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The globalisation of technology and its implications for developing countries
Windows of opportunity or further burden?

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Abstract

On the basis of a categorisation of ways in which the generated knowledge is transmitted, this paper explores the impact of the different forms of the globalisation of technology on developing countries. Through travelling, media, scientific and technical workshops, Internet and many other communication channels, globalisation allows the transmission of knowledge at a much greater pace than in the past. However, this does not automatically imply that developing countries succeed to benefit from technological advances. On the contrary, this will strongly rely on the nature of the technology and of the policies implemented in both advanced and developing countries.

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1. Introduction

The international transmission of know-how, knowledge and technological expertise is growing and it is increasingly important in the world economy [1]. The weight of science-

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based commodities is constantly increasing in world trade [2], foreign direct investment (FDI) by transnational corporations (TNCs) is an important vehicle for the transmission of innovation across the world [3], transborder scientific and technological cooperation is absorbing more energies and resources of governments and firms [4]. New opportunities are now opening to benefit from the available stock of knowledge. But how important are they for less developed countries (LDCs)? Are they participating in these flows or are they rather staying aside and observing them? How are their technological capabilities affected by the considerable increase in the flows of knowledge?

The aim of the paper is to:

- Define the globalisation of technology with the use of a new categorisation.
- Report some evidence on the degree of developing countries' participation in the globalisation of technology.
- Discuss the relevance and impact of the globalisation of technology on developing countries, and its implication for their development strategies and policies.

The specific form and extent of technology globalisation for developing countries bears important consequences for their government action, and implies an especially active attitude towards innovation policies. It will in fact be argued that the globalisation of technology offers new opportunities for development, but that they are by no means available without deliberate effort to absorb innovation through endogenous learning.

This paper is organised as follows. The next section reassesses the concept of technology which informs this paper, since we believe that this is particularly important to design appropriate strategies and policies. Section 3 reports a taxonomy on the different forms that the globalisation of technology can take; this will help us measure the significance of globalisation and assess the various strategies undertaken by governments and firms. Section 4 documents to what extent developing countries are taking part in the globalisation of technology; although the evidence available is still unsatisfactory, it clearly emerges that the bulk of technological activities is produced in and exchanged among the most advanced countries. The Section 6 discusses the advantages and the disadvantages of the strategies available to developing countries to bridge their technology gap, and to integrate themselves among the more innovative and dynamic nations.

2. Lessons learnt on the nature of technology

Economists have often studied technology with the tools of analysis of competitive markets. Thus, if technology is studied like any other commodity, and if markets were freely working and perfect competition prevailed, then no problem of technology transfer would pose. Technology (from whatever source) would be easily and instantaneously transferred and utilised. The efficiency of its use would only be a matter of ensuring the conditions for efficient resource allocation in the context of exogenously determined technological alternatives. Technology policy would only consist of government sponsorship of institutes that collect, process and disseminate technical information, justified as a provision of public goods. This theory descends from two assumptions: (i) technology consists simply of a set of techniques wholly described by their 'blueprint'; (ii) all techniques are created in the developed countries, from which they flow at no or low costs to developing countries (for a recent reaffirmation of this old belief, see Ref. [5]).

However, several authors recognised, already a few decades ago, the special features of technology and technological change, leading to a perception of technology in more complex terms (see Nelson [55]). Thus, first of all, no existing technique is completely expressed by the sum and combination of their material inputs and the codified information about it. In fact, much of the knowledge on how to perform elementary processes and on how to combine them efficiently is tacit, not easily embodied, nor codifiable or readily transferable, and 'a firm will not be able to know with certainty all the things it can do, and certainly will not be able to articulate explicitly how it does what it does' (Nelson [6], p. 84).

This means that technology is not simply a set of blueprints, or of instructions, that if followed exactly will always produce the same outcome. Although two producers in the same circumstances may use identical material inputs with equal information available, they may nonetheless employ two really distinct techniques due to their different understanding of the tacit elements. Thus, techniques are sensitive to specific physical as well social circumstances (Evenson and Westphal [7], p. 2212).

Moreover, technology is not instantaneously and costlessly accessible to any firm: a firm does not simply select the preferred option from the freely available international technology shelf, as there may be obstacles and difficulties in obtaining the desired technology. Simply choosing and acquiring a technique does not imply operating it efficiently ('at best practice'). Individual firms do not have a complete knowledge of all the possible technological alternatives, their implications and the skills and information they require. The individual firm does not know the entire production curve, illustrating an infinite number of alternatives, as neo-classical theory assumes. To the extent technologies are tacit, firm production sets are fuzzy around the edges (Nelson [6], p. 84).

Understanding technology in these more complex and realistic terms implies that tangible and intangible investments in technology are required whenever technology is newly applied. This applies to domestic as well as foreign imported technologies. Each firm has to exert considerable absorptive efforts to learn the tacit elements of technology and gain adequate mastery. This is at the opposite extreme from the neo-classical premise that technology, as well as productive inputs and outputs, is perfectly known. This knowledge is not instantaneously and costlessly available to all firms, and technology transfer poses substantial problems of adaptation and absorption that are related to investments in technological capability, i.e. the complex array of skills, technological knowledge, organisational structures, required to operate a technology efficiently and accomplish any process of technological change.[2] This dynamic technological effort implies a process of learning that is qualitatively

[2] References on the theory of technological capabilities include Bell and Pavitt [51], Enos [9], Fransman and King [52], Katz [12], Lall [13] and Pack and Westphal [53].

different from the traditional ‘learning by doing’, as it involves an active attitude. Learning may be pursued in a variety of ways [8] and the passive ‘learning from operating’ is only one possibility.

A powerful way of learning is by training within producing firms. This has the disadvantage that training will probably stay at a level below what would be socially optimal, because of the well-known problem of incomplete appropriability of its results, but in-firm training will be more appropriate as the firm will provide exactly the kind and quantity of training necessary for the absorption and advancement of technology (Enos [9], p. 80). Furthermore, learning itself has to be learnt, as it is a highly specialised process, that involves the organisation of the accumulation of technical knowledge [10].

In addition, even if the need for learning efforts is acknowledged, investing in learning does not ensure success. This is due to the stochastic nature of the learning process, which is influenced by the external environment and by firm’s actions, and results from dependence on historical circumstances, entrepreneurial skills and luck. Therefore, different firms may reach persistently different levels of efficiency and dynamism also in competitive markets [11].

Within this broader context, technology transfer becomes an important issue that has to be assessed jointly with a country’s capability to make use of technology, absorb it and adapt it to local conditions. In other words, technology transfer links foreign technology access and acquisition to its efficient use for economic development, and to the catching up of the relatively technologically backward countries [7].

Thus, the access to and acquisition of foreign advanced technology, by itself, is not sufficient to ensure local technological and industrial development. Several other elements are needed. An additional central component of a country’s industrial development policy strategy is technological effort oriented to the absorption, adaptation, mastery and improvement of technology. This itself implies a continuous process of technological change [12,13,54,62].

Once this notion of technology is accepted, it is much easier to understand that the globalisation processes have distinctive features in the technology domain, and that there is no reason to assume that globalisation will provide benefits to all regions and agents. In particular, it emerges that globalisation changed the transmission of know-how in the following ways:

- The codified component of knowledge can be transferred at low or negligible costs from one part to another part of the world. This is, however, not necessarily good news for developing countries since in order to benefit from codified knowledge, the receiving agent should already know the code and have the capabilities to use it effectively. And codes are increasing in complexity along with the increase in importance of codified knowledge.
- The tacit component of knowledge continues to be less mobile and transferable, since it still requires important face-to-face interactions. There is abundant evidence that, in spite of globalisation, the generation of knowledge in specific fields tend to concentrate in “hubs” where competencies agglomerate [14,15].

- The core of innovating firms is moving from trading embodied innovations to disembodied innovation. As shown by Naomi Klein [16], large corporations with managerial, financial and technological advantages tend to profit from their ideas, trademarks, expertise and technological innovations, while contracting out the production. This has substantial implications for the generation and transmission of know-how, which tends to become much more dependent on intellectual property rights (IPR). In turn, it is creating a new international division of labour where "wet-ware" and "soft-ware" are generated in the North, and "hard-ware" is localised in the South.

The next section presents a taxonomy of the globalisation of technology which may help identify the various forms to exploit and acquire know-how.

3. A taxonomy of the globalisation of technology

In the last few years, too many heterogeneous phenomena have been lumped together under the label of 'globalisation of technology', and the concept has thus lost much of its significance. We thus attempted [17,18] to find our way in such labyrinth by identifying three main categories:

1. The international *exploitation* of nationally produced technology;
2. The global *generation* of innovation;
3. Global technological *collaborations*.

The aim of this taxonomy is to classify individual innovations according to the ways in which they are produced, exploited and diffused internationally. Innovations are therefore classified according to the method in which they are generated. Both at single enterprise and at national levels, the categories are complementary, not alternative. Enterprises, especially large ones, may generate innovations following all the three procedures described. From a historical point of view, these categories emerged in three different stages, even though the second and the third added to, rather than substituted, the oldest one. The categories of this taxonomy and the main forms through which the three processes manifest themselves are shown in Table 1 (for an empirical assessment in advanced countries, see Ref. [18]).

3.1. The international exploitation of technology produced on a national basis

The first category includes the attempts of innovators to obtain economic advantages by exploiting their technological competencies in markets other than the domestic one. We have preferred to label this category 'international' as opposed to 'global', since the players that introduce innovations preserve their own national identity, even when such innovations are diffused and marketed in more than one country. Firms may opt for a variety of strategies in order to obtain economic returns from their innovations in foreign markets.

Table 1
A taxonomy of the globalisation of technology

Categories	Actors	Forms
International *exploitation* of nationally produced innovations	Profit-seeking firms and individuals	• Exports of innovative goods. • Sale of licences and patents. • Foreign production of innovative goods internally generated.
Global *generation* of innovations	Multinational firms	• R&D and innovative activities both in the home and the host countries. • Acquisitions of existing R&D laboratories or greenfield R&D investment in host countries.
Global techno-scientific *collaborations*	Universities and public research centers	• Joint scientific projects and R&D networks. • Scientific exchanges, sabbatical years. • International flows of students.
	National and multinational firms	• Joint ventures for specific innovative projects. • Productive agreements with exchange of technical information and/or equipment.

Source: adapted from Archibugi and Michie [17].

The oldest form which firms have used to profit from their innovations in overseas markets is to trade products with a technology-based competitive advantage. New products and processes have often been exempted from trade restrictions since the importing countries were not able to generate competitive domestic alternatives, or to device timely restrictions to trade. It is however well known that exporting technology-intensive products provides an advantage to the exporting countries (for example, in terms of more stable prices, higher rents and profit margins, and positive and dynamic externalities), and that in turn the importing countries increase their know-how dependence unless they are able to bridge the gap in competencies.

Exports are not the only form to exploit firms' technological advantage in overseas markets. Another way is to transfer their know-how to foreign firms, for example, by selling licences and patents. This form of technology transfer would however require that the host country firms already have the capital equipment and the capabilities to exploit new ideas and devices into production. It is likely that in the long run the importing country will be able to move upstream in the value-added chain, and to become able to generate autonomously at least part of the know-how relevant for production.

There is a third important form of exploiting the innovation generated at home in overseas markets: to install FDI productive facilities in host countries and produce in loco new products and processes. Of course, we consider here only production plants in host countries which do not contribute significantly to the generation of the know-how, but that simply replicate and produce already designed artefacts. If, on the contrary, the host country plants significantly contribute to the design of the products and processes, we move from the first to the second category of this taxonomy.

3.2. The global generation of innovations

The global generation of innovations includes innovations generated by single proprietors on a global scale. Only innovations produced by multinational enterprises fit into this category since it requires the existence of international but intrafirm R&D labs and technical centers. The authentic global generation of innovations requires organisational and administrative skills that only firms with specific infrastructure and a certain minimum size can attain. This can be achieved both through the acquisition of existing laboratories or with greenfield investments in host countries.

The determinants and impact of TNCs have been widely studied over the last years (for reviews, see Refs. [19,20]). Bartlett and Ghoshal [21] have singled out three main strategies of TNCs.

3.2.1. Center-for-global

This is the traditional 'octopus' view of the TNC: a single 'brain' located within the company headquarters concentrates the strategic resources: top management, planning, and the technological expertise. The 'brain' distributes impulses to the 'tentacles' (that is, the subsidiaries) scattered across host countries. Even when some overseas R&D are undertaken, this basically focuses on adapting products to the needs of the local users.

3.2.2. Local-for-local

Each subsidiary develops its own technological know-how to serve local needs. The interactions among subsidiaries are, at least from the viewpoint of developing technological innovations, rather weak. On the contrary, subsidiaries are integrated into the local fabric. This may occur with conglomerate firms, but also in the case of TNCs which follow a strategy of technological diversification through tapping into the competence of indigenous firms.

3.2.3. Local-for-global

This is the case of TNCs that, rather than concentrating their technological activities in the home country, distribute R&D and expertise in a variety of host locations. This allows the company to develop each part of the innovative process in the most suitable environment: semiconductors in Silicon Valley, automobile components in Turin, software in India. The effectiveness of such a strategy relies on intense intrafirm information flows.

3.3. Global technological collaborations

In recent times, a third type of globalisation of innovative activities has made a forceful entry into the scene. This, in some ways, is intermediate to the two preceding categories.

Technological collaborations occur when two different firms decide to establish joint ventures with the aim of developing technical knowledge and/or products. Three conditions need to be respected: (i) the joint venture should be something more than an occasional and informal collaboration; (ii) firms preserve their ownership; (iii) the bulk of the collaboration is related to sharing know-how and/or the generation of new products and processes (see Mowery [22], p. 347).

We have witnessed an increasing number of agreements between firms for the joint development of specific technological discoveries [23,24]. Such collaborations often take place among firms of the same country, but in many cases they involve firms located in two or more countries, thus emerging as authentically global ventures.

These forms of collaboration for technological advances have promoted a variety of mechanisms for the division of costs and the exploitation of results. In a way, the need to reduce the costs of innovation—and to cope with its increasing complexity—has created new industrial organisation forms and new ownership structures, which today are expanding beyond the simple technological sphere.

It was not the private sector that discovered this form of knowledge transmission. The academic world has always had a transnational spectrum of action: knowledge is traditionally transmitted from one scholar to another and thus disseminated without always requiring pecuniary compensation. Since the involvement of the academic community into the business world is more and more demanded, the forms of diffusion of know-how within Universities and other public research centers have become of increasing importance for industrial development.

4. Evidence on developing countries' involvement in the globalisation of technology

The forms of the globalisation of technology singled out in the section above have significant implications for the national economies. Each of them will have a different impact on learning and, eventually, on local economic development. This section, on the basis of the available evidence, documents the involvement of LDCs in each of the three categories discussed above.

First of all, it is important to stress that LDCs' generation of new technologies and innovations is still negligible. The production of knowledge is heavily concentrated in the Triad countries, as shown by a variety of converging indicators of scientific and technological activities. This especially applies to the more formalised forms of knowledge creation. Although data are not always comparable since countries collect them according to different criteria, the evidence is so strong that it does not depend on the indicators selected. Some evidence based on bibliometric indicators and patents granted in the USA are reported in Table 2.

Scientific papers appeared in the journals monitored by the Institute for Scientific Information show that developed countries concentrate more than 84% of the world scientific production. Developing countries have only marginally increased their participation to the scientific community. Scientific articles are classified by country according to the institutions.

Table 2
On the generation of innovations in developed and developing countries

	Scientific papers		Average annual growth[a] rate (%)	Articles per million population		U.S. patents granted		Average annual growth[b] rate (%)	U.S. patents per million population	
	1986–1988 (%)	1995–1997 (%)		1986	2000	1986 (%)	2000 (%)		1986	2000
Developed countries[c]	84.3	84.5	1.4	419.8	472.5	98.7	93.9	12.4	75.9	160.4
Eastern Europe	9.3	6.7	2.2	117.2	94.0	0.5	0.3	0.6	1.0	1.0
East Asian NICs[d]	0.6	2.2	37.9	33.0	145.6	0.4	5.3	312.1	3.6	105.5
Latin America	1.2	1.8	7.2	11.0	18.1	0.2	0.2	21.1	0.2	0.7
Other Asia and Africa	4.6	4.8	2.0	5.0	6.0	0.2	0.3	24.7	0.04	0.1
Total	100.0	100.0	1.4	75.7	85.0	100.0	100.0	13.6	11.7	26.0

Source: National Science Foundation [25,30,49].

[a] Annual growth from 1986–1988 to 1995–1997.

[b] Annual growth from 1996 to 2000.

[c] OECD (22) plus Israel.

[d] Taiwan, South Korea, Hong Kong, Singapore.

Articles authored by scientists born in developing countries but working in developed countries will be classified in the latter group and vice versa. The number of scientific papers per million population shows much more clearly how the generation of new knowledge is concentrated in the North and how small is the participation of the South. There is a notable exception, represented by the East Asian Tigers (South Korea, Taiwan, Hong Kong and Singapore). These countries have managed to generate a scientific output comparable to some OECD countries.

Table 2 also reports data on patents granted in the US. We have chosen the US since it is the largest market of the world, and inventions and innovations of a significant nature are very likely patented there. Patents are assigned to countries on the ground of the home address of the inventor. As in the case of scientific articles, data do not take into account the nationality of the inventor, but his/her country of residence only. The data show an even greater concentration in advanced countries, which in the year 2000 totaled as much as 94% of patents. Although the position of developing countries has improved (passing from around 1% in 1986 to nearly 6% in 2000), it clearly emerges that legally protected inventions and innovations are still mainly generated in the North.

Again, it is remarkable to notice that only a minuscule number of developing countries—again the East Asian tigers—have managed to bridge the gap. These countries concentrate a much higher number of patents than their share of scientific publications, further revealing the technical and industrial orientation of their innovative activities. If we exclude the East Asian tigers, it is quite clear that developing countries are not bridging the scientific and technological gap with developed countries.

One crucial issue is to identify what is the contribution of talents coming from developing countries to the scientific and technological activities developed in the North. As already mentioned, statistics on scientific publications and patents do not allow to further disaggregate between the contribution provided by nationally born and foreign-born scientists and engineers. However, some data are available for the United States. In 1999, as much as 27% of the doctorate holders in science and engineering in the United States were foreign-born, with peaks of 46% and 45% in Computer Sciences and Engineering ([25], pp. 3–29). The USA long-term attraction of intellectual capital from all over the world is continuing. Much of this labour force was trained in the USA, especially at the doctoral level.

Certainly, this labour force would have provided a larger contribution to the knowledge-base of their country if they had been allowed to have professional opportunities at home. However, many of these scientists and engineers lacked opportunities in their nations. In many developing countries, the obstacle is not the lack of individual scientific and technological talents, but the lack of appropriate institutions and infrastructures.

On the other hand, we cannot argue that this brain drain from developing to developed countries (and most notably to the United States) has produced only disadvantages for developing countries. In fact, foreign-born scientists working in North American institutions often continue to have a preferential tie with their own country and provide the link for upgrading the social, scientific and technological capabilities at home. The countries which experienced the most spectacular growth in their Science and Engineering (S&E) capabilities are also those with the higher number—in proportion—of scientists and engineers working abroad. There are 37,900 S&E doctorate holders born in China and 30,100 born in India in the United States. However, the number of S&E doctorate holders working in the United States born in small countries such as Korea and Taiwan is, in proportion, much higher and equal to 4500 and 10,900, respectively ([25], Appendix Table 3-52). The evidence reported in the following parts of this paper will refer to countries' institutions and countries of residence of scientists and engineers and not to their country of origin.

The discussion above on the nature of technology has pointed out that R&D and formalised knowledge-generating institutions do not represent the only component of technological change. We are well aware that papers and patents reflect mainly the formalised component of scientific and technological knowledge. The making of national technological capabilities also requires the ability to diffuse, assimilate and imitate the knowledge generated in other countries. Other indicators of the available skills, such as the education level, show that the gap between developed and developing countries is somehow smaller (see Ref. [26], Table A2.2; see also Ref. [27]). But, above all, they show the existence of great differences *within* developing countries. It is certainly noteworthy that countries having better skills and education indicators also report a remarkable and growing share of R&D and patents.

4.1. Evidence on the international exploitation of technology produced on a national basis

Concerning trade in technology-intensive products, received theory would lead us to expect an international division of labour where developing countries export raw materials and low skills products, and rely on advanced countries to import high-tech products.

Table 3 shows export growth and shares for industrial and developing countries. Developing countries have uniformly higher growth rates for all manufactures, expected given their smaller starting base. However, what is less expected is that their lead *rises with technological complexity*, to reach its peak for high-technology exports ([28], Chapter 2, [57]). Are the data a statistical artefact, reflecting the relocation by TNCs of simple processes in high technology industries? Or, do they reflect genuine local capabilities, which implies considerable skill formation and technical effort? The explanation is a mixture.

Table 3
Growth and shares of manufactured and high-technology exports

	Growth rates 1980–97 (% p.a.)				Developing country shares (%)		
	World	Industrialised countries	Developing countries	Difference: developing – industrialised	1985	1995	Change in share
All exports	7.0	6.5	8.5	2.0	25.0	26.9	1.9
Total manufactures	7.9	6.8	13.5	6.5	14.7	24.0	9.3
High-technology exports	11.4	9.8	21.2	11.4	10.2	27.1	16.9
Electronic	13.0	10.9	21.7	10.8	13.4	33.1	19.7
Other High Tech	8.4	7.9	17.3	9.4	4.3	8.3	4.0

Source: adapted from Lall and Pietrobelli [28].

Industrialised countries include Israel and Central and Eastern Europe. Developing countries include the new NICs (Indonesia, Malaysia, Philippines, Thailand), Turkey and South Africa.

A significant part of the growth of high-tech exports reflects the spread of low technology assembly. At the same time, such assembly in the developing world is highly concentrated, so that the figures reflect the success of a few countries. Among these, there are two groups. First are those that depend almost wholly on TNCs to export sophisticated products as part of integrated global production; these include Malaysia, Thailand, Philippines, Mexico and China. Second, there are a few that have built up competitive capabilities in domestic enterprises and spawned their own international networks, led by Taiwan and South Korea [29]. These countries have started as imitators of Western technological capabilities, but certainly they cannot be regarded any longer simply so. In 1999 they registered, 3693 and 3562 patents, respectively, in the United States ([30], Appendix Table 6-12), becoming the fifth and seventh countries in the world in terms of their patent production. These data alone prove that they trade products that embody a strong endogenous technological component.

However, the spread of high-technology manufactures and exports to the developing world is clearly confined to very few countries, as Table 4 confirms, with the bulk of South Asian and African countries still excluded by such transformation.

4.2. Evidence on the global generation of innovations

TNCs have a limited propensity to base their R&D and innovative activities in host countries. The quantitative evidence based on R&D and patents [18] indicates that not more than 10% of TNCs' technological effort is carried out in host countries. And not more than 1% of the technological activities generated by TNCs of the North comes from

Table 4
Shares of regions in developing world exports: manufactures and high-tech manufactures

	1985	1990	1995
Total manufactured exports			
East Asia	66.5	74.0	75.3
South Asia	5.2	5.0	3.7
Latin America and the Caribbean	19.4	13.9	15.2
North Africa and Middle East	4.9	4.6	3.6
All Sub-Saharan Africa	4.0	2.5	2.2
Sub-Saharan Africa less South Africa	1.2	0.8	0.5
High-technology exports			
East Asia	90.1	94.2	90.5
South Asia	1.2	1.1	0.6
Latin America and the Caribbean	5.8	4.1	8.0
North Africa and Middle East	0.7	0.3	0.6
All Sub-Saharan Africa	2.2	0.4	0.3
Sub-Saharan Africa less South Africa	0.2	0.1	0.0

Source: adapted from Lall and Pietrobelli [28].

North Africa and the Middle East includes Turkey but excludes Israel, which is counted as part of the industrial world.

subsidiaries based in the South ([31], p. 97). In other words, developing countries collect the crumbs of the transnationals' innovative activities.

It is rather clear that TNCs do not find it convenient to locate technological activities in developing countries, in spite of the significant wage differentials. But although these cases are sporadic, it is insightful to focus on them, since they might illustrate what the conditions are for a successful strategy. In this case, some significant lessons can be gathered not only by the East Asian NICs, but also by the Indian experience [32–34]. Some leading TNCs in the field of information and communications technologies (including Texas Instruments and Microsoft) have found it convenient to start up R&D facilities in India. This has been facilitated not only by wage differentials, but also by: (i) the presence of good Universities, (ii) the (related) availability of qualified engineers and (iii) the existence of a fabric of related activities.

It is of course very difficult to draw causal links among the various factors which have facilitated the birth of knowledge-intensive industrial clusters in developing countries. In many cases, the presence of an important TNC active in a new field might generate externalities and induce the public sector to give prominence to associated Faculties and other public research centers. Take the example of Bangalore, where Texas Instruments opened already in 1985 an R&D center specialised in design circuits, which now employs 500 engineers. In the absence of a counterfactual, it is difficult to assess if a hub of excellence would have existed in the area without this initial decision. Still, if Bangalore is today an area where many firms are active in Information and Communication Technologies (ICTs) and software, this is also because there have been active public polices, and mainly those that have made qualified engineers available, to assist and reinforce the specialisation in the field.

We may ask if and when firms in developing countries may find it convenient to locate their R&D and innovative activities in developed nations. There is some evidence that large companies from LDCs find it useful to own selected establishments in developed countries since these are finalised to assimilate best-practice techniques that they then transfer also to domestic production. Thus, data on the United States show that South Korea has a number of establishments in the country larger than advanced countries such as the Netherlands, Canada and Switzerland ([35], p. 308). Not surprisingly, this investment is concentrated in computer hardware, telecommunications and electronic components, where Korea already enjoys a strong specialisation at home. This supports the view that technology-intensive FDI by companies based in developing countries, if any, is mainly meant to reinforce the expertise already existing at home.

4.3. Evidence on global technological and scientific collaborations

Technology agreements have become an important and growing channel to transfer know-how across countries. Quantitative information reports that strategic technological partnerships among firms have increased from 212 in 1980 to 574 in 2000 ([25], Appendix Table 4-39). A substantial share of these agreements involves firms based in different countries. How are developing countries exploiting this source of knowledge transmission? Narula and

Sadowski [36] report some data on the total number of strategic technology partnering (STP). More than 93% of the recorded STP in 1987–1994 involve countries based in the developed world only. The share of agreements in developing countries is negligible, and equal to less than 7%. Moreover, 91% of the recorded STP are North–South: firms in developing countries undertake agreements mainly with firms in developed countries (Table 5). Pietrobelli [37] reports similar evidence.

The countries more involved in these collaborations are the East Asian NICs, which alone absorb more than half of the agreements (even if their share has slightly declined between 1980–1987 and 1987–1994). Equally important and dramatically increasing is the participation of Eastern Europe, which has nearly tripled its share of agreements after the fall of the Berlin wall. Africa and Latin America record a negligible and decreasing participation in STP.

It is certainly no surprise that, given the small amount of resources devoted to technology, developing countries are also marginal in technological collaboration. It is, moreover, a worrying signal that the few collaborations that involve developing countries are likely to be North–South rather than South–South. This also questions the nature of the technological activities carried out. There are some research agendas which are specific to developing countries and that are likely to be dismissed by developed countries.

A slightly different outcome emerges from global collaborations in science rather than in technology. The share of internationally co-authored scientific papers provides a way to measure them: they have increased from 7.8% of the total in 1986–1988 to 14.8% in 1995–1997. As expected, the distribution of internationally co-authored papers follows closely the distribution of published papers reported in Table 2 (since internationally co-authored papers are a subset of scientific papers). The share of internationally co-authored papers by developing countries has increased substantially, reaching nearly 20% of the total. By looking at the distribution among countries, it emerges that other parts of the world, and not only the East Asian tigers, are involved in scientific collaborations (Table 6).

Table 5
Newly established strategic technology alliances in developed and developing countries, 1980–1994

	1980–1987	1987–1994	Annual average growth rate (%)
Percentage of STP in developed countries	94.5	93.1	4.2
Percentage of STP in developing countries	5.49	6.89	5.0
of which			
Eastern Europe	0.7	2.5	n.a.
East Asian NICs	3.5	3.8	n.a.
Latin America	0.3	0.2	n.a.
Other Asia and Africa	0.9	0.3	n.a.
Percentage of STP of developing countries involving firms in developed countries	90.29	92.19	n.a.

STP: strategic technology partnering.
Source: elaboration on Narula and Sadowski [36].

Table 6
Co-authored scientific papers in developed and developing countries, 1986–1997

	Percentage scientific papers co-authored		Annual average growth rate (%)
	1986–1988	1995–1997	
Developed countries[a]	84.2	80.8	12.2
Developing countries	15.8	19.2	18.5
of which			
Eastern Europe	5.7	8.9	26.9
East Asia[b]	0.9	2.1	44.7
Latin America	2.5	2.9	17.4
Other Asia and Africa	6.7	5.3	8.3
Total co-authored scientific papers	100.0	100.0	13.2

Source: elaboration on National Science Foundation [30].
[a] OECD (22) plus Israel.
[b] Taiwan, South Korea, Hong Kong, Singapore.

The UNDP ([26], p. 98) reports some significant cases of research activities which have been generated in the South and for the South: Thailand's drug to fight malaria, Cuba's meningitis vaccine, Bangladesh oral rehydration therapy, Brazil's basic computer, India's wireless Internet access are some of the examples reported. There is no need to overemphasise these success stories. As already seen above, the scientific and technological innovations developed in the South are still negligible compared to those developed in the North. What is here at stake is that some significant South-generated breakthroughs are possible, and they might be beneficial for other regions of the South as well. But so far, they have not led to increasing South–South cooperation, exchange of know-how, diffusion of expertise and best practice methods.

5. Strategies for technological and industrial development

The evidence reported is incomplete and fragmentary, but the conclusion emerging is straightforward: developing countries have a marginal participation in the generation and diffusion of technology. They participate to a minimal extent to the globalisation of technology, and differently from what occurs in trade and finance. Globalisation is offering new technological opportunities, but these are not seized by developing countries. There is, of course, the remarkable exception of the East Asian NICs. These countries continue to be, even from the globalisation of technology viewpoint, the only case of a successful catching-up strategy in technological capacity as well as in income levels.

The taxonomy here reported might hopefully help policy analysis. It emerges that the label "globalisation of technology" includes a heterogeneous set of phenomena, each of which could lead to different policy implications. We are here mainly addressing the North–South knowledge flow, and given the scientific and technological muscles of the two areas, this is naturally the most significant component of technology transfer. How could the South benefit from these flows in order to start off and improve its own autonomous competencies? To assess how each form can be beneficial to the South, we will stress the importance of learning [38–40,59]. We will argue that it is in the advantage of developing countries to participate in any form of globalisation if this may allow them to learn. The three categories will therefore be assessed on the ground of their learning potential.

5.1. The policy implications of the international exploitation of technology produced on a national basis

Only a selected number of countries, and in particular, the East Asian tigers, have managed to conquer substantial and increasing market shares of the world trade in high-tech products, in consumers' electronics in particular. The evidence reported above, however, has clearly shown that these countries have succeeded by pursuing two alternative strategies: one group has relied almost wholly on TNCs to export sophisticated products as part of integrated global production (Malaysia, Thailand, Philippines, Mexico, China) [60]. Another group has built up competitive capabilities in domestic enterprises through massive efforts to build an endogenous technological capacity, and spawned their own international networks (South Korea and Taiwan, [15]). The widely studied case of these countries, and especially of the second group, cannot be generalised [56].

All other developing countries have negligible exports in high-tech products. Instead, they have traditionally been 'invaded' by technology-intensive products coming from the Triad countries under the balance of payment constraint. These inflows of technology do not allow building endogenous capabilities and therefore developing countries continue to be dependent on technology generated elsewhere. The learning associated to high-tech manufactured imports is small, and the technological standards imported are not necessarily the most appropriate to serve the needs of developing countries. Developing countries can have better learning opportunities when importing machinery and equipment from developed countries. In fact, machinery allows to engage in learning by using [41]. The imports of capital goods not only help manufacture consumers' goods, but can also lead to the birth in loco of skill-intensive services such as technical assistance [58].

In recent years, firms from developed countries have tried more and more to profit from their disembodied innovations in international markets. So far, this strategy has been only partially successful since the possibility to prevent imitation is often low (growing industries such as software and cinema have managed only partially to prevent duplication in developing countries, see Ref. [42]). It is therefore not surprising that a priority for the North has become to strengthen the IPR regime, and the WTO has been particularly active in the field. It is however clear that it is not in the interest of the South to protect the inventions and innovations of the North in their own markets without a counterpart [43]. In many cases, the South would not simply be able to benefit from innovations developed in the North, as the case of HIV/AIDS drugs well illustrates (see UNDP [26], p. 106). IPRs can be guaranteed only if companies in the North agree to make their knowledge available to the South at affordable prices and conditions.

Developing countries might also search to affirm their productions in developed countries. In selected niches, they have been able to exploit overseas the competitive advantage based on low wages; some Indian firms, for example, have managed to penetrate Western markets selling software services and products [32]. An increased open economy generally leads domestic firms to upgrade their technological capabilities [44]. This has been possible because of some key characteristics of the industry (such as the standardisation of the product, the low cost of data transmission, the technical possibility of daily exchanges between suppliers and purchasers). Indian firms do not sell their products to final consumers, but rather they have become specialised suppliers for developed countries' firms. This would have not been possible without the existence of specific engineering expertise in India, and without the links with some developed countries' firms. This example indicates that if an appropriate market niche is identified, and this is combined to existing and potential capabilities, and to crucial links in developed countries' markets, it is possible to acquire a market share in technology-intensive industries even in the most developed countries.

5.2. The policy implications of the global generation of innovations

There is a wide literature on the nations' advantages and disadvantages associated to FDI [45]. The issue here at stake is how the South can benefit from the FDI of the North in terms of acquisition and dissemination of know-how and incentives to local learning. Once foreign production facilities are accepted in the country, it is certainly an advantage if they also include a technological component since the latter will generate externalities which are beneficial for the whole economy. Substantial investments by foreign firms in a country do not occur in the absence of some negotiations between the firm and the host government. Government policies have therefore an important role to use FDI as a learning opportunity, and as a channel of technology transfer.[3]

Developing countries have adopted a variety of strategies vis à vis TNCs' investments. Some countries, such as South Korea and Taiwan, have traditionally preferred to pursue a strategy of industrial development based on national firms [15,46]. This has required the active attitude of governments opening alternative channels of knowledge flows, for example, by fostering scientific and technical collaboration with developed countries at the highest degree available, while simultaneously investing in technological capabilities and infrastructures at home [39,47]. Many other countries, including South Africa, Chile, Brazil, India, Malaysia and Thailand, have encouraged foreign firms to operate in the country and have tried to use them for acquiring productive, managerial and technological expertise. In some cases, however, these governments willing to accept FDI in their territories have not given enough emphasis to linking it to the building of local technical competencies, whenever they implicitly assumed that the latter are directly and automatically associated to production. In other words, in some cases, industrial policy through FDI has not been linked to technology policy through FDI. While certainly production involves the mastering of certain technical know-how, there is a specific technological component within FDI that can be negotiated.

[3] UNCTAD [61], with its *Investment Policy Reviews*, is making an interesting effort to help developing countries' governments in designing and implementing the appropriate policies to attract and benefit from FDI.

Multinational corporations can decide to locate either at home or in the host country many skill-intensive functions, including R&D and technical laboratories, engineering units, standards setting and implementing units. The more the FDI includes these activities, the more it is likely that the host country will benefit from useful- and learning-enhancing externalities.

In other cases, the localisation of one or a few TNCs has generated an endogenous net of local firms supplying or imitating what the TNCs do. The experience of some "hubs" in developing countries would illustrate this point [26].

An excessive concentration of technology-intensive activities in the hands of foreign TNCs would have the disadvantage to increase the dependence on the strategic choices of foreign firms and sometimes even to obstacle the growth of domestic firms. Governments keen to host FDI should therefore not only negotiate the presence of a technological component, but at the same time adopt policies to allow other parts of the economy outside the foreign firm to benefit from the expertise developed. A policy fostering externalities and spillovers is therefore desirable.

5.3. The policy implications of global technological collaborations

Cross-border technological collaborations, in industry and in the academic community, appear to benefit both the parties involved since they allow an increase in learning and an exchange of information. Each country has an advantage to become a junction of techno-scientific information. In order to be engaged successfully in these collaborations, it is however relevant to have appropriate institutions, and in particular, firms with a sufficiently sophisticated technical expertise to be of interest for potential partners.

As in any marriage of convenience, one of the partners may get greater benefits than the other one. In principle, the partner that has more knowledge has more to teach but is also quicker in learning. As we have seen, firms of the South are involved in collaborations mainly with partners from the North. This is hardly surprisingly given the worldwide distribution of scientific and technological capabilities. In general, it seems that collaborations provide better learning opportunity for the South than FDI, since they allow to start a learning process within South-based firms and institutions, and they are more likely to set up "two-way" knowledge and technology flows [37,48]. However, it is unlikely that the partner from the South will be the one to drive the technological agenda. On the contrary, the partner from the North may steer the direction of research and technological development towards its own interests.

This provides an incentive to increase the number of collaborations among firms in the South. There are a few significant cases where firms and public institutions in the South have generated innovations which are addressing problems specific to developing countries (a selection of significant cases is reported in UNDP [26], p. 98). These innovations could be disseminated among Southern countries, and the best vehicle to do is to use cross-border scientific and technological collaborations. But it is unlikely that this will occur without active policies to support and promote local firms and other research organisations. The role of international organisations can be vital in order to achieve multilateral, rather than bilateral collaborations, and of a South–South nature to spur research relevant to LDCs' industrial and technological development.

Another important form of knowledge acquisition is by training human resources in developed countries. Many developing countries provide financial facilities in order to allow some talented students to study in Universities abroad. This is a successful strategy to acquire expertise, especially when this is strongly embedded in human skills. This strategy has, however, also its risks: it often happens that the most talented students of the developing countries, sent to study abroad at taxpayers' expenses, decide to stay abroad. In fact, more than

Table 7
Strategies for developing countries for the access and use of international know-how

Categories	Targets	Instruments
International exploitation of national innovations	• Achieve lower foreign dependency and fill technology gaps	• Promoting collaborations between national firms and leading firms in the field.
	• Increase learning relevant to national industry	• Incentives to selected FDI in the country and to their learning–enhancing modes of operation.
	• Obtaining competitive supply prices of technology-intensive products	• Negotiations on imports with foreign firms.
	• Obtaining IPRs at fair conditions	• Multilateral agreements on IPRs and licences.
Global generation of innovations by TNCs	• Use TNCs to enhance national technological capabilities	• Providing real incentives to the location of new innovative activities with foreign capital.
	• Benefit from local technological activities of TNCs	• Upgrading S&T infrastructures and institutions. • Supply qualified workforce. • Monitoring the technological strategies and location choices of TNCs.
	• Disseminate TNCs expertise locally	• Associate TNCs centers to hubs of specific knowledge and industrial firms located in developing countries.
Global techno-scientific collaborations	• Use the foreign academic community to upgrade the scientific competence of the nation	• Scientific exchange programmes. • Student flows to developed countries. • Incentives to international scientific projects. • Participation to international S&T organisations.
	• Allow the country to become a junction of technical and industrial information	• Developing infrastructures for techno-collaborations (scientific parks, consortia, etc.).
	• Apply knowledge to production	• Promoting University/industry linkages and their international reach. • Participating to international organisations for technical and industrial collaborations.

80% of PhD students in the United States in natural science and engineering from China and India plan to remain there ([49], vol. 2, Table 2-34). This implies a transfer of talents from developing to developed countries, rather than the contrary, as it would be necessary. It is not surprising that the governments of many developing countries, including Indonesia and Thailand, provide grants to their students to study abroad under the condition that they will return to work in their native country. The magnitude of the ''foreign legion'' (that is, scientists and engineers born in the South but working in the North) is so relevant that developing countries should consider institutional policies to link the Diaspora to their native homeland.

In addition, LDCs governments may actively raise the attractiveness of local employment of their foreign-trained talents by encouraging TNCs to locate their S&T departments abroad, and employ them there. This has recently occurred in the electronics and software sectors, especially in India [33]. Table 7 recapitulates the policy implications of our analysis.

6. Conclusions

Globalisation offers a new opportunity for knowledge dissemination, but this does not mean that all the nations and institutions will equally benefit from it. On the contrary, it seems that the institutions that have managed to benefit most from globalisation are those that already are at the core of scientific and technological advance.

Developing countries are not automatically excluded from the advantages. They can benefit from globalisation of technology if they implement active policies designed to increase learning and improve access to knowledge and technology [39]. A few success cases have been pointed out here. A larger number of successful cases are presented by Conceição et al. [50]. We are aware that these cases, unfortunately, represent an exception, not the rule, and that huge parts of the world are not benefiting yet from the opportunities offered by technological change and its globalisation. However, the few success stories can be instructive in order to indicate a suitable development strategy.

We have also argued that the three categories of the globalisation of technology require different learning strategies, and therefore that, if a country has a choice, it might have good reasons to prefer one form to another. In particular, we have argued that the import of foreign technology, either embodied or disembodied, has a negligible learning impact per se, unless when accompanied by local policies to promote learning, human capital and technological capabilities. Public policies should therefore try to induce foreign firms to move from exporting their products to producing locally, and transferring a technological component.

Furthermore, it is often more advantageous for a developing country to set up interfirm strategic technological agreements than simply hosting production facilities of foreign firms. Public policies should therefore also try to ''upgrade'' FDI to strategic technological partnering. We have argued that collaborations among public and business organisations can provide substantial benefits to developing countries. Policies at both the national and intergovernmental levels should therefore consider these collaborations as a preferential channel to transfer and acquire technological competencies.

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