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**The Impact of
Technology Transfer
on Employment and
Income Distribution in
Developing Countries:**

**A Survey of Theoretical
Models and Empirical
Studies**

Mariacristina Piva

Integration

WORKING PAPER NO. 15

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The Impact of Technology Transfer on Employment and Income Distribution in Developing Countries:

A Survey of Theoretical Models and Empirical Studies

Working Paper No. 15

Mariacristina Piva

**International Policy Group
Policy Integration Department
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The Impact of Technology Transfer on Employment and Income Distribution in Developing Countries: A Survey of Theoretical Models and Empirical Studies

by

Mariacristina Piva

Abstract

The aim of this paper is to offer an updated survey of recent theoretical models and empirical studies analysing the impact of technology transfer on both employment and income distribution within developing countries.

The transfer of technology from developed to developing countries depends on trade liberalization and internationalization of production through various channels. A critical discussion compares the positive implications of technology transfers (such as positive spillovers, technological catching-up, growing complementarities with domestic firms) with negative implications (displacement of workers, negative welfare implications, competitive effects with domestic firms).

Moreover the nature of transferred technologies (labour-saving and/or skill-bias, embodied or not embodied in capital), together with the different institutional ‘absorptive capacities’ and sectoral specializations of both middle-income and low-income developing countries, are considered.

Preface

Within the Policy Integration Department, the International Policy Group (IPG) focuses on developments in the global economy and undertakes analytical work with a view to promoting the ILO's Decent Work Agenda in the formulation of international economic policy. IPG also serves as the technical secretariat to the ILO Governing Body Working Party on the Social Dimension of Globalization.

This Working Paper is an output of the first phase of a research project funded by the Department for International Development (DFID) of the United Kingdom Government, on the impact of opening to trade and Foreign Direct Investment on employment, income distribution and poverty in developing countries. In this phase of the project the studies are based on international cross-section data. The second phase, currently underway, will consist of country studies

In her contribution, Mariacristina Piva* critically contrasts the positive implications of technology transfer, such as spillovers, technological catching-up, complementarities with domestic production with negative effects such as possible displacement of workers due to labour-saving and skill-biased technologies and crowding-out of domestic firms.

The views expressed are those of the author.

As an INTEGRATION Working Paper, this document is intended to stimulate further debate on key issues of globalization and its social dimension.

September 2003

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The Impact of Technology Transfer on Employment and Income Distribution in Developing Countries: A Survey of Theoretical Models and Empirical Studies

1. Introduction

It is well known that there are significant differences between per capita income across countries and that the accumulation of physical and human capital does not explain all of these differences. Most economists have viewed technological change¹ as the most important driving force of the economic growth process and point to technological differences as one of the most significant explanation dealing with income disparities. Until the mid-1980s, growth theory assumed that economic growth and technical change were determined exogenously; later it underwent a fundamental change going beyond Solow's residual approach and assuming that technological progress is determined endogenously² (Romer, 1986 and 1990). Grossman and Helpman (1991) enlarged this approach and explored endogenous growth theory in an open economy – recalling Krugman's model (1979)³ – under the hypothesis that goods embody technological know-how that foreign countries can acquire through imports and international trade⁴.

The international dissemination of technology is therefore an important determinant of per-capita income in the world: this is especially true for developing countries (DCs)⁵ relying heavily on the research and innovations emanating in developed countries⁶. Moreover, technologies can now migrate more easily and quickly than ever before due to the reduction of transport costs and the introduction and distribution of information and communication technologies (ICTs). If this mechanism works, relatively backward

¹ Technology is generally assumed to be non-rival (or infinitely expansible, as in Quah, 2001), as well as the outcome of intentional research activities conducted by economic agents in order to develop new products and/or new processes.

² See Aghion and Howitt (1998) for a complete survey of models of endogenous growth.

³ The Krugman model (1979) is constructed on the assumption that innovations in developed countries take the form of new products in new industries imitated by the DCs only with a time lag. The strength of the DCs in terms of low wage rates threatens the developed nations forcing them to strive to maintain the rents they reap through higher wage rates. As a consequence developed nations have to innovate continuously to keep the monopolistic position of new technology.

⁴ Technology-endowed countries are different from countries which can be described as technological-latecomers. Industrialized economies - with a relative abundance of human capital - undertake more research and greater technological improvement and grow faster than developing ones. The authors show that DCs - engaging in international trade with developed countries - obtain more intermediate inputs than otherwise and therefore grow faster than without trade. Even if there is no convergence in growth rates, openness is beneficial for growth to take place in DCs.

⁵ In this discussion, DCs are taken to include all countries except Australia, Japan, New Zealand, and countries in North America and Western Europe. A more precise classification (World Development Indicators, 2002) is: *Low income countries* (if 2000 GNI per capita is less than US\$ 755 – most of them are in Africa–), *Lower middle income* (if 2000 GNI per capita is between US\$ 755 and US\$ 2,995) and *Upper middle income* (if 2000 GNI per capita is between US\$ 2,995 and US\$ 9,265).

⁶ Spending on R&D is highly concentrated in OECD countries. Moreover within developed countries there is a strong concentration by industry: Keller (2002) reports that about 80% of all manufacturing expenditure in R&D is conducted in four three-digit ISIC industries: chemical products, electrical and non-electrical machinery and transportation equipment.

economies can grow rapidly by investing in and adopting already existing technologies⁷ ('investment-based growth strategy' as in Acemoglu *et al.*, 2002) as far as replicating technologies is less costly than inventing new ones since they do not need to reach or improve the 'technology frontier', and there is no race for technology supremacy. Moreover, economic shocks may create low persistence in economic growth and employment, but technological transfer prevents countries from drifting too far apart over the long-run (Hall and Jones, 1999).

A number of other factors may, for obvious reasons, be relevant to explain the permanent technology gap between developed and developing countries (and the consequent permanent significant differences in total factor productivity – TFP): the degree of property rights enforcement, the efficiency of public administration, the existence of barriers to technology adoption (weak physical infrastructures and lack of basic services and/or human capital: Alcorta, 1995), the endowment of production inputs and the international dimension of production.

From this between-country perspective, it is convenient to move to a within-country perspective in order to better understand the impact of technology and technological transfer within each single country (in the DCs group). The within-country perspective is the main topic of this paper, especially looking at the GDP/income growth and its distribution⁸ and at the employment/skills dynamics⁹ with respect to the transfer of technologies. These two dimensions of this problem need to be analysed carefully as there could be a trade-off between, on the one hand, an average per-capita income growth together with employment creation, and, on the other hand, a potential unequal income distribution¹⁰ (which may, in turn, itself be adverse to economic growth: Singh and Dhumale, 2000) connected to effects on demand for different categories of employees and their relative wages.

⁷ A more general classification of conditions for technology adoption, derived from the appropriate international literature on the subject, would identify three progressive stages: passive adoption (foreign direct investment is the main channel, as in Korea, Colombia, Mexico and Malaysia), adaptation (which usually occurs when firms face increasing competition) and creation (which requires relatively mature innovation-related institutions supporting the creation of new knowledge). The nature of innovations at earlier stages is essentially 'coded' or embodied (therefore it is easier to transfer), but it becomes progressively more 'tacit' (De Ferranti *et al.*, 2002).

⁸ The within-income inequality is less responsible than between-country for world income inequality, but it is still worth studying (Vivarelli, 2002). Cornia (2002) underlines how there has been an increase in the income per capita gap between developed and developing countries, as well as a generalized increase in within-country inequality. The secular trend towards rising between-country inequality has slowed down to partial convergence on per capita income (South-East Asia, coastal China, some parts of India and OECD countries). Sala-i-Martin (2002a, 2002b) using data between 1980 and 1998, finds that most global disparities can be accounted for by between-country and not within-country inequalities, even if the second ones are increasing in the last years. The expectation is that if Africa does not start growing, then China, India and the OECD countries together with the rest of the middle-income and rich countries will diverge away from it and global inequality will rise.

⁹ It is quite difficult to have reliable data on employment and skills in DCs: data collected are few (in general they weakly cover the manufacturing sector) and do not compute all the employees due to serious data collecting problems and the relevant presence of the informal sector. The 'jobless growth' is, in large part, due to productivity growth induced by technology, and which has characterized some developed countries (see Pini, 1997, for analysis of the economies of the G6 countries and Sweden), should be avoided in the context of DCs where the positive link between growth and employment should work well. Moreover the demand for different classes of workers and skills should easily be driven by the needs of technologies developed and adopted originally in developed countries and then transferred in DCs, in order to avoid that the skill-mismatch induces unemployment (see Berman and Machin, 2000).

¹⁰ See also Clarke (1995) and Dollar and Kraay (2000) for empirical analysis of the relationship between economic growth, income inequality and poverty reduction.

This potential trade-off must also consider the international dimension of technology transfer to DCs. The facilitated dissemination of technology around the world in recent years is connected to the increasing openness in terms of trade; while it is sometimes difficult to disentangle the effects generated separately by these two phenomena of technology and openness (Lall, 2002), the consequences on income distribution and skill effects may, however, be different. In the trade theory, the Stolper-Samuelson (1941) theorem predicts that openness raises the incomes of the owners of abundant factors and reduces the incomes of the owners of scarce factors, thus DCs are relatively well endowed with unskilled labour as compared to developed economies, with the resulting effect that their imports are expected to hurt capital owners and skilled labour, while their exports should benefit the unskilled (the opposite is true for developed economies). Trade should, therefore, raise income inequality in developed economies and reduce it in DCs (Reuveny and Li, 2003). However, whenever technology transfer comes into play, matters can take a different course. If technology transfer favours skilled even in DCs, as it generally does in advanced nations (see Machin and Van Reenen, 1998), there will be greater demand for relatively skilled workers in DCs, probably generating skill-mismatch (unemployment) and/or increasing wage dispersion between the different categories of workers and a slower growth rate of income per capita (Berman, 2000).

The rest of the paper will deal with a survey of the recent theoretical models applicable to technology transfer (Section 2), a brief discussion on proxies for technology transfer (Section 3), an analysis of positive and negative consequences of technology transfer in DCs (Section 4) considering a survey of recent available empirical studies on the impact of technology transfer on productivity (Section 4.1), employment/skills (Section 4.2) and income distribution (Section 4.3) for DCs taking into account the geographical dimension, where applicable. Finally, in Section 5, some conclusions are presented together with open issues and suggestions for further research.

2. Theoretical models of technology transfer

In this survey of the theoretical literature, recent models considering the problem of transferring technologies between countries, especially between developed countries and DCs¹¹, are reviewed. Three approaches are taken into consideration: General Purpose Technology, appropriate technology and evolutionary economics.

General Purpose Technology (GPT) approach

The General Purpose Technology approach is based on an original model devised by Bresnahan and Trajtenberg (BT, 1995). Bypassing the endogenous growth approach, which considers technological change as being all-pervasive and uniform (Romer, 1986 and 1990) and where no interactions between production sectors are allowed¹², the two authors assume that peculiar technologies, General Purpose Technologies (GPTs), represent drastic innovations, occurring as discontinuous events. The steam engine¹³ is

¹¹ This topic is largely dealt with in the literature on innovation and trade (see Eaton and Kortum, 1999).

¹² This does not explain the differential productivity patterns experienced in different industries depending on technology-intensive use.

¹³ Rosenberg and Trajtenberg (2001) examine the role that a particular innovative design in steam power, the Corliss engine, played in the processes of industrialization and urbanization characterizing the US economy in the late 19th century. Water power offered abundant and affordable energy, but restricted the location of manufacturing. Steam engines offered the opportunity of relaxing this severe constraint. Using data on the location of Corliss engines and waterwheels, they show that the Corliss engines indeed served as a catalyst for the massive relocation of industry away from rural areas and into large urban centres favouring agglomeration economies and stimulating population growth.

widely regarded as the icon of the Industrial Revolution and a prime example of a GPT, as is electricity in the early 20th century; in the same way that semiconductors and information and communication technologies (ICTs) can now be regarded as GPTs. The latter can have potential multiple uses in a wide range of sectors in ways that drastically change the modes of operation and that increase the return of innovation (increasing returns to scale). To make this concept operational, BT introduce a sector that produces GPTs and many Application Sectors (AS) as users/potential users of GPT inputs, which lead to innovative AS activities and further gains in productivity.

BT use a game theory approach based on a two-period game whereby the incentives to innovation of the GPT sector (first player) depend on the market structure, appropriateness and the demand function of the AS –the second player– determining GPT sector's revenues after maximizing profits. The number of AS that finds it profitable to use GPTs increases the greater the quality of GPTs and the lower the price. Thus, holding prices fixed, higher quality induces higher demand for new AS technologies adopting GPTs. The mechanism has an inbuilt backward procedure as well: any improvement in AS technology increases the incentive for the GPT sector to upgrade its technology in a continuous complementarity between technologies. Unfortunately, if the relationship between the GPT sector and the AS does not exchange technological information, it will be difficult for an AS to anticipate GPT updating and the quality itself will probably be too small. However, if all technically relevant information flows freely between the two players, this leads to faster innovation and higher levels of long-run equilibrium technologies. In this procedure the institutional and organizational arrangements may have a determinant role in affecting the present/future pace of innovation. Helpman and Trajtenberg (1998) enlarge the perspective and look at the macroeconomic consequences of GPTs such as the initial productivity slowdown. They demonstrate that, when a new and more productive GPT is introduced, some of AS resources shift in order to develop new components compatible with the new GPT, these components are then used to produce the final output (which then temporarily falls). Once enough components have been developed, the new GPT can be exploited with the result that final output level soars.

The GPT approach is close to reality as it considers a more reasonable dimension of technology than before, but unfortunately it just deals with a partial and not a general equilibrium dimension. Some more recent models try to go deeper into the GPT literature considering at least open economies instead of closed ones.

Cooper and Madden (2002) employ the GPT approach in a general equilibrium model to decide ICT investments¹⁴ for vertically integrated prototype-firms in the North (developed country) and in the South (developing country). ICTs are produced and used in the North, while, in the South, they are just adopted in an uncertain framework. Firms in the North and South are not identical: in the North they have superior GPT and enjoy more coherent AS; in the South they have a relatively less productive ICT stock which is used inefficiently, this – in addition to absolute ICT endowment disparity – further inhibits the productivity of firms in the South. Moreover, in order to adopt ICTs by firms in the North, firms in the South must incur transfer costs during their optimization problem. The model finally suggests that hoped-for technology transfer solutions to induce growth and convergence are too simplistic. In addition, opportunities potentially available to AS in the South and ICTs in the North may be outweighed by a local skills shortage or inadequate infrastructures (Jalava and Pohjola, 2002).

¹⁴ See also Bresnahan and Greenstein (2002) for a discussion of factors influencing AS adaptation of North ICT to a regional context.

In dividing the world economy between the North and South, Chung (2002) predicts that with the introduction of GPT, resources in the North move to the R&D sector in order to develop intermediate goods and gain from comparative advantages in relation to the South. Resource competition in the North is accompanied by wage increases, and because Northern firms in marginal sectors lose their competitiveness to the South, the boom in the South turns out to be temporary as the North regains the industries lost when the R&D process was in competition. The final result is that the disequilibria are temporary and real wages and profits do not change in the long run.

Even if these models take into account the nature of relevant technologies, they do not help us to better understand how the technology transfer process works between developed and developing countries. The next approach –appropriate technology– is better focused on the problem of transfer and efficient adoption of technologies in DCs.

Appropriate technology approach

The idea that many technologies used by DCs are imported from more advanced countries means that technologies produced mainly in, and for, OECD economies are probably inappropriate for the economies of DCs and this could help explain differences in productivity between these countries. Endowments between developed and developing countries are different, as are their needs. The idea that countries with different factor endowments use different technologies was first formalized by Atkinson and Stiglitz (1969) who started the ‘appropriate technology’ tradition with the idea of ‘localized learning-by-doing’ (arguing that the standard Harrod-neutral view of technological progress – in which improvements in technology increase the productivity of all techniques of production – is not credible). The application of new technologies does not provide identical yields in all countries: the technology may be ‘inappropriate’ due to innate differences in the ability to implement them, to specific pre-conditions determining the environment where technologies can be developed and adopted or to differences in the absorptive capacity of institutions, firms and individuals. Minimum standards in terms of education and technology, or a certain ‘absorptive capacity’ or ‘social capabilities’ (Abramovitz, 1986) are fundamental. This literature was referred and updated by Diwan and Rodrik (1991), Basu and Weil¹⁵ (1998), Acemoglu and Zilibotti (2001) and Caselli and Coleman (2000).

¹⁵ Basu and Weil (1998) present a two country-model of growth and technology transfer based on the hypothesis that technologies are specific to particular combinations of inputs. Their growth model (AK-type) implies that technology changes and improvements will be diffused slowly even in the absence of barriers to the flow of knowledge and without adoption costs. Technology transfer is not immediate because countries take time to achieve a sufficient level of development in order to be able to take advantage of the progress being made by the technology leaders.

The last two models use the relative endowment of skilled and unskilled labour as the key determinant of each country's appropriate technology (*skill factor*). Acemoglu and Zilibotti base their paper on the relative supply of skills. A developed country (the North is perceived as one big country) is more skill-abundant and tends to develop a greater number of technologies¹⁶ complementary to skilled workers¹⁷ than DCs (the South composed of many small countries) which have larger numbers of unskilled workers¹⁸ and are simply adopters of Northern technologies. The state of technology –the technology frontier– is the same in both the North and the South. Differences in the supply of skills create a mismatch between the requirements of these technologies and the skills endowed in DCs causing low productivity levels. This stands in contrast with the models constructed by Parente and Prescott (1994; 1997) in which the adoption of new technologies is blocked by 'physical' barriers, such as monopoly rights (explaining productivity differences between countries). Acemoglu and Zilibotti believe that there are no barriers to technology transfer.¹⁹ In their model each final good can be produced by two technologies whose productivity differs depending on the skills of its workers. This has two consequences: more sectors in the South will use unskilled workers and technologies and the relative prices of skill-intensive goods will be higher. The second proposition they demonstrate is that even though the South has access to the same technological opportunities as the North, aggregate productivity is higher in the North than in the South because the North invests more in skill-biased technologies. The model basically suggests that if this trend to invest in skill-based technologies continues (as suggested in Berman *et al.*, 1998), income differences and productivity differences between the North and South will probably increase. In the empirical part of the paper, using data on TFP for 27 industries in 22 developed and developing countries, they show a relatively robust relationship between sectoral TFPs (measured with different proxies) and skill intensity of the sector, consistent with the theory.²⁰

¹⁶ Research and new technologies are developed in advanced nations as purposeful and directed activities and not as unintentional by-products of production.

¹⁷ It is still not clear which comes first out of technology and skills: if new technologies require skilled people, or, endogenously, the supply of skilled workers induces the development of new technologies. Probably the two mechanisms interact continuously. This model's approach is consistent with the endogenous approach made by Acemoglu (1998), showing theoretically and empirically how an increased supply of educated workers in the US has stimulated the invention and the adoption of skill-friendly technologies inducing a reduction in the wage dispersion between the skilled and unskilled in the short term, but inducing an increased demand for skilled workers once technologies are adopted in the long run with an increase in the wage dispersion between the two categories of workers. Caveats are made by the author regarding the empirical evidence, which is difficult to test econometrically.

¹⁸ The basic idea is that technology transfer is complementary to skilled workers, even if a precise definition of 'skill' and specifically, the identification of skills in a single country, is problematic. In the latter case, transferred technologies are complementary to the most skilled workers even if they are unskilled when compared to those in developed countries adopting those technologies. It is a relative skill dimension (Feenstra and Hanson, 1997).

¹⁹ Ideas and innovations can freely move across countries, but the skill requirements mismatch can cause an inefficient use of these new technologies and the *skill factor* becomes a barrier to technology transfer or at least to an efficient adoption of transferred technologies: due to scarcity, unskilled workers have to perform inefficiently some of the tasks implemented by skilled workers in the advanced nations.

²⁰ Like the neoclassical model, their model underestimates the productivity gap between rich and poor countries, but much less so (both considering as the North just the US, or alternatively averaging data from many rich countries to avoid exaggeration of inappropriateness induced by US data). In any case, as in Gemmell and Kneller (2002), skill-biased technologies from the US are not readily applicable in DCs, therefore TFP growth even in the richest DCs is incapable of keeping up with the US productivity growth.

One assumption in the model has to be considered carefully. The hypothesis of all industries being on the technological frontier can be misleading as long as many DCs prefer to buy or adopt second-hand equipment, not following the technological frontier²¹ but finding the technology appropriate to their skill-endowment. Barba Navaretti *et al.* (1998) develop a model considering how developing economies frequently discriminate against imports of second-hand goods, including production machinery. The prediction, through a cost minimization function, is that the lower the level of development of the importing country (especially low-income countries), the higher the share of used equipment. The authors also prove that the higher the levels of used machinery imports the faster technical change, and the larger the changes in the skills required to run machines efficiently. Empirical tests were produced to analyse US exports of metalworking machine tools to 23 countries between 1990 and 1994 (classified in new/used and technical complex/not complex depending on skills required). 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. Their results robustly show how technology (measured as speed rate of depreciation), skill requirements (measured by a skill index) and educational factors (average years of school) are more important than traditional factor prices in determining the choice of used *vs.* new machines. The fact that DCs buy a larger share of vintage machines when the latter are subject to rapid technological change is a source of concern as the technological gap between North and South is likely to increase. The policy implications are that, instead of imposing useless restrictions on machinery imports, countries should concentrate on improving overall investment to enhance their absorptive capacity for new technology by developing technical education.²²

For their part Caselli and Coleman (2000) build a model in which firms have to select the technology they wish to adopt from a menu of technologies; they do so in a different way than Acemoglu-Zilibotti (2001) who consider that DCs are forced to use the same technology as the developed countries. Their optimal choice depends on the endowment of different inputs (unskilled labour, skilled labour and capital). They empirically test their model and find a negative cross-country (52 countries) correlation between the efficiency of unskilled labour and the efficiencies of skilled labour and capital, signalling the existence of a World Technology Frontier (WTF) where increases in the efficiency of unskilled labour are obtained depending on the declines in the efficiency of skills and capital. The estimation allows for country-specific technology frontiers due to barriers to technology adoption. They show that poor countries tend to be the ones that would gain the most by having access to the technological menu of the most advanced countries; they therefore found themselves disproportionately inside the WTF.²³

²¹ With respect to the choice of people managing the innovation activity in countries having in mind the technology frontier, in a theoretical paper Acemoglu *et al.* (2002) analyse an economy where managers engage both in the adaptation of technologies from the world frontier and in innovation activities. The selection of highly-skilled managers is important for innovation activities; moreover, as the economy approaches the technology frontier, selection becomes even more important. As a result, countries at the early stages of development (technological followers) pursue an investment-based strategy, with long-term relationships, large average investments, but little selection. Getting closer to the technology frontier encourages them to switch to an innovation-based strategy with short-term relationships, less investments and better selection of managers (technological leader). Relatively backward economies may switch from one strategy to another too soon and some policies encouraging the first strategy may be beneficial. However societies not able to switch from the first strategy to the second may fail to converge towards the world technology frontier (*non-convergence trap*). The choice of managers is essential for undertaking innovations and adapting to local conditions.

²² Some restrictions are imposed by governments denying firms the access to older equipment – in order to avoid the use of obsolete technologies and to push industries closer to the technological frontier – which is usually more labour-intensive than new equipment and thus more appropriate for low-wage countries.

²³ Guasch and Brehon (2002) build a composite index of 18 technology indicators to assess the distance from the technological frontier.

The appropriate technology approach is therefore relevant, considering the differences that exist between countries in the production and efficient adoption of new (but also old) technologies. This approach underlines the importance of country specificities that needs to be fully investigated by giving more detailed consideration of the learning process and the institutional context.

Evolutionary approach

Since the 1960s, the central purpose of most contributions in the field of technology and trade has been to highlight the crucial importance of technological change and innovation in explaining international trade patterns, and particularly the international asymmetries in technology as the main determinants of trade flows and specialization patterns.

Starting from the technology-gap theories, the first systematic approach is developed by Posner (1961) as he describes how the production of new products is a continuous process in innovative countries able to explain their exporting activity to non-innovative but imitating nations in a dynamic framework.²⁴ Moreover, the product life cycle is the basis of the theory developed by Vernon (1966). Vernon believes that, as the innovation is demand-pulled, proximity to potential consumers can determine the probability of discovering new products. Afterwards, whenever a specific design is imposed, innovative nations export the new product and, whenever the production is completely standardized, it is developed in low-cost countries, following the traditional theory of comparative costs.

Enlarging the previous approach, evolutionary theory tries to lay out a formal theory driven by technological innovation and seeks to understand technical change, its origins and its impacts at different economic levels (Nelson and Winter, 1982). The core of evolutionary theory is a dynamic process in which the behaviour patterns of firms and market outcomes are jointly determined over time. Firms do not operate in a neoclassical production mode, but in a fuzzy world in which they have imperfect knowledge of technologies and need to invest efforts to master and adapt to new technologies (Lall, 2002).²⁵

One of the building blocks of evolutionary thinking is constituted by the recognition of the specificities of technical change. According to Dosi (1988) one model of technical change suitable to describe the characteristics of all sectors is simply not possible. Indeed, the peculiar characteristics of innovative processes historically observed in empirical analyses of different sectors have led to Pavitt (1984) formulating a taxonomy describing industry- specific models of technical change.²⁶

²⁴ All countries can access to the same technologies. Opportunities for trading come from product innovation: insofar as the introduction of a new product brings with it a totally new demand in the worldwide market, it creates the opportunity for exports to non-innovative countries. This situation is not an endless story: through an imitation process the new product is afterwards produced everywhere. Therefore the international trade continues until the technology-gap exists.

²⁵ The assumption based on the presence of maximizing agents becomes an inadequate representation of the behaviour of agents when technological change interaction is present with its uncertainty.

²⁶ Pavitt identifies five sectoral patterns which allow the derivation of industry specific models of technological change: the supplier dominated sector (traditional manufacture), the scale intensive (consumer durables), the information intensive (finance, retailing and travel), the science-based (electronics and chemicals), and the specialized suppliers (machineries, instruments, and software). In the supplier dominated and information intensive sectors the main sources of technical knowledge are situated outside the firm. In science-based sectors, the main sources of technical advance are in-house R&D and basic science. The scale intensive, characterized by continuous processes, finds its main sources of technology in production engineering, production learning, suppliers and design offices, whereas design and advanced users are the sources for specialized suppliers.

The recent evolutionary formal approach places increasing attention on uneven international technological change as an engine of growth with emphasis on the dynamics of specialization, as in Soete and Verspagen (1992), and on the dynamics of catching-up, as analysed in Verspagen (1991) and Fagerberg (1995). In this context, the formal approach developed in Cimoli and Soete (1992) has highlighted the importance of the interplay between absolute and comparative advantages as determinants of the participation of each country in world trade; the dominance of technological gaps in the process of international specialization; and the limits imposed by the dynamics of innovation and trade on the 'growth possibility sets' of each economy. Posner and Vernon's theories are almost complementary. Cimoli and Soete (1992) have integrated and generalized the technology-gap theory in the two directions: the first is the opportunity for technologies to be diverse in different countries; and the second is the loss of homothetic preferences and the explicit consideration of the role of differences in demand conditions over the world. The result is that multiple equilibria are possible and the structure of trade cannot be calculated from the supply conditions alone.

Cimoli and Dosi (1994) make the following points on the general predictions of evolutionary approach: (1) At any point in time one or very few best practice techniques are dominant, irrespective of relative prices; (2) Different agents are characterized by persistently diverse techniques; (3) Observed aggregate dynamics of technical coefficients in each particular activity is the joint outcome of the process of imitation/diffusion of existing best-practice technique, of the search for new ones, and of market selection among heterogeneous agents; and (4) Changes over time of best-practice techniques themselves highlight rather regular paths (trajectories).²⁷

From a methodological point of view, institutions are important in the relationship between scientific knowledge, innovation and economic performance. As suggested by Perez (1983) and Abramovitz (1986), the production of knowledge can translate into innovation and economic success only if there is adequate 'social capability' able to assure a good match between the opportunity offered by technological change and the institutions (private and/or public organizations) which confer a specific shape to a given economic system.²⁸

In achieving a good match rapid and efficient 'learning' can make a great difference: Lundvall's 'learning economy' concept is central to the analysis (Lundvall and Johnson, 1994).

From Verspagen's perspective (1991), the successful adoption and use of new technologies is undoubtedly a costly activity requiring investment in indigenous capabilities, capital equipment and infrastructures. Without these endowments a nation risks falling behind its starting position, thereby distancing itself from the 'catching up.'²⁹

²⁷ A trajectory represents the normal problem solving activity determined by a paradigm (Dosi, 1988).

²⁸ National technological capabilities are associated to: "a complex of skills, experience and conscious effort that enables a country's enterprises to efficiently buy, use, adapt and improve and create technologies. The individual enterprise is the fundamental unit of technological activity, but national capability is larger than the sum of individual firm capability. It comprises the non-market system of linkages, business culture and institutions that enable firms to interact with each other, exchanging the information needed to co-ordinate their activities and to undertake what effectively amounts to collective learning" (Lall, 1997).

²⁹ The international diffusion of technologies depends on the technological backwardness, the 'technological congruence' and 'social capability' (Abramovitz, 1986).

The notion of ‘catching up’, especially for newly-industrializing countries (NICs) is often associated with technological imitation which is not just the pursuing of the same path of development, but also involves a critical stage in the process of learning to industrialize. Catching up must not be necessarily seen in a simply linear and unidirectional manner (Juma and Clark, 2002). “As long as technology is understood as a cumulative unidirectional process, development will be seen as a race along a fixed track, in which catching up will be merely a question of relative speed. Speed is no doubt a relevant aspect, but history is full of examples of how successful overtaking has been primarily based on running in a new direction” (Perez and Soete, 1988, p. 466). For the latter authors, the real windows of opportunity for latecomers opens in periods of techno-economic paradigm shifts. Moreover a counter-intuitive aspect of the catch-up is that followers tend to catch up faster if they are initially backward (Abramovitz, 1989). This is because new introductions of capital stock embody relatively more productive potential in less developed countries than in more industrialized ones.

The rate of imitation is greatly influenced by existing technological capabilities, policies and institutional structures and organizations together with the nature of technological systems and the market for technologies.

Cimoli and Katz (2001) consider that institutional and firm-level variables operate in developing societies in a micro-to-macro environment which is radically different from the one prevailing in mature countries. DCs are characterized by a high degree of macroeconomic turbulence, a potentially rapidly changing production specialization, and a difficult transition period from command to market-oriented economies. They guess that successful firms trying to get involved in advanced economies and adopting updated technologies scarcely try to increase local knowledge (imports increase and therefore local production is reduced; R&D efforts may be replaced by online imports of knowledge). Therefore they suspect there is a certain need for an adequate set of incentives and institutional changes for the local production and diffusion of knowledge.

Clear planning for the adoption of transferred technologies depending on in-situ experimentation and the accumulation of site-specific knowledge and experience does not always occur: for instance many of the technologies transferred in DCs, especially in Africa, were probably designed to produce certain commodities and not to promote technological development.

The approach of evolutionary economists is important due to their effort to comprehend the nature of technical change, its dynamics and the associated learning process considering the relevant heterogeneity of countries and the role played by different institutions. This framework can be extended and fully applied to DCs.

3. Measurement problems

From an empirical point of view one of the main problems encountered when considering innovative activity/technology and technology transfer is to find proxies which are good enough to measure technological capabilities. The best known and most widely used technology proxies can be classified (Chennells and Van Reenen, 2002) under R&D expenditure (as inputs to the knowledge production function following uncertainty about the innovation output and also because it is not a relevant variable for countries far from the technology frontier); patents (as outputs from the knowledge production function, but not all innovations can be patented and not all patents have the same value); embodied technical change (innovative physical capital); and computers and ICT expenditure. Innovations, moreover, can be distinguished and measured through product and process innovations.

Looking further at the problem of international technology transfer, there are five main channels for the transmission of knowledge and technology linked to the international dimension of trade and production.³⁰

International trade: imports³¹

More than other imports, imports of capital goods, embodying technological innovations, are important because of the knowledge and potential applications they play in contributing to capital upgrading (Xu and Wang, 2000; Eaton and Kortum, 2001). Machines and technical equipments used for physical production represent the bulk of imported technologies. Importing machines depends on the cost of the machines themselves and on the cost and availability of relative factors essential to an efficient use (for example skilled labour). Mayer (2000 and 2001), looking at data regarding imports – especially machinery – in 46 low-income countries (1970-1998), classifies imports according to their country of origin, also considering other DCs. Less technologically developed, low-income countries, absorb technologies imported from technologically more advanced DCs more easily than those coming from developed nations. Textile/leather machines together with metalworking equipment account for the majority of imports³² and, even if developed countries are the most important, the relative dimension of these imports from technologically more advanced DCs is growing substantially. From correlation analysis it appears that the absolute change in the GDP ratio of machinery imports has a positive and significant association with a high GDP ratio of domestic investment and a comparative advantage in the manufacturing or mineral sector, while there is no association with trade barriers and FDI inflows (see Table 3, Mayer, 2001).

³⁰ International technology transfer is a difficult phenomenon to measure. The fact that it occurs through different channels makes it especially difficult to achieve an aggregate measure of the activity.

³¹ The export dimension of international trade could allow firms to learn and imitate technologies applied in the countries of destination. Learning by export, even if less commonly used, might be important as well, depending on the capabilities of the firm and the nature of the export order (see Rhee *et al.*, 1984, for Korea). Unfortunately, there is not much empirical evidence sustaining the role of exporting as a learning opportunity. Clerides *et al.* (1998), using Colombian, Mexican and Moroccan data, show no robust evidence that past experience in exporting activity and in new technology adoption causes (in the Granger way) improvements in the performance of firms, once the heterogeneity between firms has been taken into account.

³² Agricultural machinery and tractors, paper and pulp mill machinery and food-processing machinery imports are very small, even though the primary sector should still be the most important in low-income countries. This is probably a crucial bias signal towards the manufacturing sector, ignoring too soon the relevance of agriculture which could probably become more endogenously productive if advanced technologies were implemented.

International Dimension of Production: Foreign Direct Investment (FDI)

FDI flows are mainly concentrated within developed countries, but during the 1990s the great increase in FDI flows to DCs formed an integral part of their development strategies, even though a small number of countries attracted most of them (respectively in China and Brazil)³³. The sector of specialization³⁴ can also be very important for measuring the potential technology transfer (Carr *et al.*, 2001) together with the type of FDI inflow (for example, M&A – operation financial investment – or greenfield investment – new productive investment –).

There are four channels through which technology spills over from foreign to local firms,³⁵ this can occur through the: *demonstration effect* (local firms adopt technologies introduced through imitation or reverse engineering: Findlay, 1978; Blomström *et al.* 1999; Saggi, 2000); *vertical spillover* (backward and forward linkages with the foreign firms lead to inter-industry technology upgrading: Pack and Saggi, 1999); *labour turnover* (workers trained in transnational firms may transfer important acquired technological know-how to local firms by switching employers or by starting up (spin-off) their own business: Kokko, 1992; Kinoshita, 2000); and *competition effects* (the technology upgrading in local firms can be introduced by competitive pressures coming from FDI affiliates: Bayoumi *et al.*, 1999). There is a good amount of evidence that for a country to be able to benefit from technological spillovers of FDI, a minimum threshold of human capital is necessary (Borenzstein *et al.*, 1998).

Licensing

Licensing involves the contractual transfer of knowledge and technology between firms. Given that licensing provides knowledge in a more accessible manner than FDI, some countries (Brazil, India, Mexico and Japan) have, in the past, favoured technology licensing over direct investments (De Ferranti *et al.*, 2002). However, there is usually a greater risk of losing the technology to host country firms when using the licensing option. In this case, the explicit sale of technology to external agents is a less advantageous alternative than keeping the technology ‘in-house’ (Fors, 1996): for example, the value of the technology could be dissipated because of increased competition (Ethier and Markusen, 1996; Saggi, 1999). In these cases it seems that multinational firms use licensing or joint ventures to transfer older technologies and prefer FDI for the latest technologies (Fortanier, 2001).

³³ Low-income countries have received small or no FDI, but in some countries they are now increasing (Angola, Bangladesh, Uganda), even though they are probably more resource-seeking FDI than market-seeking investments (Chudnovsky and Lopez, 1999).

³⁴ With respect to the East Asian electronic industry, Hobday (2001) shows that a large proportion of pacific Asian electronics production is carried out by multinational firms in South-East Asia. The greatest part of the export growth in electronics in South-East Asia has been carried out by the subsidiaries of large foreign multinational firms. Local suppliers to multinationals emerged from existing small and medium-sized firms in Singapore, Malaysia and, even if to a lesser extent, Thailand.

³⁵ Wang and Blomström (1992) show, in a theoretical model, that the smaller the technology gap between domestic firms and foreign affiliates, the higher the rate of technology transfer. Moreover, Glass and Saggi (1998) focus on the problem of the quality of the transferred technologies from multinationals, showing how shrinking technology gap between foreign affiliates and domestic firms tends to improve the quality of the transferred technologies. Both these studies highlight the critical nature of the interaction between domestic and foreign-owned firms.

Patents can be included when purchasing technology in a contractual form activity (Eaton and Kortum, 1999). However, in light of the lack of comprehensive data for DCs in this regard, these studies have typically been confined to technology dissemination among the most developed countries.

ICTs

ICTs can be an effective instrument to transfer and obtain access to technological information, and also represents a means to disseminate knowledge and communicate best practices between distant plants, firms, regions and countries (Keller, 2002³⁶). ICTs can be considered as basic technologies which can contribute to building sufficient quantities of technological capital goods to allow further technology transfer. However, ICTs endowment is still limited in the DCs, (see International Telecommunication Union, 2002).

R&D expenditure

Research and development (R&D) have a slightly different role from an innovation input of the knowledge production function. R&D have an important role to play in learning and absorption of new technologies from the environment (Cohen and Levinthal, 1989). A few empirical studies have tried to distinguish between innovation and learning (see Griffith *et al.*, 2001, for developed countries and, especially, Ray and Bhaduri, 2001, for Indian electronic and pharmaceutical firms). Some papers (see Mohnen, 2001, for a survey on this topic) have used foreign R&D expenditure (weighted sum of other countries' R&D in which weights are usually given by import shares) as a proxy for technological transfer coming from other countries.

These channels for technology transfer do not guarantee automatic technology dissemination.

At the level of the firm, there can be problems of time, cost and technical expertise in accessing information on available technologies; at the level of an industry, its organization and the intensity of competition and relationships between firms also play a role in facilitating or impeding the spread of technology; at the system level, human capital can be an important constraint limiting the absorptive capacity of new technologies.

4. Positive and negative effects

The transfer of technology, especially towards DCs, is often connected with the globalisation process in such a way that it is hard to isolate the positive and negative consequences it has on a given economic system. Positive implications of technology transfers might include productivity improvements, technological catching-up and growing complementarities with domestic firms; while negative consequences might include adverse competitive effects with domestic firms, displacement of workers, negative welfare implications.

³⁶ The geographical dimension or proximity can still interfere with technology transfer, even though transportation costs are now low and ICTs play an important role.

4.1 Empirical studies of the impact of technology transfer on productivity

Following Kaldor's approach (see Targetti, 1992) the growth output rate in a country is governed by the rate of growth of the only exogenous component of demand in the long run— the demand for exports. The growth rate of exports depends on the growth rate of world demand and the growth rate of productivity of a country in relation to that of the leaders. The productivity growth rate therefore depends on the gap between a country's productivity level and the same level as those countries with the highest levels (leaders) (catching-up theory), and the growth rate of output of the country itself, the so-called Kaldor-Verdoorn Law: the higher the Kaldor-Verdoorn's coefficient, the greater the introduction of new technologies borrowed from the leader, the faster the convergence process will be.

In adopting this model in their empirical estimates (a simultaneous model), Targetti and Foti (1997) refer to two groups of DCs countries: Latin American countries (Argentina, Bolivia, Brazil, Chile, Colombia, Mexico, Peru, Uruguay and Venezuela) – with US data as comparative data– and fast growing areas of East Asia (Hong Kong, SAR (China)), Indonesia, Korea, Malaysia, Singapore, Taiwan, China and Thailand) –with Japanese data for comparison. The second group of countries show a clear convergence process in productivity, but not the first group. A fast growing economic area is more likely to introduce frontier technologies than a stagnant one. Another result is that the introduction of frontier technologies does not seem to depend on the investment share. These results imply a Kaldorian conclusion: despite a middle-sized gap with the technological leader country and a higher share of investment, if output growth is somehow constrained in an economic system and/or if it has low dynamic economies of scale, they will not have the opportunity to enjoy a higher rate of productivity growth.

Coe *et al.* (1997) (following Coe and Helpman, 1995, which applies only to developed countries) suggest that R&D spillovers³⁷ from developed to developing countries (77 over the period between 1971 and 1990) are substantial and that the larger the amount of foreign R&D capital stock involved, the more open the trade with developed economies and the more educated the labour force, the larger the effects on TFP. Schiff *et al.* (2002) update previous work and estimate the impact on TFP in DCs (25 DCs over the period from 1976 to 1998 for 16 manufacturing industries) from analogous proxies, and show that the technology gap between North and South is larger for R&D-intensive industries. Likewise, in trading with the North, the South experienced a greater 'catch-up' effect in those industries, although low R&D-intensity industries learned essentially by trading within the South. Finally, education had a positive significant effect on TFP.

Moreover, Hakura and Jaumotte (1999) using data for 87 countries (1970-1993) find that trade is indeed a channel for international technology diffusion to DCs (growth of TFP), but they also show that inter-industry play a greater role than intra-industry trade in technology transfer because countries are likely to absorb foreign technologies more easily when their imports are from the same sectors as where they produce. As intra-industry trade is more pervasive among developed nations than it is between developed and developing countries, the implication is that DCs will enjoy a less marked transfer of technology from developed economies. In any case, it appears that DCs acquire technology by trading with developed countries: results were confirmed for both the full sample and a subgroup of 20 African countries.

³⁷ R&D spillovers are measured as a weighted average of the domestic R&D capital stock of 22 industrial countries with which DCs trade, using bilateral import shares with the industrial countries as weights.

Mazumdar (2001), using panel data techniques, finds evidences in favour of the claim that imported machineries from OECD countries –due to their technological content– lead to higher growth in 30 non-OECD countries developing countries. Moreover the author shows that, on the one hand, investment in domestically-produced equipment reduces the growth rate because it leads to a misallocation of resources, and that, on the other hand, investment in imported equipment increases it. This implies that, in comparison with some high-income nations, poor countries gain more from machinery imports than rich nations.

Despite a premise of potential gains from FDI, the evidence is somewhat mixed when looking at the empirical studies of technology diffusion via FDI³⁸. Xu (2000), using US data on the outward FDI of multinational firms and productivity growth in the host country (40 developed and developing countries in the period between 1966 and 1994), shows a positive correlation between technology transfer (measured as the spending of foreign affiliates on royalties and license fees as a share of their added value) and productivity growth, especially in developed countries. The result also works for the most developed DCs if, and only if, a minimum level of human capital has been reached.³⁹ Urata and Iriyama (1998) study the impact of technology transfer through FDI in China and find that FDI inflow to China has been increasing since the Chinese government began its economic reform process in 1978 and this increase reached extraordinary levels in the 1990s. They investigate the technology spillover effect of FDI by comparing regional TFPs, including the share of foreign firms in total production in a region in the mid-1990s. Technology spillover is detected if the estimated coefficient on this variable is positive. The variable is positive and significant at the standard levels. Controlling the secondary school enrolment ratio and the ratio of technical engineers over the total employment to capture the educational level and the technical capabilities of workers, the findings show that technological capability is important for improving productivity, but education is not.

At the firm and plant level – the most disaggregated level of data reducing the bias induced by aggregation – some empirical analyses reveal heterogeneous results in various DCs. Haddad and Harrison (1993) show that, in Morocco, foreign firms exhibit higher levels of TFP than domestic firms. Moreover the effect of FDI at the sectoral level is more positive in low-tech sectors; this result is interpreted as indicative of the lack of absorptive capacity on the part of local firms in the high-tech sector where they may lag behind multinationals and are unable to absorb foreign technology. Biggs *et al.* (1995) investigate the effects on the production function for manufacturing firms in Ghana, Kenya and Zimbabwe in the early 1990s. They show that both foreign ownership and technology transfer have a significant impact on a firm's efficiency. Görg and Strobl (2002b) present a first attempt to measure the channel labour turnover from foreign to domestic firms in a sample of Ghanaian manufacturing firms between 1991 and 1997 (in some specific industries) as far as they have data on whether or not the entrepreneur worked for a foreign multinational before setting up his own firm and they can determine whether this experience was gained in the same or in other industries. Econometric evidence show that firms whose entrepreneur worked in multinational in the same industry are more productive than domestic one; the same evidence is not found for entrepreneurs who worked in multinationals in different industries.

³⁸ Several studies show how multinational firms provide DCs with capital and technology, rising labour productivity and promoting economic growth. Therefore FDI should reduce income inequality by means of the Kuznets effect (Reuveny and Li, 2003).

³⁹ Xu shows that a country needs to reach a human capital threshold of about 1.9 years in terms of male secondary school attainment to benefit from technology transfer of US multinational affiliates.

Using panel data of manufacturing firms in India in the period between 1974 to 1981 – the period preceding the introduction of India's industrial liberalization policies – Basant and Fikkert (1996) show how the returns in terms of productivity of the technology purchase from outside are highly stable across various specifications both for scientific and non-scientific sectors. Still in India, Kathuria (1998), using firm-level data for medium- and large-sized manufacturing firms (in the periods between 1975-1976 and 1988-1989), shows that domestic firms tend to benefit from the presence of foreign-owned firms irrespective of the technological requirements of the various sectors involved. However, when the initial productivity gap level is considered, the scientific sector firms are the ones that experience spillover – in a significant manner– from the presence of foreign-owned firms. On the other hand, the disembodied technology import variable does not have a significant effect.⁴⁰

Djankov and Hoekman (1998) examine the impact of FDI on productivity of Czech firms and find that firms with foreign links have higher productivity growth than those firms with no foreign links. They also find that foreign investments have a negative effect on the productivity growth of domestic firms with no other linkages than those with foreign links; this is probably due to the competitive effect on local firms. However, in the Venezuelan manufacturing sector, Aitken and Harrison (1999) show that there is no positive impact of FDI on productivity of domestically owned firms –foreign investors in Venezuela tend to locate in more productive industries leading to a decline in productivity among domestic firms– and there are benefits of foreign investment, but they are captured by foreign joint ventures and are not transferred locally to domestically-owned firms. These contradictory findings suggest that the incidence of technology spillovers may be dependent on the initial level of technology of local firms relative to that of foreign firms.

Available evidence on the magnitude of the nature of these spillovers is generally positive, but not conclusive. In the next Section the consequences of technology transfer on employment (especially categories of employees) and on income inequality will be analysed reviewing the most recent papers on this topic.

⁴⁰ In the period 1989-1993, Vishwasrao and Bosshardt (2001) find, in a sample of Indian firms, that foreign ownership is an important variable which impacts on the firm's probability of adopting new technologies. They also prove that 1991 liberalization of technology transfer policies appears to have had a larger impact on foreign-owned firms than on domestic ones.

4.2 Empirical studies of the impact of technology transfer on employment/skills

A strong consensus exists among economists that technological innovation is one of the main factors driving the labour market today, and particularly its skill-composition, which explains the common upskilling trend of employment in many developed countries.⁴¹ As we saw in Section 1, some economists argue that the recent wave of technological innovation has a strong impact on the structure of the labour demand in that changes are more labour-saving (quantitative effect⁴²) and more intensive in their use of skilled labour⁴³ (saving less skilled labour: qualitative effect). Likewise there is also a potential growth in wage inequality between skilled and unskilled workers (demand for skilled workers outstrips the available supply which creates scarcity rents for skilled workers while reducing the demand for unskilled workers).⁴⁴ Much empirical evidence supports this interpretation of Skill Bias Technological Change (SBTC) in developed countries (especially in the United States and the United Kingdom where technology plays a fundamental role and it is directly produced).⁴⁵

The situation in DCs has not been studied as thoroughly. Although some DCs have experienced fast technological modernization (as is the case for Brazil, China, India and South Korea), they have tended to import from developed countries rather than create technologies (Arbache, 2001), which are also skill-biased in DCs.⁴⁶ If greater trade accelerate technology diffusion from North to South, then trade can be skill-enhancing (Skill-Enhancing-Trade, SET; Robbins, 1996a). In the empirical papers, analysis is only usually conducted in the manufacturing sector, which is not very representative of overall economic trends of these countries, but it is the only one where collected data are sufficiently reliable.

⁴¹ See OECD (1996 and 1998).

⁴² Recent literature is focusing on the impact of technologies on different categories of workers more than on its overall effect on employment, which is very difficult to measure even in developed countries where better data are available for all sectors (agriculture, manufacturing and services).

⁴³ When talking about skills it is quite common to rely on different classifications of workers depending either on qualification/tasks or on educational levels where the first is an expression of demand, while the second is an expression of supply. In any case, difficulty in adopting new technology comes not just from the endowment of technical skills, but also from the need for a certain amount of tacit knowledge (Evanson and Westphal, 1995) that cannot be transferred so easily as technical knowledge.

⁴⁴ Under the assumption that wages are rigid or sticky and that the labour market is less flexible or that there are efficiency wages or a slow matching procedure, it is possible that labour market doesn't clear: relative wages for skilled workers have small or no movements at all and the technological change has an effect on employment, generating a decreasing demand for the less-skilled that is translated into structural unemployment –a possible explanation for increased unemployment in the EU in the 1980s (Freeman and Katz, 1994).

⁴⁵ Because less univocal results have been obtained in other countries, especially European countries, alternative explanations have been analysed in the literature: the international explanation (Wood, 1994 and 1995) and the organizational change explanation (Caroli and Van Reenen, 2001). See Sanders and ter Weel (2000), Piva and Vivarelli (2001) and Chennells and Van Reenen (2002) for extensive surveys of the empirical studies on the determinants of the skill-bias dynamics in the labour market.

⁴⁶ During the 1990s an increasing number of DCs embarked on a trade liberalization process and trade barriers between developed and developing countries declined after the Uruguay Round of WTO negotiations. These trade developments might encourage more technology transfers as the relative price of imported technologies decreases and firms are pressured to improve their productivity when faced by increasing foreign competition. Trade liberalization and the exchange rate devaluation that frequently accompanies it increase trade flows permitting higher levels of machinery imports (see Robbins 1996a).

Following a breakdown of the upskilling trend (skilled workers/total workers in employment shares or in wage bill shares) in manufacturing sectors into two components,⁴⁷ within-industry (driven by technological change and/or organizational change, therefore a signal of adoption of transferred technologies in DCs) and between-industry (induced by globalisation and international dimension of production), Berman and Machin (2000) propose a within-between breakdown of changes in the non-production (wage-bill) shares of workers extended to some DCs. The within-industry component seems to be the most important in both the 18 middle-income economies and in the seven low-income economies (over the period covering 1970-1980 and 1980-1990), thus showing the important role of technology in determining the upskilling of employees. Pair-wise correlations show common industry patterns between US shifts in skill demand and those in DCs (this is particularly true in middle-income countries), thereby sustaining the idea that technology transfer from the advanced world has shifted skill demand in DCs. Moreover, Berman and Machin (*ibid*) relate the change in skill demand in DCs to computer usage in the US and R&D intensity matching industry by industry in OECD countries. In middle-income countries there is a significant and positive link between faster industry skill upgrading and technological measures in developed countries, however no evidence was found in low-income countries. This result suggests that –with a time lag– DCs adopt technologies disseminated in developed countries requiring skills for efficient use.⁴⁸ Berman and Machin (2002), extending their previous work, show how the capital/employment ratio (assuming technology is embodied) in manufacturing has increased quickly in both high and middle-income countries during the 1980s and throughout the mid-1990s. There are cross-country correlations of changes in industry capital labour ratios between the US and six middle-income countries.

In considering 46 low-income countries, Mayer (2001) breakdowns the imports of machineries (1970-1998) into two categories: imports characterized by pervasive technologies, usable in various industrial sectors and sectorally-biased imports. He shows that specialized-technology imports (a sector in which DCs play a substantial role) have always been small compared to imports of pervasive technologies (principally from developed nations); he also shows that this fraction has been getting smaller over the years. Moreover the importance of specialized technology imports related to low-skilled labour-intensive activities has increased more than in the other activities. This suggests that technology transfer to many low-income countries has not been associated with an increased demand for skills.⁴⁹ Rather, it seems to have been associated with a decline in individual skills. Even though this could be welcomed in countries with high initial income inequality, it can also be interpreted as a reduction in the incentive to invest in education, encouraging a decrease in future per-capita income levels and perhaps slower long-run growth.

⁴⁷ Technically the employment breakdown is the following:

$$\Delta P_j = \sum_i^n \Delta P_{ij} \bar{S}_i + \sum_i^n \Delta S_i \bar{P}_{ij} \text{ where } P_{ij} \text{ is the share of workers in class } j \text{ in sector } i \text{ and } S_i \text{ is the}$$

weight of sector i on overall employment of all n sectors. The bar is a time mean. The first term is called the within-industry effect and the second the between-industry effect. For wage-bill breakdown a similar approach applies. See Berman *et al.* (1998) for this breakdown applied to developed countries in the 1980s and Piva and Vivarelli (2002) for the same breakdown applied to a smaller number of developed countries in the 1990s. The within-effect clearly dominates.

⁴⁸ This suggests that skills needs in DCs (at least in middle-income DCs) can be endogenously defined by knowing the dynamics that have characterized developed countries. It can be expected that in low-income countries too the same mechanism might work with the adoption of technologies transferred from middle-income countries - more appropriate that those coming from developed nations.

⁴⁹ This is a possible explanation of why some low-income countries have not been very successful in keeping up with the labour productivity increase in the United States of America (see Table 4, Mayer, 2001).

Still, for a small group of countries (Argentina, Chile, Colombia, Costa Rica, Malaysia and the Philippines), Robbins (1996a), pooling data, shows that the correlation of relative skilled demand (university/primary equivalents) with the imported capital stock over GDP is positive and statistically significant and stable in manner consistent with his SET hypothesis.

Görg and Strobl (2002a), using an employer-employee matched dataset of 200 manufacturing firms (1991-1997), investigate for Africa, whether the transfer of technology from abroad provides a plausible explanation for the dynamics characterizing skilled workers in Ghana. The purchase of foreign machinery for technological progress purposes increased the relative demand for skilled labour, measured by its share of the wage bill, while a greater participation in the world output market via exporting has not played a direct role in the skill composition.

For East Asia, Tan (2000), uses panel establishment data from Malaysian manufacturing and identifies an increase over the period 1977-1995 in the employment of highly skilled professionals, managers and technician workers (PTM). The author finds support for the hypothesis that technological change – proxied either by TFP and by using new information and communication technologies (ICTs) – is skill-biased for the most highly skilled group of PTM workers. This result is stronger in foreign firms than in joint-ventures and local firms.

More empirical evidence is available for Latin America, probably because these countries have made significant progress in opening their economies since the 1980s before which they were practically cut-off behind high levels of protection. The 1990s have seen a significant lowering of trade barriers in most Latin American countries.

In a within-between wage-bill share breakdown for tertiary workers, Sanchez-Paramo and Schady (2002) show that a dominant role is played by the within-effect in Argentina, Bolivia, Brazil, Chile, Colombia and Mexico. Pavcnik (2000) examines whether investment and adoption of skill-biased technology have contributed to within-industry skill upgrading in Chilean plants (more than 4,000 from 1979 to 1986 in panel dimension). Using parametric and semi-parametric approaches, she investigates whether plant-level measures of capital investment –the use of imported materials, foreign technical assistance and patented technology– affect the relative demand for skilled workers. Some of the increased relative demand for skilled workers can be attributed to capital deepening; however, once the author checks for unobserved plant characteristics,⁵⁰ the relationship between skill upgrading and the three technology measures disappears, suggesting that plant adoption of foreign technology is not associated to plant skill upgrading. In any case the relationship between skill upgrading and the use of imported materials and foreign technical assistance may be even important in the future.

The patterns observed at the firm-level in Chile, a country that experienced changes a decade before other Latin American countries, are reasonably similar to those observed elsewhere in Latin America. In Colombia, Robbins (1996b) examines the changes of the skill composition responding to an increase in exports, but also to an increase in the proportion of capital goods in imports over GDP. He finds a positive correlation between the increase in imports of machines, equipment and the introduction of new technologies and the rising demand for skilled labour. Results are also confirmed at the firm-level by (Kugler, 2002).

⁵⁰ Doms *et al.* (1997) reach similar conclusions once they control for plant heterogeneity in their firm-level study in the US in the 1987-1992 period.

Feenstra and Hanson (1997), using state-level data on two-digit industries (for the period between 1975 to 1988), study the impact of FDI on the share of skilled labour in Mexico. The '*Maquiladoras*' in northern Mexico, which have received significant levels of FDI, generated an important increase in the relative demand for skilled workers. With a breakdown process they find that most of the change in the structure of demand is explained by intra-industry variations correlated with the introduction of new technologies imported through FDI and complementary to skilled labour. In those regions where the greatest levels of FDI have been received, FDI growth can account for over 50% of the increase in the skilled labour share of total wages that occurred during the late 1980s. Menezes-Filho and Rodrigues (2001) almost adopt the same breakdown and observe similar results in the case of Brazilian manufacturing firms. From descriptive analysis of the dynamics of employment, imports and exports in various manufacturing sectors in Brazil (Galhardi, 1999), it appears that the opening of the economy improved export performance and, hence, the output and employment growth of sectors based on abundant natural resources and unskilled, labour-intensive activities with a generalized upskilling in manufacturing sectors (in relation to the skill profile of the employed population). In Brazil, therefore, exporters are more technologically sophisticated than non-exporters, supporting the conclusion that more skilled workers are needed to use sophisticated technology competitively (Corseuil and Muendler, 2002).

In summary, as emphasized by O'Connors and Lunati (1999), the empirical evidence available for DCs suggests a relationship between technical change, imported through different channels, and required skills comparable to that documented in OECD countries. Unfortunately, no general conclusions can be derived on the quantitative effect of technological transfer on employment due to incomplete data and statistics in DCs.

4.3 Empirical studies of the impact of technology transfer on income distribution

Looking at the income inequality effect of technological transfer, the empirical literature is not copious, especially when traditional measures of income inequality, such as the Gini coefficient, are considered.

In so far as income depends on wages, the income inequality can also be proxied by the wage dispersion between different categories of skills⁵¹ (Berman and Machin, 2002). Unfortunately the skill premium⁵² may not be strongly correlated with trends in national inequality in those countries where agriculture represents a relatively high share of total employment, such as Thailand and the Philippines, or where informal employment is relevant. However, the quality of data available in DCs suggests considering the skill premium as a potential indicator of income inequality, even if this only refers to the manufacturing sector.

⁵¹ Inequality depends on how wages of different categories of workers change (more or less rather than proportionally) reflecting the relative labour market equilibrium. The skill premium can be considered a good proxy of inequality in the developed countries. It has risen to varying degrees in the US and many other OECD countries (see Gottschalk and Smeeding, 1997, for a survey of inequality index in OECD countries).

⁵² FDI inflows, for instance, might generate higher employment and better economic conditions for all the employees, but, if FDI inflows are associated with transfer of skill-biased technologies – dropping the hypothesis of neutral technical change – the transfer of technologies affects wage dispersion, increasing within-country inequality. Other factors, such as transformations in firms' organizations and changes in labour market institutions, amplify the direct effect of technology transfer and adoption on inequality, contributing to the fall in the wages of low-skill workers.

New technologies generate a more skewed earning distribution than old technologies, this is because of the complementarities which exist between technologies and skills, even when assuming a balanced evolution of demand and supply of new skills.⁵³ What happens is that, in contrast with the expectations of Heckscher-Ohlin's (H-O) fall in income inequality, some countries which have undergone trade liberalization are associated with an increase in returns to human capital and a worsening in wage distribution (as in developed countries), due to technological modernization. Arbache (2001) underlines how the increase in wage dispersion will depend on the technological gap between new and old technologies in DCs, as well as on the intensity of capital imports and the short-term substitutability between skilled and unskilled workers.

Looking at studies considering various countries, Batra and Tan (1997) analyse the role of technological change and transfer hypothesis as a plausible explanation of wage inequality using firm-level data for Colombia, Mexico, and Taiwan (China). They find that the impact of technology on wages is greatest for skilled workers and lowest for unskilled workers, thereby supporting the SBTC hypothesis. It seems that trade –mainly imports in capital equipment– has a significant effect on technology acquisition and skills demand.

Te Velde and Morrissey (2002) focus on the relationship between FDI, skills and wage inequality in East Asia and cover three 'traditional' Asian tigers (Korea, Singapore and Hong Kong, SAR (China) and two 'new' tigers (Philippines and Thailand). They limit their attention to changes in wage inequality between skilled and unskilled workers (giving a more satisfactory dimension of the inequality that exists in Hong Kong, SAR (China) Singapore and Korea than in Thailand and Philippines where the agriculture sector is more important). They are in essence relying on the technology-transfer aspect of FDI. Results have shown that FDI have raised wages significantly in all countries regardless of their skill level in 1985-1998 and have increased wage inequality, especially in Thailand.

Matsuoka (2002) finds that the foreign-ownership⁵⁴ wage premium for Thai manufacturing firms is higher for skilled than for unskilled workers (5,000 manufacturing plants in 1996 and 2,400 in 1998). Because labour productivity was not found to differ significantly by ownership (including other controls), Matsouka argues that wage differentials between foreign and local firms should be explained by labour market imperfections, thus attributing this result not to the skill-specific technical change often associated with foreign ownership, but to the more effective bargaining power of their

⁵³ Over long periods, if skills supply and demand grow at the same pace, skills premia would not be able to show very significant secular changes, but their short-period trends would induce a mismatch, causing growing premia. Moreover, due to the highly skewed distribution of education, the skilled workers supply adjustment can take more time than expected in DCs (O'Connor and Lunati, 1999). It is also possible that, inasmuch as the unskilled workers are subject to bequest constraint, poor people remain poor, risking being trapped (with a permanent polarization effect). In a theoretical model, Pissarides (1997) shows how the wage inequality in DCs might only be a temporary effect and not a permanent one. The idea is that openness favours easier and faster technologies transfer to DCs (through efforts by DCs to imitate technologies or importing capital goods available in the North), requiring skilled labour and increasing the returns to human capital. Pissarides' hypothesis is that technology transfer becomes neutral after the 'learning period' to assimilate the new technology. The economy reaches a new technological steady state level so that skilled workers benefit in terms of returns only during the transition period to the new technology level. Furthermore, if the supply of skills increases in the long term in order to bring the labour/skill market to a new equilibrium, the wage differential gain for skilled employees would disappear even sooner in the long run.

⁵⁴ In Thailand there was a shift to high tech industries driven by FDI (especially from Japan and Asian sources) in the 1990s. Both FDI and the export data indicate that the manufacturing sectors - which attracted more export-oriented FDI - are technology-based sectors, especially electronics, electrical and automotive industries (see Phongpaichit and Sarntisart, 2001).

skilled workers. Two critical surveys analysing the electronics industry in Thailand show that technology transfer is minimal and that a very large share of inputs are imported. There are therefore few backward linkages to domestic producers in terms of increasing training and domestic workers (Doner and Brimble, 1998; Francis, 2000). FDI appear to have created islands of high wages with limited linkage effects to the rest of the economy, thus contributing to an increase in inequality.

Sanchez-Paramo and Schady (2002) study the dynamics of the Gini coefficient from 1965 to 1999 in Latin American countries,⁵⁵ and find that a worsening distribution in most of them (Bolivia, Brazil, Colombia and Mexico); this gives cause for great concern because of the already high levels of inequality. The results from Chile – the first country in the region to open to international trade and technology transfer in this geographical area – where the Gini coefficient in the late 1990s is not very different from that for the late 1970s, could however suggest that this worsening situation is temporary and transitional once the period of rapid technological diffusion and upskilling has been overcome.

In Colombia, Birchenall (2001) shows that income distribution followed a specific path, and that, in the second half of the 1970s, human capital accumulation reduced the dispersion of income distribution leading to a period of stagnation until 1990 when structural reforms based on trade liberalization inducing a skill-bias technological change were introduced. At that time, the Gini coefficient was increasing, and the wage differential for skilled workers was giving rise to inequality following a polarization in the bi-modal distribution of income. It also seems that, by means of the transition matrix of intergenerational education mobility and graphic representations, income stagnation in the 1980s was accompanied by a reduction in mobility of workers, while in the 1990s the process of declining mobilization stopped in a manner consistent with the increasing importance of educational premium conditions. The author concludes that in the case of Colombia, liberalization interpreted as a skill-biased technological change induces and leads to wage inequality, polarization and high mobility. Unfortunately, it is beyond the scope of this paper to test these conclusions econometrically; moreover the relationship between trade liberalization and technological change is taken for granted.

Pavcnik *et al.* (2002) study the impact of trade liberalization policy in the 1990s on wage distribution in Brazil (between skilled and unskilled – the share of skilled labour has increased together with a growing skill premium) in manufacturing industries in the period between 1987 and 1998. They examine three channels potentially affecting the wage distribution: increasing returns to skilled workers due to H-O adjustments to trade policy; trade-induced the Skill-Bias Technological Change (SBTC) (larger in sectors with larger import penetration); and changes in industry wage premiums. Their conclusions show that trade reform in Brazil contributed to the growing skill-premium through SBTC instigated by increased foreign competition (even though the overall effect on wages is relatively small).

⁵⁵ See also Behrman *et al.* (2000). Using data for employed urban males in 18 countries in Latin America (1980-1998), the authors suspect that technological progress (technological exports over GDP), rather than trade flows, appears to be a channel through which reforms in this area affect inequality.

For Africa, te Velde and Morrissey (2001), using individual data in Cameroon, Ghana, Kenya, Zambia and Zimbabwe in the early 1990s, showed that foreign-owned firms are associated with a wage premium ranging between eight and 23%, taking into account age, tenure and education of workers and the fact that firms are larger and tend to locate in high-wage sectors and regions. Even with firm-specific controls, results suggest that individuals in foreign-owned firms earn higher wages (premium ranges: eight percent in Cameroon, 13% in Zimbabwe, 17% in Kenya, 22% in Ghana, 23% in Zambia). After controlling for sectors, there is a clear tendency for more senior occupations (manager and administrators) in almost all countries and relatively skilled jobs (supervisors, sales and technicians) as a result of the presence of foreign-owned firms. They suspect this could depend both on the foreign-owned firms employing technologies that are more skill-biased (embodied technical change in equipment) than technologies in local firms and on skilled workers in foreign firms being more effective in rent-sharing than other workers.

From a policy maker's point of view, growing wage inequality depends on different factors such as the initial income distribution, the manner the distribution changes and its main driving forces (channels for technology transfer), and the expected persistence of the situation. Increasing income inequality is always a problem, but it becomes a more serious concern when it pushes governments to adopt redistributive policies that, before they can be efficiently implemented, require a clear understanding of inequality itself and its potential trend in the future (O'Connor and Lunati, 1999).

5. Conclusions

Understanding the role technology is playing and the way it will play it in the future in DCs may have important consequences on the economic and social growth of these countries. The technology is basically the result of a transferring process derived directly from developed countries and/or from exchanges between developing countries. Channels to transfer technologies are strictly connected to globalisation, and consequently DCs receive more technology transfer as their markets are open to imports, FDI, ICTs, R&D and licensing activities. Technology transfer is often a by-product of these activities; technological innovation is rarely the result of intentional research activity as in developed nations. This generally means that it is difficult to separate the effects of globalisation on DCs from those caused by technology. Moreover DCs encompass a large number of different countries in various geographical areas characterized by very heterogeneous historical and cultural traditions, various endowments of natural resources, different sectoral specialization and specific institutional frameworks, as well as different climatic conditions. All these factors might all play a very relevant role in determining their economic and social development.

Economic models on the transfer of technologies from the North (developed countries) to the South (developing countries) do not help us to take into account the heterogeneity of countries in the South, but it does supply clues on the technology transfer process, as well as its dynamics and consequences both in the North and in the South.

The GPT approach is focused on the multi-tasking nature of most relevant and new technologies (such as ICTs), but not much attention has been paid to the situation in DCs. The appropriate technology approach specifically considers the differences between the North and South in terms of their respective efficient adoption of technologies due to the existence of barriers depending on the level of human capital. A low skill factor represents a constraint for DCs and forces them not to be on the technological frontier –where developed countries are–. The transfer of technologies from the frontier might be at least so efficient not to increase in the long run the gap between income per capita and productivity between North and South. This suggests the opportunity to not transfer the latest and most updated technologies, but rather those technologies which can be readily adopted in DCs, even if they originate from the second-hand market and from more

advanced DCs, not directly from developed nations. The consequence is that, instead of restrictions imposed by some governments on the access of older equipment to avoid the use of obsolete technologies, especially in low-income countries, it seems more appropriate to use old equipment as it is less costly and more labour intensive and requires lower skills. Finally, evolutionary economists overcome the neoclassical tradition by laying out a formal theory driven by technological innovation. They make an effort to consider that the production of knowledge can translate into innovation and economic success only if there is adequate 'social capability' able to ensure a good match between the opportunity offered by technological change and the institutions, in a 'learning' process.

But, what is the impact of technologies transferred on the economic growth path of DCs? Positive implications from technology transfers might include productivity improvements, technological catching-up and growing complementarities with domestic firms, while negative consequences might lead to adverse competitive effects with domestic firms, displacement of workers, and negative welfare implications.

The empirical evidence, using the few data available, exploit consequences in terms of productivity, employment/skills and inequality. The first reminder is that the heterogeneity of countries is so high that no common trends can be discerned. With respect to productivity, empirical studies, using data at the aggregate and firm/plant level in countries in different geographical areas (Czech Republic, Morocco, Ghana, India, Kenya and Zimbabwe), show a predominant positive correlation between technology transfer and productivity growth. In some cases this result is found to be stable only if a certain level of human capital has been reached, underlining the generalized important function of qualified workers to adopt efficiently transferred technologies. Studies at the firm level are able to eliminate the bias due to aggregation of data, but unfortunately they cannot explain the complete dimension of the phenomenon: imports of machinery and equipment or inward FDI might be responsible for a 'crowding out' effect on domestic production. This approach must be considered carefully: analysis at the firm level should be complemented with studies at the sectoral level. The time dimension also needs to be emphasized as short- and long-run outcomes at the firm and industry level can diverge due to the functioning of different compensation mechanisms.

Technological impacts on labour markets are even harder to understand due to lack of complete data in DCs and the significant presence of an informal sector, especially in low-income economies and agricultural-based countries. The majority of studies analyse the qualitative impact of transferred technologies more than the quantitative effect they may have. Therefore, available empirical evidence shows that the Skill-Bias Technological Change (SBTC) hypothesis is confirmed both developed countries and DCs. SBTC is more robust in middle-income countries (for example in economically-developed East Asian countries and Latin American DCs such as Chile) as opposed to low-income nations, where the income level, the poverty dimension and specialization in agricultural activities are so important that they do not require more skilled workers, and therefore do not need to change their labour market substantially. In the case of low-income countries, we can expect that they will follow the pattern of middle-income countries as soon as they reach an analogous level of economic development.

Finally, looking at the income inequality effect of technological transfer, the empirical literature is not copious, especially when traditional measures of income inequality, such as the Gini index, are considered. In this case, most of the empirical literature tests the effect of the transfer of technology on the wage dispersion between various categories of workers. Even if this is a weak proxy (especially in DCs), the majority of empirical analysis, particularly the ones at firm level in Thailand, Latin America (Chile and Colombia) and in Africa, show that the transfer of technologies explain a large part of the wage dispersion between skilled and unskilled workers (moreover potential widening rural-urban real wage differences can contribute to enlarge inequality).

Obviously conclusions cannot be drawn from the fact that different geographical areas have different economic traditions and sectoral specializations.⁵⁶ East Asian countries are generally dominated by new technologies and ICTs, and will therefore continue to produce the most advanced technologies and favour the acquisition of *ad hoc* inward FDI. Latin American countries are opening up to the free market by abolishing protectionism and trade barriers, and in the process increasing high levels of imports of equipments and attracting FDI with a strong effect on the skills required and within-income inequality. African countries have not been studied a great deal. Most of them are low-income countries where the economy is stagnant, the primary sector, agriculture, is still dominant and the data available are not sufficient to explain the situation.

From the perspective of a policy maker, the opportunity to adopt and develop technologies depends on financial institutions, training institutions, markets in which knowledge intensive goods and services are traded, institutions for the sharing and dissemination of scientific and technological knowledge.

In the poorest DCs where agriculture still enjoys a dominant position, technology transfers should involve agricultural productivity enhancing technologies able to attain food security, reduce poverty, provide employment and produce their own raw material for industrial transformation.

Three progressive stages for the technological evolution of DCs can be considered once the first needs of a country have been satisfied: adoption, adaptation and creation (De Ferranti *et al.*, 2002). Adoption is suitable for countries with low skill levels and few innovation-related institutions, a good policy strategy is focused on primary and secondary education and open trade policy. Adaptation is for countries with more specialized skill needs; countries are advised to meet these needs by providing incentives to private providers of advanced education. Creation is for most advanced DCs stimulated to produce internal *ad hoc* innovations and R&D.

As the aim is the maximization of the net balance between positive and negative effects of transferred technologies, building local 'technological capability' can seriously affect the ability to employ technologies effectively and efficiently. Education and training are crucial to optimize the absorptive capacity of DCs (individuals, firms and institutions), following suggestions coming from the skills demand in more advanced economies.

⁵⁶ See also the 'cone of diversification' approach which identifies a group of countries characterized by similar endowments of goods and similar production functions (Davis, 1996).

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