995, which focuses on knowledge diffusion among OECD countries, and Coe, Helpman and Hoffmaister, 1997 which extended this work to developing economies.

These works use aggregate data to measure the impact of knowledge diffusion through trade flows. Yet, most of the effects of learning on productivity are often observable primarily at a micro level. For example, learning by doing is frequently sector specific; imported technologies are also frequently sector specific; technological upgrading and the enhancement of production processes take place at the firm level and depend upon firms' characteristics; the organisation and the effectiveness of '*knowledge departments*' is also observable at the firm level. It is therefore important to combine the empirical analysis of generalised country-wide learning processes, with a more focussed understanding of how these processes take place at the micro level.

This is precisely the objective shared by the papers collected in this issue. They analyse the role of three international channels of learning at the industry and at the firm level: imports of machines and other inputs, along with the R&D spillovers they generate; foreign direct investments or other forms of collaboration between local and foreign firms; and learning by exporting. This introductory essay reports the main findings of these papers and relates them to the broader literature.

If technology transfers are assumed to be exogenous, the scope for carrying out micro-focussed empirical work is simply to measure the different components of this external learning process more accurately and to test whether this process does indeed take place in the predicted direction. However, it is quite clear that the demand and the supply of international technological inputs are not exogenous. This is well grounded in theory. For example, the endogeneity of learning is at the hart of growth models with international trade, where the stock of knowledge grows because innovators derive profits from their investments in R&D. Equally, the form of the transfer (wholly owned FDIs, joint ventures, licensing or direct sale of machinery) affects the level of dispersion of proprietary knowledge, and thus monopoly rents. Firms will choose the channel of technology transfer based on profit maximising conditions, which implies that the form of the transfer is also an endogenous decision variable. Consequently, in this context different channels may have different impacts on the accumulation of knowledge and productivity. It is therefore important to analyse the impact of each form of technology diffusion, the role of which may not be observable in the aggregate.

The empirical works collected here are rooted in theories developed by earlier models of endogenous growth in open economies. Two main mechanisms of knowledge accumulation have been taken into account by this literature. The *first one* relates to the fact that trade may change the pattern of specialization of a country. Learning is faster if the country specializes in goods with higher learning potential (Lucas, 1993, Krugman, 1987, Stockey, 1988 and 1991, Young 1991).

Technological upgrading, though, is not just based on domestic resources. If innovation depends on knowledge developed through cumulative R&D experience and if this knowledge travels internationally, innovation and economic growth benefit from both national and foreign R&D. Therefore, the *second* mechanism on which this special issues focuses is that trade in goods and factors of production open up new potential sources of technological inputs. Some of these technological inputs are deliberately purchased (new machines, foreign investments, skilled personnel) and others are acquired through spillovers, by trading with more technologically advanced partners, by gathering information in foreign markets, by learning from sophisticated imported goods (Grossman and Helpman, 1991, Rivera Batiz and Romer, 1991).

The next section briefly summarises these main endogenous growth contributions Section 2 examines at the sector level the role of trade in channelling R&D spillovers and its impact on total factor productivity of importing countries. Section 3 reports firm level evidence on learning by importing foreign intermediates, by exporting and through foreign direct investments. Section 4 examines the demand for technological inputs and the choice of technology of importing countries and discusses policy implications. Section 5 concludes.

1. TRADE, LEARNING AND GROWTH: THE THEORETICAL BACKGROUND

The literature on learning and growth in open economies postulates different mechanisms through which knowledge is accumulated. Broadly speaking we can consider two groups of contributions: models where learning is essentially a domestic affair and models where knowledge is imported from abroad and gathered by accessing the global knowledge base[1].

Many of the models with domestic learning relevant to our analysis involve learning by doing. Young 1991[2], for example, posits a model where in the process of manufacturing output, managers and workers acquire experience that makes them more productive. This well-documented phenomenon is typically summarised by a "learning curve" relating process-specific production costs to cumulative units produced[3]. The learning curve is downward sloping, but it eventually flattens out as the potential for learning is exhausted. If each process is associated with a given product, knowledge accumulation is a non-decreasing, concave and bounded function of that product's cumulative output. Stokey, 1991 shows in a second model that schooling can be substituted for learning by doing without changing Young's 1991 conclusions much.
Young, 1991 and Stokey 1991 each attribute productivity growth to learning processes that make feasible the production of increasingly sophisticated products, and to the associated knowledge spillovers which are limited to the country in which the learning takes place. The more rapidly learning takes place—either through schooling or through learning by doing—the higher the rate at which new high-end products are introduced, and the higher the rate of productivity growth.

Now, if learning only takes place at home why should we be concerned with trade? Because trade affects the pattern of specialisation of countries in goods with different degrees of learning potential and indirectly influence the accumulation of knowledge. A likely, but not necessary, consequence of trade liberalisation in developing countries is that demand for high-end goods is dampened, thereby limiting the amount of learning taking place.

Although the Young and Stokey models are too restrictive to be applied in a policy context for developing countries, they are important contributions because they show clearly what happens when trade does not generate international knowledge flows. Indeed, not all learning is a by-product of learning by doing or of education. In particular, there are various ways in which knowledge accumulation diffuses across national boundaries, i.e., knowledge of countries may increase as a result of knowledge accumulation of their trading partners. That is, there are international knowledge spillovers that are likely increased through trade.

Therefore, we now turn to models where knowledge is not foreclosed within national boundaries and the channels through which it is transmitted are indeed important. Trade (especially the import of a larger variety of technological inputs), foreign investment, travel by executives and

---

1 This section does not aim at providing a comprehensive survey, but simply to convey the main findings of this type of literature. For a comprehensive survey on trade and technology diffusion see Grossman and Helpman, 1995

2 Earlier contributions with growth and learning by doing include Lucas, 1988, elaborating on Krugman,1987 and Stokey, 1988

3 Many studies have found corroborating evidence that production experience decreases unit costs. Benkard, 1997 provides an excellent recent contribution and documents partial spillovers from experience producing one generation of wide-body aircraft to the next generation's efficiency. Malerba, 1992 provides a recent review of the literature and some evidence of his own.

technicians are all channels through which knowledge can be transmitted internationally. Open economies benefit from a wider range of learning channels.

One important model which allows for the international transmission of knowledge is by Rivera-Batiz and Romer, 1991. They assume an economy where inputs are horizontally differentiated. Research creates new input varieties and additional input varieties positively influence productivity growth in the final good industry. When more input varieties are available, the final goods sector can choose inputs that more closely adapt to its precise requirements. Thus, for the same cost expenditure, it can purchase a bundle of intermediate inputs that has a greater productivity. This is a dynamic extension of the Ethier, 1982 application of the Dixt-Stiglitz model. They examine two alternative channels to transfer technological knowledge: the transmission of ideas, which can be traded independently from goods (the *knowledge driven R&D* model[4]), and the transmission of intermediate inputs incorporating new ideas (the *lab equipment* model).

In both models, international flows of knowledge influence growth positively, as the stock of knowledge available to producers in any country increases. Note, though, that the two models imply very different mechanisms of technology diffusion. In the first case the stock of knowledge is common to all researchers in the world economy and distributed at no costs by way of spillovers[5]. In the second case knowledge is immediately excludable, in that it is only transmitted through the purchase of inputs and there are no spillovers.

In the lab equipment model, knowledge is diffused internationally only if there is trade in goods, as knowledge is embodied in goods. There is a significant productivity improvement from trade and the steady state growth rate increases. In the knowledge driven model, if trade is permitted countries have an incentive to specialise in completely non-overlapping innovations. Then knowledge diffuses through both through trade in goods and through ideas. The welfare effect is larger since countries obtain both the productivity effect of additional foreign varieties as well as an increase in the growth rate due to increased relative returns to the R&D sector.

Although both models generate the prediction that trade in goods is important for the international diffusion of knowledge, their empirical implications are different. In the research lab model trade effects productivity directly since ideas are embodied in goods. In the knowledge driven model, trade has both a direct and indirect effect. It has the same direct effect as the lab equipment model, but also indirectly affects productivity because the incentives to the R&D sector increase. Since it is profitable to specialise, the number of new varieties and thereby productivity increases by a greater amount. Thus the form of knowledge diffusion is important.

Rivera Batiz and Romer focus on symmetric countries. Grossman and Helpman, 1991[6] extend this framework to the case of asymmetric countries and more than one final good. Also in Grossman and Helpman's framework, inputs are horizontally differentiated and additional varieties developed by the research sector increase final goods productivity. Research technology is similar to Rivera Batiz and Romer's knowledge driven economy, in that productivity depends on cumulative R&D stocks. An open country can use world R&D experience: under spillovers which are global in scope, foreign R&D will have the same effect than domestic R&D on productivity. The same conclusions can be reached in a quality ladder model, where inputs are vertically differentiated[7].

---

4 Initially developed by Romer, 1990

5 However, once a design is incorporated in an intermediate producers must pay for the exclusive use of such a design. This mechanism generates monopoly profits to the research sector and an incentive to innovate.

6 Grossman and Helpman 1991 also include a model with no spillovers

7 . For quality ladders see also Aghion and Howitt, 1992 and Seagerstrom, Anant and Dinopulos, 1990

Grossman and Helpman's have one prediction analogous to that of Young, 1991[8]. Industrialised economies with a relative abundance of human capital will undertake more research and grow faster than developing ones. On the other hand, they show that by engaging in international trade, developing countries obtain more intermediate inputs than otherwise and therefore grow faster than without trade with the industrialised counties. Thus, although there is no convergence of growth rates, openness is a benefit for the growth of developing countries.

Thus, according to the endogenous growth literature, the impact of trade on the growth of developing countries depends crucially on the international scope of knowledge diffusion and on the mechanisms through which knowledge is transmitted. A way to test these predictions is to analyse how inflows of technologies affect productivity in the importing countries.

2. Imported Inputs Learning and growth: the Evidence

Although earlier work had estimated international knowledge spillovers[9] the first and most widely quoted attempt to relate empirically international R&D spillovers to economic growth is by Coe and Helpman, 1995[10]. They estimate whether variations in total factor productivity (TFP) for a sample of OECD countries are explained by variations in both domestic and foreign R&D capital stocks. The foreign R&D capital stock is defined as the import-share weighted average of the domestic R&D capital stock of trade partners. The impact of foreign R&D in a given country is expected to be higher, the more a given country imports from the country undertaking the R&D. Consequently, foreign R&D capital stocks are also weighted for the share of imports in GDP.

Note the mechanisms of knowledge transmission implied by this specification. Knowledge is acquired through the international purchase of intermediates, thus it does not travel if there is no trade in goods. Additionally, productivity in country i is expected to increase if R&D capital stock in country j increases, even if j's share in i's total imports remains constant. One way to interpret this last assumption is that if the overall R&D stock in a given country grows, the goods imported from that country are more R&D intensive. Another one is that through trade country i is able to obtain access to the R&D of country j enabling country i to more easily introduce new designs in production. In the first case Coe and Helpman's 1995 empirical specification reflects Rivera Batiz and Romer's lab equipment model, in the second case their knowledge driven model.

They find evidence that both foreign and domestic R&D have beneficial effects on TFP. Whereas in large countries, the elasticity of TFP with respect to domestic R&D capital stocks is larger than with respect to foreign R&D capital stock, the opposite holds in small countries, i.e., foreign R&D is more important for small countries. These results are also confirmed in the analysis of North South R&D knowledge diffusion by Coe, Helpman and Hoffmaister, 1997, based on a sample of 77 developing countries. Interestingly, they find that East Asian countries have benefited the most from foreign R&D. Thus, for the typical developing country, these findings imply that access to foreign R&D is crucial and that openness and trade with technologically developed countries is fundamental to obtaining that access.

These contributions focus on aggregate TFP at the country level and knowledge spillovers are channelled by total import flows. Yet, much of the learning process is probably related to intra-

8 Grossman and Helpman 1991 is essentially a Heckhser-Olin model of international trade combined with a model of endogenous growth through profit seeking R&D. Young, 1991, like Krugman, 1987, is a Ricardian model where trade is driven by differences in technology rather than in comparative advantage. See Aghion and Howitt, 1998, ch. 11 for a survey of these models.

9 . For example Jaffe, Henderson and Trajtenberg, 1993 examine geographical localistion of knowledge spillovers by looking at patent citations

10 Eaton and Kortum, 1996 in a later paper analyse patterns of productivity and international patenting.

industry trade[11]. Learning takes place within specific sets of activities[12] and, most likely, technical progress concerns specific purpose technologies. This is the case for learning by doing, but in some cases it also occurs when new knowledge is embodied in specific machines or procedures.

Moreover, the potential for technical progress differs across industries. As discussed above, the theoretical literature on endogenous growth discusses how much of the growth process takes place as economic activities shift towards industries or specific products with higher learning potential. Consider two trade partners of country i (j and k) which have the same level of R&D capital stock, equal weights in i's total imports, but differ in the basket of products that i imports from them. If the products imported from j are mostly consumer goods, whereas products imported from k are mostly intermediates, the impact of k's imports on i's TFP is expected to be larger. Equally, if imports from k are mostly made of goods with a high learning potential, compared to imports from j, the former will have a larger effect on i's TFP.

The paper by Wolfgang Keller in this issue addresses this problem, and examines the impact of international R&D spillovers on industry specific TFP. His measure of foreign R&D for a given country is the trade weighted *sector specific* R&D capital stock in foreign partner countries[13]. Keller also computes trade weights just considering imports of machines used in production in a given industry[14]. In doing so, he leans closer to the lab equipment model, as he focuses on those imports which are more likely to carry embodied new knowledge. His results are not dissimilar from Coe and Helpman's, in that domestic and foreign R&D stocks are estimated to have a significant and positive influence on TFP levels.

There is a second problem arising from the simple specification of the TFP function in Coe and Helpman's estimations. International flows of knowledge can be embodied in imports or they may take place as knowledge flows independent from trade flows or as knowledge flows augmented through trade flows. It is not possible to distinguish between these three hypotheses in the Coe and Helpman estimations. To address this point, Keller carries out an alternative battery of estimations using random weights for foreign R&D stocks instead of import weights.

In line with Coe and Helpman's 1995 results he finds that domestic intermediate inputs have a statistically significant and different impact from imported inputs and that the impact of foreign intermediate imports is more important the smaller the importing country. In contrast, he finds that the regression results are to some degree invariant to the import weights for the foreign R&D stocks of trading partners, especially when importing countries are large and exporting countries have similar R&D capital stocks. Consequently trade is an important conveyor of foreign technological knowledge to small countries but less so to large ones.

Since Keller only studies OECD countries, there is a question of the implications for knowledge transmission to developing ones. His finding that foreign imported inputs are particularly effective for small OECD countries is important in this context. Developing countries typically have a weak domestic R&D sector and technologies are mainly acquired internationally. For this reason it is likely that a change in import shares assigning a larger weight to less developed economies, with lower levels of R&D stocks, would clearly diminish their access to foreign

---

11 A recent paper by Hakura and Jaumotte, 1999 rigorously supports this hypothesis

12 For a pioneering case study see Lall, S., 1987

13 Keller argues that R&D expenditures on GDP are never higher than 0.5% in the industries he considers. He therefore compute sector specific R&D stocks in each country, by assigning a sector specific weight (given by the share of the sector in total manufacturing employment) to the R&D stocks of each country's non-electrical machinery sector, where most innovations are likely take place.

14 Note that also Coe, Helpman and Hoffmaister 1997 use import of intermediates and not total imports to construct import shares

technologies. In other words, the likely effect of a developing country's shift in the acquisition of machinery from France to Germany is smaller than a shift from France to Ethiopia[15].

In a recent paper Coe and Hoffmaister, 1999, argue that Keller's random weights are in fact not random, but simple averages with a random error. They derive three alternative sets of random weights and use them to restore Coe and Helpman's original results. Note, however, that the controversy mostly concerns technological flows between large countries, as Keller never dismisses the evidence that trade flows to small countries are important in transmitting foreign knowledge[16]. This is also consistent with the findings obtained by Eaton and Kortums',1996. On the basis of patent data they argue that 90%of growth in small Oecd countries derives from foreign innovations.

In conclusion, the available empirical evidence supports the direct and indirect role of trade in diffusing knowledge, and suggests that it is particularly important for developing countries to trade with technologically rich countries. This result is not surprising, given that rich countries have many more alternative means for exchanging knowledge between themselves than developing ones. Indeed, the papers reviewed up to here provide indirect evidence that other channels are at work, besides foreign trade, which may not be observed in aggregate estimations. The next papers of this issue adopt a firm-level perspective to analyse two other potential channels of learning: foreign investments and exports.

3. Learning at the Firm Level: Foreign Direct Investments and Exports

There is now fairly well documented evidence that Multinationals (MNEs) are a major channel for transferring technologies. According to UNCTAD, 1997, over eighty percent of royalty payments for international transfers of technology were made from subsidiaries to their parent firms[17]. This is not surprising, given that multinationals are linked by many studies to the existence of knowledge capital[18]. MNEs are more often found in industries with high levels of R&D expenditures relative to sales, larger numbers of scientists and technicians, new and technically complex products and high levels of product differentiation and advertising. These stylised facts are well rooted in theory: intangible assets like knowledge are more mobile than tangible ones and frequently have a public good feature in that knowledge use in one application does not reduce its availability for other applications either within or across firms.

The fact that MNEs transfer technology, does not necessarily imply that such transfer is beneficial for the local economy. It is therefore necessary to consider whether productivity for foreign owned companies is higher than for domestic ones and whether there are transfers of knowledge from foreign owned to domestic companies. The channels through which these spillovers can take place are many, including: employees of foreign affiliates moving to domestic companies, backward and forward linkages between multinationals and domestic firms, demonstration effects.

The early statistical analyses of spillovers at the industry level[19] use a production function framework, and estimated the impact of foreign direct investment (measured by the foreign share of

---

15 Keller's results are challenged in a recent working paper by Coe and Hoffmaister, 1999. The authors argue that Keller's random weights are in fact not random, but simple averages with a random error. They derive three alternative sets of random weights and use them to restore their original result: with these new weights there is no evidence that randomly created trade patterns give rise to positive international R&D spillovers

16 See also Coe, Helpman and Hoffmeister, 1997 estimations for developing countries

17 Reported in Saggi, 1999 which extensively reviews this evidence. Blomstrom and Kokko, 1998 is another major survey on the role of multinationals in diffusing technology.

18 Markusen, 1995, and Caves 1996 are surveys of the theoretical and empirical studies on this matter.

19 Caves, 1974, Globerman, 1979 and Blomstrom and Persson, 1983

each industry's employment or value added) on labour productivity. They all find significant evidence of positive spillovers.

More recent studies use panel data at the firm level for a few developing countries. They obtain controversial conclusions. They report that firms with foreign ownership have higher levels of TFP. In contrast, there is no evidence of positive short run spillovers to domestic firms and the concentration of foreign investments in particular sectors sometimes has a negative effect on domestic firms' productivity levels in the same industry[20]. These results are partly explained by the fact that foreign investors acquire market shares at the expenses of domestic producers, who face negative scale effects. All together, the effects of FDI very much depend on the absorptive capacity and on the competitiveness of local firms. Spillovers will be larger, when locals are able to quickly adopt and absorb the new imported technologies and when they are able to face the competition of more efficient foreign producers. [21].

The paper by Djankov and Hoekman in this issue examines the impact of foreign investments on productivity for a sample of 513 Czech enterprises listed in the Prague stock exchange between 1992 and 1997. Their sample includes firms with foreign linkages (either because they had formed one or more joint venture or because their equity was at least partially foreign owned) and firms without formal foreign linkages. In line with earlier contributions, it examines the impact of formal foreign linkages on TFP and whether the presence of foreign investors generates positive indirect intra-industry effects (spillovers) on firms which have no apparent formal foreign links.

As expected, the paper finds evidence that firms with foreign linkages have larger productivity growth than firms without foreign linkages. To analyse the impact of foreign investment on domestic firms, Djankov and Hoekman examine a sub-sample of firms with no formal foreign linkages. To determine the impact of foreign investment on TFP of domestic firms not affiliated with foreign firms, they employ a variable which is the share in total industry assets of firms with formal foreign linkages. Like some of the earlier studies using firm level data, they find that foreign investments have a negative effect on productivity growth of domestic firms with no formal foreign linkages. This result could perhaps reflect a competitive effect as local firms lose market share in favour of those with foreign linkages. Firms without foreign linkages still are able to restructure and improve their productivity, but at a slower pace than their foreign owned counterparts and at a slower pace than when there is no foreign investment among competitors in the industry.

An alternative channel through which firms based in open economies can acquire foreign knowledge is by exporting. They get in touch with foreign markets, technologies and products and they may specialise in products with a higher learning potential. Many case studies and empirical evidence support this view, by showing that exporting firms are more efficient than non-exporting ones (Pack, 1992). Yet, this evidence does not say much about the causal relationship between the exporting status of firms and their productivity. Firms could be more productive because they learn by exporting, or simply because more productive firms enter the export market. The relevance of these two hypotheses was first tested by Clerides, Lach and Tybout, 1998 for Colombia, Mexico and Morocco and by Bernard and Jensen, 1999 for the United States. They find that self selection is the dominant explanation and that there is little evidence of learning by exporting.

The paper by Aw, Chung and Roberts in this issue addresses this question for Korea and Taiwan, using panels of exporting and non-exporting firms. They study the relationship between productivity and transition patterns in and out of the export market. If self-selection is the important

---

20 Harrison, 1996, Aitken, Hanson and Harrison 1997, Haddad and Harrison, 1993

21 A key element that is lacking in these studies, however, is that they do not examine the impact on downstream industries and overall economic welfare or growth. For example, if there is FDI in accounting services, while the domestic accounting sector may be adversely affected, productivity and welfare in the economy may rise. On this point see also Lall 1999

explanation, then a firm's initial productivity should be higher when it enters the export market. If learning by exporting is the relevant explanation, then producers who enter the market should experience an increase in their productivity growth compared to firms that stay out.

In the case of firms in Taiwan, interestingly, they find evidence that both explanations (models of self-selection and learning by exporting) are important. For Korea results are much less satisfactory. There is weak evidence of the self selection hypothesis and no evidence of the learning by exporting hypothesis. Among other factors, the authors claim that the weak results on Korea could be explained by the country's export policies. Firms' decisions to enter the export market are more linked to their ability to have access to governments' promotion policies than to their ex-ante productivity levels.

This discussion on the Korean results brings policy into the picture. It is quite clear that the link between international flows of knowledge and productivity is affected by many different factors, including policy. But to understand the role of policies we should briefly explore how the market for international flows of knowledge works. In the paper by Aw, Chung and Roberts the decision to export and implicitly the decision to learn are endogenous. We have not yet explored the decision-making process characterising other channels for acquiring knowledge. This is the object of the next section that focuses on imports of manufacturing machines and agricultural inputs..

4. Markets for Imported Technologies and the Role of Policy

The empirical literature discussed above implicitly assumes any country opening up to trade, even the most advanced one, will benefit from a wider variety of technologies and from technologies that are, at least in some fields, superior to those available in the domestic market. But the absorptive capacity of the liberalising country is important in determining the input mix or the technologies imported.

Let us focus on machines used in production, which represent the bulk of imported technologies. Machines for a given purpose may vary in terms of vintage and complexity. Choice of appropriate technology depends on the relative costs of the machines and on the costs of the factors of production required to use them. Also, as emphasised by various contributions, the availability in a given firm or country of the required skills is important in technology choice[22]. Skills, such as human capital or other technological capabilities, acquired through learning by doing or deliberate learning can be specific to a given technique. The larger such complementarities between the required skills and the new technology, the more costly the switch to an alternative technology.

The contribution by Barba Navaretti, Soloaga and Takacs to this issue looks at the choice between new and used equipment when there is labor saving technical progress and complementarity between technology and skills within the firm. Their analysis is based on a theoretical model of trade in used equipment among heterogeneous firms. If factor markets are imperfect, firms will face different factor prices even in the same country. Moreover, firms are allowed to differ in their technical and managerial skills. Heterogeneity among firms located in different countries provides the underlying motives for trade in new and used machines and allows the authors to generate predictions on the share of used equipment imported.

These predictions are tested by looking at US exports of metalworking machine tools to 23 countries. Machines can be classified according to their vintage (new or used) and their technical complexity[23]. The empirical analysis shows that the share of used equipment is larger the lower the level of development of the importing country. Moreover, for low income countries the share of used machines is larger the faster the technical change embodied in new machines compared to old ones and the more complex the skills required to use them efficiently. These results imply that

22 see Benhabib and Rustichini, 1991, Chari and Hopenhayn, 1991, Jovanovic and McDonald, 1993 and Jovanovic and Nyarko, 1995 and 1996

23 technical complexity is measured in terms of the minimum skills necessary to use the machines.

technological factors and skill constraints are as important as relative factor prices in determining the choice of the machine. The Barba Navaretti, Soloaga and Takacs results are thus consistent with contributions emphasizing that the ability of a given country to benefit from imported technologies depends on its absorptive capacity, i.e. on its ability to master quickly and efficiently new and more complex technologies[24].

These results also bear important policy implications. The first one is that policies to promote technological development should address the complementarities between different factors of production. In this framework, if there are explicit market failures of the education sector, fostering human capital should be a central goal of these policies. The second implication is that policies constraining access to foreign capital, which are often implemented, particularly in developing countries, are ineffective and damaging. In particular, quantitative restrictions on imports of used machines appear inappropriate. The aim of these policies is to foster technological upgrading. In fact, they deny firms access to more appropriate techniques and force them to buy machines that they may be unable to use efficiently.

This point is further pursued by David Guisselquist and Jean Marie Grether, in the last paper of this special issue. They analyse several case studies of technology transfer in agriculture. They show that attempts by governments to select the right technologies to be imported generate the perverse result of preventing local producers from getting access to the best technologies. They identify two stylised patterns in the institutional arrangements governing the international flows of new agricultural inputs. Most economies, particularly industrialised ones, rely on multiple channels, where farmers are exposed to new technologies because of the activities of different private and public actors. In contrast, many developing and transition countries centralise access to foreign technologies which are subject to the approval of government committees based on lengthy performance tests.

Relying on two case studies in Bangladesh and in Turkey, they show that deregulation leads to a significant increase in technology transfer, a fall in their prices, an increase in their use and in a dramatic increase in farmers' productivity. At least for seed technology, there are enough varieties available world-wide that these developing countries were able to import and effectively use a subset of them to increase productivity.

CONCLUSIONS

The empirical analysis in this volume of the micro link between trade and knowledge diffusion allows us to assess some of the key predictions derived in the theoretical literature on endogenous growth. Under different assumptions, this literature indicates that TFP is higher because trade provides access to a wider or more sophisticated range of technologies. The papers reviewed here find considerable evidence that imported technologies positively affect TFP in the importing countries, particularly when technologies are acquired by way of imports of intermediates (Keller; Gisselquist and Grether). It also provides some support for the view that exporting improves firm productivity (Aw, Chung and Roberts). The role of foreign direct investment is more mixed. Although the productivity of in the economy increases, foreign investments are found to generate intra-industry negative externalities on domestic producers (Djankov and Hoekman).

Skill and knowledge endowments along with relative costs are shown to affect the choice of imported technologies. Developing countries purchase older and simpler technologies and the more so the faster the rate of technological progress embodied in new machines (Barba Navaretti, Soloaga and Takacs).

These results bear important policy implications, especially for developing countries. The fact that imported technologies do not invariably bear a large learning potential does not support governments' attempts of limiting or guiding their selection. These policies have a negative effect

24 See for example Nelson and Pack, 1999 on the Asian Miracle.

on growth, because they force producers either to chose sophisticated technologies they are unable to use or they prevent them from getting the most appropriate and efficient technologies. The fundamental policy objective should be to allow as diverse a choice of technology inputs as possible since diverse inputs are likely to increase productivity. Attempts to centralise the decision-making and limit technology imports harms productivity (e.g., Gisselquist and Grether).

Moreover, policies aimed at promoting technological development and at strengthening the absorptive capacity of importing countries should address the relationship of complementarity between human and physical capital. If the development of human capital is constrained by market failures in the education sector technological policies should also directly target such constraints. Indeed, all the theoretical literature and the evidence reviewed support the conclusion that inflows of technology are more beneficial the more importers are able to master quickly new and complex knowledge[25].

The works discussed here can be extended in many directions. First, there is a clear need to foster our understanding of learning processes at the micro level. For this purpose it is necessary to define more accurate measures of technological flows and to extend panel data collection at the firm level. Second, the literature on North South technological flows generally assumes that the South purely imitates Northern technologies. There is now growing evidence of relatively dynamic R&D activity based in many developing countries[26]. A further development of Southern technologies could change the pattern of international knowledge flows. These developments should be studied more accurately. Finally, innovation in information technology makes it even more difficult to observe empirically patterns of knowledge diffusion. Thus, empirical analysts searching for international technological flows should be aware that the hidden factor of production they are searching for is every day becoming more and more concealed.

REFERENCES

Aitken, B. and A.Harrison, 1997, ‘Do Domestic Firms Benefit from Direct Foreign Investments?’, Columbia University, mimeo

Aghion, P. and P. Howitt, 1992, ‘A model of growth through Creative Distruction’, *Econometrica*, 60, pp. 323-351

Aghion, P. and P. Howitt, 1998, ‘*Endogenous Growth Theory*’, Cambridge, Ma., MIT Press

Aitken, B., G. Hanson and A. Harrison, 1997, ‘Spillovers Foreign Investments and Export behaviour’, *Journal of International Economics,* 43, 103-132

Barba Navaretti, G. and C. Carraro, 1998 ‘From Learning to Partnership: Multinational R&D Cooperation in Developing Countries’, *Economics of Innovation and New technologies*

Benhabib, Jesse and Aldo Rustichini, 1991, ‘Vintage Capital Investment and Growth’, *Journal of Economic Theory*, 55, pp. 323-339

Benkard, Lanier. 1997. “Learning and Forgetting: The Dynamics of Aircraft Production,” Yale University, processed.

25 Neary, 1999 reviews research on R&D policy in developing countries and concludes that raising the general level of education is likely to have a more important impoct than targeted policies like R&D subsidies

26 See Barba Navaretti and Carraro, 1998

Bernard, A. and J. B. Jensen, 1999, 'Exceptional Exporter Performance: Cause, Effect or Both?', *Journal of International Economics,* 47, 1-25

Blomstrom, M. and H. Persson, 1983, 'Foreign Investments and Spillover Efficiency in an underdeveloped Economy: Evidence from the mexican Manufacturing Industry', *World Development,* vol 11, 493-501

Blomstrom, M. and A. Kokko, 1998, 'Foreign Investment as a Vehicle for International Technology Transfer', in G.Barba Navaretti, P.Dasgupta, K.G. Maler and D.Siniscalco (eds) *'Creation and Transfer of Knowledge: Institutions and Incentives',* Springer Verlag, Heidelberg and Berlin

Caves, richard, 1974, 'Multinational Firms, Competition and Productivity in Host Country Markets', *Economica,* vol. 41 pp. 176-193

Caves, Richard, 1996 *'Multinational Enterprise and Economic Analysis',* London, Cambridge University Press, second edition

Chari, V.V. and H. Hopenhayn, 1991, 'Vintage Human Capital, Growth and the Diffusion of New Technology', *Journal of Political Economy*, vol. 99, n.6, pp1142-1965

Clerides, S, S. Lach, and J.Tybout, 1998'Is Learning by exporting Important? Micro-Dynamic evidence from Colombia, Mexico and Morocco', *Quarterly Journal of Economics*

Coe, D. and E. Helpman, 1995, 'International R&D Spillovers', *European Economic Review, vol.39, pp. 859-887*

Coe, D., E. Helpman and W. Hoffmaister, 1997, 'North South R&D Spillovers', *The Economic Journal,* vol. 107, January, pp 134-149

Coe, D. and W. Hoffmaister, 1999, 'Are There International R&D Spillovers Among Randomly Matched Trade Pairs?' IMF Working Papers, 99/18

Dixit, A. and J.E. Stiglitz, 1977 'Monopolistic Competition and Optimum product Diversity', 1977, *American Economic Review,* 67, pp.297-308

Ethier, W., '1982, 'National and International Returns to Scale in the Modern Theory of International Trade', *American economic Review,* 72, pp. 389-405

Globerman, S, 1979, 'Foreign Direct Investments and Spillover Efficiency Benefits in Canadian Manufacturing Industries', *Canadian Journal of economics, vol 12, pp.42-56*

Grossman, G., and E., Helpman, 1991 *Innovation and Growth in the Global Economy,* Cambridge Mass., MIT Press

Grossman, G. and E., Helpman, 1995, 'Technology and Trade', in G. Grossman and K. Rogoff, (eds.) *Handbook of International Economics*, vol 3, Amsterdam, Elsevier

Haddad, M. and A. Harrison, 'Are there Positive Spillovers from Direct Foreign Investments?',*Journal of Development Economics,* 42, pp.51-74

Hakura, D. and F.Jaumotte, 1999, 'The Role of Inter- and Intraindustry Trade in Technology Diffusion', IMF Working Paper n.99/58

Haddad, M and A. Harrison, 1993, 'Are there Positive Spillovers from Direct foreign Investments?? Evidence from Panel Data from Morocco', *Journal of Development economics,* 42: 51-74

Harrison, A., 1996, 'Determinants and Effects of Direct Foreign Investment in Cote d'Ivoire, Morocco and venezuela', in M. Roberts and J. Tybout, eds., *Industrial Evolution in Developing Countries*', World Bank and Oxford University Press, New York

Jaffe, A., R.Henderson and M. Trajtenberg, 1993, 'Geographic localization of Knowledge Spillovers as Evidenced by Patent Citations', *Quarterly Journal of Economics,* 1993

Jovanovic Boyan and Glenn MacDonald, 1993, 'Competitive Diffusion, NBER Working Paper n.4463

Jovanovic, Boyan and Yaw Nyarko, 1995, 'The Transfer of Human Capital', *Journal of Economic Dynamics and Control*', 19, June, pp. 1033-1064.

Jovanovic, Boyan and Yaw Nyarko, 1998, How does Productivity Depends on Past R&D?', in G.Barba Navaretti, P.Dasgupta, K.G. Maler and D.Siniscalco (eds) *'Creation and Transfer of Knowledge: Institutions and Incentives',* Springer Verlag, Heidelberg and Berlin

Krugman, Paul. 1987. "The Narrow Moving Band, The Dutch Disease, and the Consequences of Mrs. Thatcher: Notes on Trade in the Presence of Scale Economies," *Journal of Development Economics* 27: 41-55.

Lall, S., 1987, '*Learning to Industrialise. The Acquisition of technological Capabilities in India*', Macmillan, London

Lall, S, 1999, 'Foreign Direct Investment, Technology and Competitiveness: Trends and Challenges', background paper for UNCTAD, World Investment Report, 1999

Lucas, Robert. 1993. "Making a Miracle," *Econometrica* 61 (2): 251-272.

______. 1988. "On the Mechanics of Economic Development," *Journal of Monetary Economics* 22 (1): 3-42.

Malerba, Franco. 1992. "Learning by Firms and Incremental Technical Change," *Economic Journal* 102 (413): 845-859.

Markusen, James, 1995, 'The Boundaries of Multinational Enterprises and the Theory of International Trade', *Journal of Economic Perspectives,* 9, pp.169-189

Nelson R and H. Pack, 1999, 'The Asian Miracle and Modern Growth Theory', *The Economic Journal*

Pack, H. , 1992, 'Technology Gaps Between Industrial and Developing Countries: Are there Dividends for Late-comers?', *Proceedings of the World bank Annual Conference on Development economics, Supplement to the World Bank Economic Review and the World Bank Research Observer,* World bank, Washington DC, pp. 283-302

Neary, P., J., 1999, ‘R&D in Developing Countries: What Should Governments do?’, University College Dublin, mimeo

Rodriguez-Clare, A, 1997. The Neoclassical Revival of Growth Economics: Has it Gone Too Far?” *Brookings 1997 Macroeconomics Annual*.

Rivera-Batiz, L. and P., M., Romer, 1991, 'Economic Integration and Endogenous Growth *Quarterly Journal of Economics,* 106(2), pp 531-555

Romer, P.M., 1990, 'Endogenous Technological Change, *Journal of Political Economy*, 98 5 part 2, pp71-102

Saggi, K, 1999, ‘Trade, Foreign Direct Investments and International Technology Transfer’, World Bank, mimeo

Seagerstorm, P.s, T.C.A. Anant and E Dinopulos, 1990, ‘A Schumpeterian Model of Product Life Cycle’, *American economic review,* 80, pp. 1077-1091

Stokey, Nancy. 1988. "Learning by Doing and the Introduction of New Goods," *Journal of Political Economy* 96: 701-717.

______. 1991. "Human Capital, Product Quality and Growth," *Quarterly Journal of Economics*: 587-616.

Unctad, 1997, ‘*World Investment Report: Transnational Corporations, Market Structure and Competition Policy’,* United Nations, New York

World Bank, 1999, '*Knowledge for Development*' World Development Report, World Bank and Oxford University Press

Young, Alwyn. 1991. “Learning by Doing and the Dynamic Effects of International Trade,” *Quarterly Journal of Economics*: 369-405.