www.elsevier.com/locate/worlddev

World Development Vol. 39, No. 7, pp. 1204–1212, 2011

0305-750X/$ - see front matter

doi:10.1016/j.worlddev.2010.05.009

The Role of Foreign Technology and Indigenous Innovation in the Emerging Economies: Technological Change and Catching-up

XIAOLAN FU
Oxford University, UK

CARLO PIETROBELLI
Inter-American Development Bank, Washington, DC, USA
University of Roma Tre, Italy

and

LUC SOETE *
UNU-MERIT, The Netherlands

Summary. — This article explores in depth the role of indigenous and foreign innovation efforts in technological change and catching up and their interactions in the emerging economies. It presents original evidence and argues that, despite the potential offered by globalization and a liberal trade regime, the benefits of international technology diffusion can only be delivered with parallel indigenous innovation efforts and the presence of modern institutional and governance structures and conducive innovation systems. This conclusion is compounded by the expected inappropriateness of Northern technology for countries in the developing South that calls for greater efforts to develop indigenous innovation. In this sense, indigenous and foreign innovation efforts are complementary.

Key words — indigenous innovation, technology transfer, technological capabilities, technological change, emerging economies

1. INTRODUCTION

It is widely recognized that differences in productivity are a major source of cross country income variations and that technological change is a driver of productivity growth. Technological innovation is, therefore, a key element of industrialization and catch-up in developing countries. One of the controversies is whether the sources of technological change are indigenous or rather based on foreign innovation efforts, or a combination of the two, and which combination. On the one hand, innovation is costly, risky, and path-dependent. Hence it is more efficient for developing countries simply to acquire foreign technology created in developed countries. In principle, if innovations were easy to diffuse and adopt regardless of their nature and type, a technologically backward country could catch up rapidly by absorbing the most advanced technologies (Barro & Sala-i-Martin, 1995; Eaton & Kortum, 1995; Grossman & Helpman, 1994; Romer, 1994). With the expectation to "trade market for technology," many developing countries "raced to the bottom" to attract foreign direct investment (FDI) using various financial and fiscal incentive schemes.

On the other hand, there is the view that technology diffusion and adoption is neither costless nor unconditional. It relies on substantial and well-directed technological efforts (Lall, 2001, 2005) and on absorptive capacity (Cohen & Levinthal, 1989). An additional related difficulty in the debate on indigenous *versus* foreign technology upgrading is due to the fact that technical change is often biased in a particular direction and foreign technologies developed in industrialized countries may not be appropriate to the economic and social conditions of developing countries (Acemoglu, 2002; Atkinson & Stiglitz, 1969; Basu & Weil, 1998). In addition, we cannot simplistically assume that the private interests of multinationals coincide with the social interests of the host countries (Lall and Urata, 2003). The available empirical evidence on the effects of the sources of indigenous or foreign innovation is mixed. Studies largely fail to provide convincing evidence indicating significant positive technological transfer and spillover effect of FDI on the local firms.[1]

Within this broad and ongoing debate, the role of indigenous innovation and its diffusion/spillover effect in the catching up process has not received the attention it deserves. Many relevant questions still remain unanswered. Thus, what are the drivers of technological change and catching up in developing countries, and in middle income countries in particular? To what extent can developing countries successfully build up their own modern industries through technology acquisition via imports and FDI? What are the roles of indigenous innovation and its diffusion? What is the relationship between indigenous innovation and the acquisition of foreign technology in an increasingly globalized world, and how does this interaction

* The authors thank participants at SLPTMD Oxford Conference (May 2008) and an anonymous referee for helpful and constructive comments and UNIDO for financial support. The opinions expressed in the paper are of the authors and do not necessarily reflect those of their respective organizations. Final revision accepted: May 20, 2010.

change to respond to the specific characteristics of a country? How does integration in global value chains enable a developing country to access to and learn from foreign technology? This Special Section addresses these questions, based on a series of empirical studies on technology acquisition through FDI and indigenous innovation in the emerging economies.

Impressively rapid economic growth in Brazil, India, and China in the past three decades is changing the landscape of the world economy. [2] These countries are catching up fast with the leading industrial countries, and this process is becoming a remarkable economic force influencing the world economy. They account for about 40% of world total population, 13% of world total income (in 2007), and most importantly, their incomes are rising at a speed similar to that of Japan and Korea during their take-off period (World Bank, 2007). The emergence of these economies has important implications for the world, not only in terms of its economic impact, but also in terms of their experiences in guiding and promoting the growth process. These countries have opened up to international trade and investment though to different degrees and with different speed and strategies, while at the same time they all have put an increasing emphasis on indigenous knowledge creation and innovation, though again to different extents and with varying success. Experiences from these emerging economies may provide valuable lessons also for other developing countries with regard to industrial, technology, and trade policies.

The remainder of this introductory article proceeds as follows. Section 2 examines some stylized facts on these emerging economies. Section 3 analyzes the possible benefits from international technology transfer and the transmission channels. Section 4 discusses the importance of the appropriateness of technology for catch-up and the capabilities of developing countries in creating new technology. Section 5 discusses the interactions between foreign technology transfer and indigenous innovation. Section 6 concludes with an evaluation of the evidence and discusses policy implications for other developing countries struggling for technology upgrading and catch-up.

2. TECHNOLOGY AND ECONOMIC TAKE-OFF IN THE EMERGING ECONOMIES

The rise of these emerging economies is changing the landscape of the world economy. The average annual GDP growth rate of China in the past 30 years, for instance, has been as high as 9.8%, more than three times the average 3.0% annual growth rate of the world economy. In 2007, the annual GDP growth rate was 13.0% in China, 9.1% in India, and 5.4% in Brazil. Again, all growth rates which were substantially higher than the world average growth rate in 2007 of 3.8%. In 2008, in spite of the crisis, these economies continued to grow much faster that the world 1.7% average: 9.0% in China, 6.1% in India, and 5.1% in Brazil. [3] By 2007, China was ranked among the four largest economies in the world in terms of total GDP. The pace and duration of economic growth of these economies resembles Korea and Japan's performances during the three decades after 1960 (Figure 1). The combination of this fast growth with the large size of these economies makes them a significant economic development experience with a global impact (Freeman, 2005).

Technological capabilities in these emerging economies—a central driver of technological upgrading—have also grown significantly, and in some industries they are catching-up with the industrialized countries. Since 2000, China and India have experienced a rapid surge of patent application. The number of patents that belong to so-called Triadic Patent Families [4] applied by Chinese researchers has increased more than seven times over the period from 2000 to 2007. For India the number has increased about three times (Figure 2). China's export market share of R&D intensive products increased from 3% to 13% over the period 2000–08 moving close to the 15% and 19% market share held by the United States and the European Union 15 countries as a whole. This illustrates the rapid structural change and industry upgrading which is currently taking place in China (Table 1).

Of course, despite sharing common features such as their large size, these emerging countries are very diverse in their factor endowments, economic structure and development history, and strategy. All these countries have opened up to international trade and investment. While Brazil mostly relied on its large domestic market (trade/GDP ratio was 27% in 2007), India relied much more on the international economy with a trade/GDP ratio of 46% in 2007, and China experienced a dramatic export-led growth path with a trade/GDP ratio as high as 76% in 2007 All of these countries have also significantly reduced tariff barriers and opened up to imports of foreign goods. Over the 1990–2006 period, the average weighted tariff rate was reduced from 27% to 7% in Brazil,

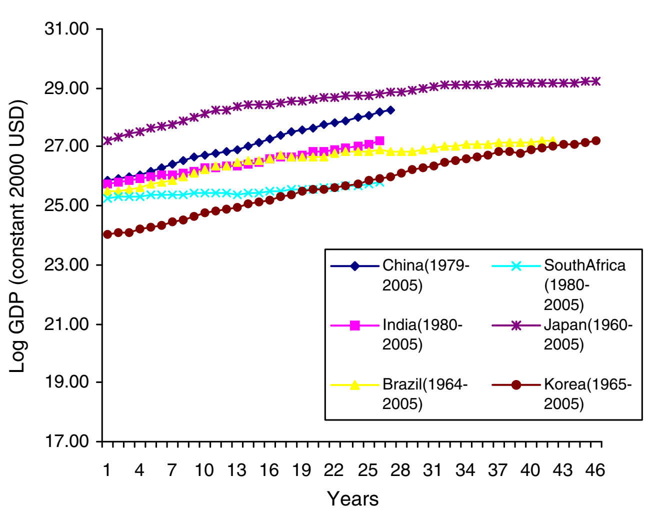

Figure 1. *Growth rate of BASIC economies in comparison with Japan and Korea. Source: World Bank (2007).*

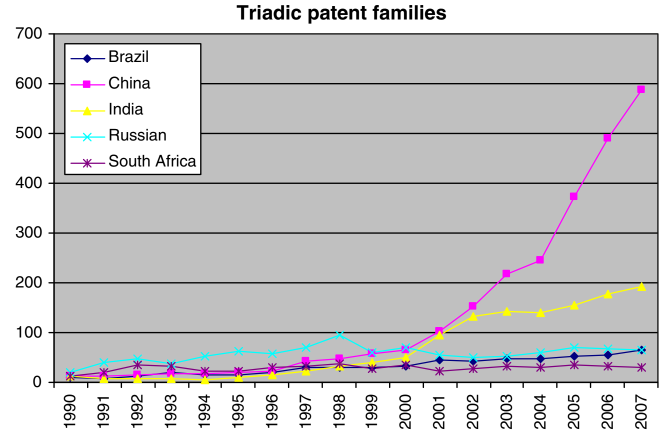

Figure 2. *Granted patents belong to Triadic patent families. Source: OECD. R&D efforts in selected countries, 2006.*

from 41% to 5% in China, and from 83% to 14% in India. All of them have also opened up to international direct investment with China and Brazil enjoying an average FDI/GDP ratio of 3.2% and 3.4% over the period 2000–05. While the figure in India was lower than that in China and Brazil at 0.9%, it has been increasing rapidly since the liberalization. These countries have also spent significant and rising shares of GDP on royalty and licensing fees for foreign technology acquisition: from 0.8% (India) to 2.6% (China). They have sent many students abroad for education and introduced various policies to attract overseas diasporas to return to their countries (Table 2). On the other hand, China, India, and Brazil, are putting great efforts in indigenous capabilities building. These three countries together with the United States and the Russian Federation stand as the top five countries in the world in terms of number of university enrolments in 2007 (Dahlman, 2010). Their expenditure on research and development (R&D) has also increased exponentially. In 2006, the total R&D expenditure in China was greater than that of Germany, United Kingdom, and France and was about a third of that in the European Union as a whole. In terms of its gross R&D expenditure to GDP ratio, China is now moving close to the European Union average (Figure 3).

3. INTERNATIONAL TECHNOLOGY DIFFUSION AND TECHNOLOGICAL UPGRADING IN DEVELOPING COUNTRIES

As discussed earlier, innovation is costly, risky, and path-dependent. This may provide a rationale for poor countries to rely on foreign technology acquisition for technological development. Foreign sources of technology account for a large part of productivity growth in most countries. In fact, most innovation activities are largely concentrated in a few developed countries: the US, Japan, and a number of European countries. International technology diffusion is, therefore, an important condition for economic growth. If foreign technologies are easy to diffuse and adopt, a technologically backward country can catch up rapidly, even leapfrog through the acquisition and more rapid deployment of the most advanced technologies (Barro & Sala-i-Martin, 1995; Eaton & Kortum, 1995; Grossman, 1994; Romer, 1994; Soete, 1985).

Table 1. *Export market share (%): R&D intensive industries*

	1995	2000	2005	2008
Japan	14.51	8.12	5.55	4.73
Korea	3.22	2.68	3.05	3.41
Mexico	1.56	2.02	1.74	1.92
United States	23.47	20.37	15.89	15.41
EU15	22.92	18.80	18.96	18.76
China		2.97	9.21	13.09
Russian		0.20	0.22	0.17
South Africa		0.10	0.12	0.10

Note: Five R&D intensive industries are: aerospace, electronics, instruments, office machine, and pharmaceutical. The figure is a simple average of the share of the five industries.
Source: OECD STAN.

Technology is nonrival. The marginal costs for additional use are negligible. Although Frontier technology created through innovation enjoys rents, the public good nature of knowledge suggests that it can generate positive externalities (or spillovers) to others who are also exposed to this knowledge in various ways. However, although some of the technologies can be codified, a large amount of technological knowledge is tacit. Therefore, knowledge spillovers are geographically bounded (Jaffe, Trajtenberg, & Henderson, 1993) due to the requirement of proximity for the transfer of tacit knowledge.

Technology can be diffused between firms and across regions and countries through various transmission mechanisms (Pietrobelli, 1996). These include: (i) movement of goods through international trade; (ii) movement of capital through inward and outward foreign direct investment (FDI and OFDI); (iii) movement of people through migration, travel, and foreign education of students and workers; (iv) international research collaboration; (v) diffusion through media and internet of disembodied knowledge; (vi) integration into global value chains to benefit from the foreign technology transferred within the supply chain. Some knowledge is transferred intentionally from the knowledge owner to the recipient—and this may spur a learning process—but a large proportion of knowledge spillovers take place as unintended knowledge leakage. In recent years the mode of innovation is becoming more and more open and is making good use of external resources. International knowledge diffusion can, therefore, benefit firms' innovation at every stage of the innovation process. The growing technological diversification of companies makes successful integration of new external knowledge into the innovation process increasingly important. Such successful integration further fosters innovation performance. The factors that explain the accelerating trend of utilizing external sources of knowledge include, among other things, technological convergence, declining transaction costs of acquiring external R&D inputs, and shortening product cycle times (Narula, 2003).

(a) *Foreign direct investment and technology transfer*

Foreign direct investment as a bundle of technological, managerial knowledge, and financial capital has been regarded as a major vehicle for the transfer of advanced foreign technology to developing countries for a long time (Dunning, 1994; Lall, 1992). Multinational enterprises (MNEs) are regarded as the major driver of R&D in the world. They are also likely to offer training to their employees though in an uneven fashion depending on the case/industry. MNEs are also found to have internal incentives to transfer technology across border to share technology between parent companies and subsidiaries (Markusen, 2002). Therefore, it is expected that in the medium- to long-run, local firms will benefit from MNEs spillovers and linkages. The competition effect of FDI is also expected to push inefficient firms to exit from the market and force other

Table 2. *Acquisition of foreign knowledge: Brazil, China, and India*

Trade as% of GDP	Brazil	China	India
1980	22	21	15
2007	27	76	46
Merchandise imports% of GDP			
1980	9.8	–	7.5
2007	9.6	29.8	18.4
Manufactured imports% of Merchandise imports			
1980	41	–	39
2007	64	68	46
Average Tariffs (%)			
1990–92			
Average simple tariff	25.1	42.9	81.8
Average weighted tariff	26.7	40.6	83.0
2006			
Average simple tariff	12.3	8.9	17.0
Average weighted tariff	6.8	5.1	13.8
Average Gross FDI/GDP			
2000–05			
Royalty and license fee payments ($ million)			
	3.4	3.2	0.9
1990	54	0	72
2007	2,259	8,192	949
As% of GDP	1.72	2.56	0.80
Tertiary students studying abroad 2007*	21,556	421,128	153,312
As percentage of students studying abroad	0.77	15.03	5.47
As percentage of tertiary students in country	0.4	1.9	1.1

Source: Dahlman (2010).
*The total number of tertiary students studying outside their home country was 2,800,470.

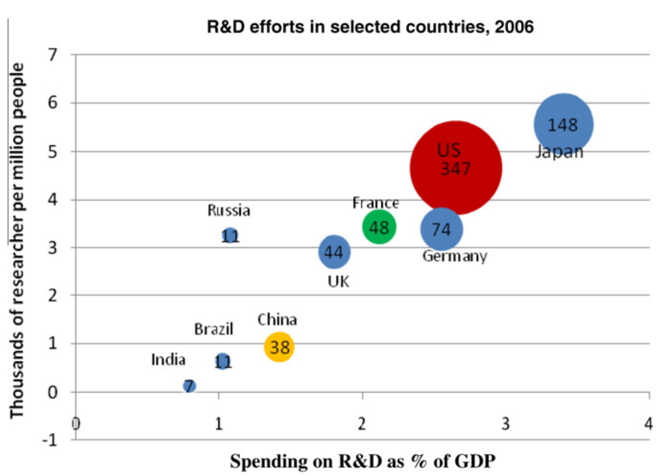

Figure 3. *Spending on R&D as% of GDP. Source:* World Bank (2010). *Note: Area of the bubbles shows the size of gross R&D expenditure.*

local firms to innovate to be competitive. Technology transfer may take place within the foreign-investing firm through imported machinery and equipments and through labor training. Horizontal technology spillovers may occur from foreign investing firms to other firms in the same industry and/or the same region via demonstration effects and the movement of trained labor from foreign to local firms (Caves, 1974; Fosfuri, Motta, & Ronde, 2001). There may also be vertical technology spillovers taking place between foreign and local suppliers and customers within the value chain through forward and backward linkages (Javorcik, 2004; Pietrobelli & Rabellotti, 2007; Pietrobelli & Saliola, 2008).

Some empirical research shows that technology transferred through FDI has positive effects on developing countries (Eden, Levitas, & Martinez, 1997; Kokko, Tansini, & Zejan, 1996; Buckley, Clegg, & Wang, 2002). However, some of these studies suffer from several limitations: they are carried out at the industry level and are likely to be affected by the endogeneity between industry productivity and industry level FDI intensity, and they fail to control for firm level heterogeneity. An exception is the paper by Javorcik (2004) who investigated the vertical spillovers from FDI through the supply chain using firm level panel data from Lithuania and did find significant positive spillovers effects from backward linkages.

However, despite the possible benefits of technology transfer and FDI spillovers, these may also have significantly negative effects on technological upgrading in the domestic firms. This may be due to a variety of reasons. First, FDI may make the competing domestic firms worse off, and even crowd them out from the market (Aitken & Harrison, 1999; Hu & Jefferson, 2002). The strong competition from foreign subsidiaries may reduce local firms' R&D efforts (OECD, 2002). Moreover, foreign subsidiaries may remain as enclaves in a developing country with lack of effective linkages with the local economy.

Many developing countries have established export processing zones (EPZs) to attract FDI. Research on such EPSz in developing countries found that foreign firms located in these EPZs were mostly engaged in process trade based on cheap unskilled or semi-skilled labor available in the host country and did not generate sufficient linkages with the local economy (Johansson, 1994). Fu (2004) finds that processing trade-oriented FDI in coastal regions of China generated limited linkages and weak spillovers across regions which exacerbated the existing regional inequalities in China. Using a large firm level panel dataset from China, Fu & Gong (this issue) find depressive effects of foreign R&D labs on local firms in China. This is likely due to the strong competition for talents, resources, and markets between foreign and indigenous firms, and to the limited linkages between foreign and local firms. Most of the foreign R&D labs indicated that they have no intention to collaborate with local firms, universities or research institutions due to concerns on IPR protection (Zhou, 2006).

(b) *FDI is not an unalloyed blessing*

FDI is not an unalloyed blessing for technology transfer in developing countries. There are many necessary pre-conditions to meet for an effective technology transfer process. First, trade policy matters. It is argued that openness facilitates linkages and directs resources to the "right" sectors, as well as a competitive and dynamic environment (Balasubramanyam, Salisu, & Sapsford, 1996). Heavy restrictions on foreign investors and import substitution policy provide foreign affiliates with low incentives for technology transfer (Aitken & Harrison, 1999). Second, legal and regulatory policies especially those related to intellectual property rights (IPR) are important. Foreign firms will not bring core technology into their subsidiaries in developing countries with weak IPR protection. They have also little incentive to invest in R&D and innovate in an environment with weak IPR protection. Third, there need to be sufficient linkages between foreign and local firms to make effective technology transfer possible. Over a certain period China has required joint venture as a condition for FDI inflows. China and Brazil both have negotiated export and local content requirements on FDI in certain industries such as the automobile industry so as to create linkages between foreign and local firms. They have also imposed training requirements on FDI in some cases, for example, Motorola in China.

Fourth, FDI with different characteristics also benefit technology transfer to a different extent. For example, we expect that investments made by R&D-intensive MNEs from R&D active countries will *ceteris paribus* transfer more technology. Technological gaps between foreign and local firms also matter. The relationship between the strength of spillovers and the technology gap follows an inverted-U shape. Spillovers are found to be present when the technology gaps are moderate and when they are much larger (Kokko *et al.*, 1996; Meyer, 2004). Finally, the most necessary condition for effective technology transfer is sufficient absorptive capacity, which we will discuss below.

Fu and Gong (this issue) contribute to this debate in a new and original fashion. They explore the sources/drivers of technology upgrading in China in its recent wave of science and technology take-off using a recent manufacturing firm-level panel dataset for 2001–05. They decompose total factor productivity growth into technical change and efficiency improvement and examine the drivers of these changes. Their results suggest that FDI has served as a vehicle transferring advanced foreign technology from global reservoirs of knowledge. This improves static technological capabilities through imported machines and equipments. However, R&D activities of foreign firms appear to exert a significant negative effect on local firms' technical change. Instead, it is collective indigenous innovation that contributes to the dynamic technological capabilities of local firms and pushes forward the technological Frontier.

Firm-level evidence from India further supports this hypothesis. Using an unbalanced panel data of 1843 Indian manufacturing firms operating during the period 1994–2005, Sasidharan and Kathuria (this issue) examine the relationship between FDI and domestic firms' R&D in the post-liberalization regime. In most regression specifications, they find that the foreign equity participation acts as a disincentive for investment in R&D. Foreign presence has a positive effect on the R&D intensity of only new domestic firms, which were incorporated after 1985, during the newly liberalized regime.

Technology spillovers from FDI may also take place along the spatial/regional dimension. Although knowledge is a nonrival public production asset, which can generate positive externalities or spillovers to others (Griliches, 1979; Nelson, 1959), knowledge spillovers are geographically localized (Audretsch, 1998; Audretsch & Feldman, 1996; Jaffe *et al.*, 1993), and there may be geographic boundaries to information flows or knowledge spillovers among the firms in an industry (Marshall, 1920; Krugman, 1991). Social bonds fostering trust and frequent face-to-face contacts may facilitate knowledge and information flows among agents located within the same area (Breschi & Lissoni, 2001). These spatially bounded knowledge spillovers allow companies operating nearby important knowledge sources to introduce innovations at a faster rate than rival firms located elsewhere.

Using product innovation information for nearly 40,000 Chinese firms in high technology industries over the period 2000–05, Chen, Li, and Shapiro (2008) investigate the impact of foreign direct investment (FDI) on the product innovation activity of Chinese firms. They find that in locations with a strong clustering of innovative foreign firms, local firms benefit from knowledge spillovers and are themselves more likely to introduce product innovations. However, this does not occur in locations where foreign concentration is measured not by innovations but by employment or capital. After controlling for firm- and location-level effects, no general evidence of industry-level spillovers from FDI in the high-technology industries emerges from their analysis. This is consistent with the findings from Fu and Gong (this issue) and Sasidharan and Kathuria (this issue). The clustering of only innovation activities by foreign firms has a knowledge spillover impact on local firms.

(c) *Imports and technology transfer*

Imports of machinery and equipments are another important channel for foreign technology acquisition. Cross country studies on bilateral imports data suggest imports as an important channel for countries to acquire advanced technology and enhance competitiveness (Coe & Helpman, 1995; Fagerberg, 1994; Freeman & Soete, 1997). Note, however, that technology transferred through imports of machinery and equipments is embedded in this machinery. Products that used these imported machines will probably be of higher quality, but this does not mean that developing countries thus necessarily master the technology of designing and producing those advanced machines. Substantial technological learning and reverse engineering are required to grasp the technologies embedded in the imported machinery.

Li (this issue) empirically investigates the effect of three types of investment in acquiring technological knowledge (in-house R&D, importing foreign technology and purchasing domestic technology) on the innovation output of Chinese domestic firms in hi-tech industries based on a dataset constructed from a panel of 21 four-digit hi-tech sectors over the period 1995–2004. The results show that investing in foreign technology alone does not enhance innovation in domestic firms, unless it is coupled with an industry's own in-house R&D effort. On the contrary, domestic technology purchases alone are found to contribute to innovation, suggesting that indigenous technology is much easier to be absorbed by domestic firms.

(d) *Internationalization of R&D and technology transfer*

Internationalization of R&D activities by Multinational Enterprises (MNEs) has been a major trend in recent years (UNCTAD, 2006). Many developing and developed countries introduced various selective policies to attract R&D-related FDI, with the hope that such investments would contribute to the technological capabilities building of the host country. The evidence on these effects is not clear-cut yet, but Franco, Ray and Ray (this issue) provide original evidence from a comparative study of the innovation practices of multinational affiliates in Brazil and India. Their paper seeks to identify MNE's Innovation Practices (IPs) in these emerging economies through the analysis of the technological asset-seeking patterns pursued by MNEs. Although both countries have similarities in location advantages (large internal markets and abundance of natural resources), MNE affiliates appear to follow significant differences within and across-countries in terms of their innovation-oriented strategies. While MNEs in Brazil have taken more "stand-alone" practices, focused on one specific kind of technological asset-seeking strategy (licensing, physical capital, or skilled human resources), MNEs in India have adopted a more integrated approach, using complementary IPs and combining different kinds of local and foreign knowledge to leverage innovative capabilities. The results suggest that MNEs have different levels of involvement with local productive and innovation systems in Brazil and India. Such heterogeneity in technological assets-seeking MNEs behavior combined with different country competences in attracting knowledge intensive foreign investments have created different opportunities for these countries to transfer technology and enter global value chains (GVCs).

In the case of China, innovation practices of MNEs have been mostly of "stand-alone" type in the three decades after the reforms. Foreign R&D centers are reported to have limited interest in sharing knowledge with domestic firms and R&D labs (Chang, Shih, Luh, & Wu, 2006; Zhou, 2006). This may perhaps be explained by the strict intellectual property rights protection of these high-end MNEs against the indigenous firms. Consistently, Fu and Gong (this issue) found that R&D activities of foreign invested firms at the industry level exert a negative spillover effect on technical change of indigenous firms. Foreign R&D activities may well intensify competition for the limited domestic talent pool (Chang *et al.*, 2006) and crowd out indigenous firms from local labor, resource, and product markets.

(e) *Integration into global value chain and technology transfer*

International knowledge and innovation exchange and collaboration, through for example, inter-firm and intra-firm networks and Global Value Chains (GVC) has a significant impact on the innovation and technology upgrading of those firm that successfully integrate in the GVC. In developing countries this argument becomes even more stringent, given that a new frontier innovation is scarcely created and the bulk of knowledge and technology needs to be imported. For firms in developing countries integration in GVCs does not only represent a new market for their products, but it does also play a growing and crucial role to access knowledge and enhance learning and innovation. However, the literature has not yet clearly settled how innovation systems and GVCs interact, and how this interaction is likely to affect enterprise learning.

Pietrobelli and Rabellotti (this issue) argue that the different characteristics of the value chains have an impact on the mechanisms of learning prevailing in the chain. The learning mechanisms can be very different in the various forms of governance the chain may have: they can be the result of pressure to accomplish international standards or they can be facilitated by a direct involvement of the chain leaders when the competence of suppliers is low and the risk of unsatisfactory compliance is very high. When the competences among actors in the chain are complementary, the learning mechanism is mutual and based on intense face-to-face interactions. Secondly, as Innovation Systems (IS) open up to foreign knowledge, the relationship between GVCs and IS turns nonlinear and endogenous, with each mutually affecting the other. The authors expect that a well-structured and efficient IS may help to reduce the complexity of transactions, and, therefore, make transactions based on arms' length or on relational forms of GVC governance possible. In other words, the risk of falling into a captive relationship, or even of being acquired by a leader, diminishes with a stronger IS. The system of organizations in charge of Metrology, Standards, Testing and Quality (MSTQ) plays a central role in this interaction, and may affect the convenience of different forms of governance for developing country firms' learning and innovation.

4. INDIGENOUS INNOVATIONS, APPROPRIATE TECHNOLOGY, AND CATCHING-UP

Despite the possible benefits from international technology transfer and the prospect of income convergence among countries brought about by this technology diffusion, empirical evidence on the gains from international knowledge spillovers is mixed. [5] Cross country studies observed increasing income inequalities between rich and poor countries and the marginalization of the poorest African countries. One of the explanations of these income divergences is that foreign technology may be inappropriate with respect to the local socio-economic and technical conditions since technological change is a "localized learning by doing" process (Atkinson & Stiglitz, 1969). All this points to the importance of indigenous innovation efforts for technology upgrading, and catching-up in particular.

There are different methods and technologies for production. Different technologies are specific to particular combinations of inputs (Basu & Weil, 1998). For a particular country, appropriate technology is "a technology tailored to fit the psychosocial and biophysical context prevailing in a particular location and period" (Stewart, 1983; Willoughby, 1990). Foreign technology may not fit the specific socio-economic and technical context prevailing in the technology recipient. Moreover, because of the innovator's incentive to maximize innovation returns, technical change will be biased to make optimal use of the conditions and factor suppliers in the country where the technology is developed (Acemoglu, 2002). Many developing countries use technologies developed in the North, but the factor endowments in the South are significantly different from those in the North. Therefore, these advanced technologies, no matter whether imported or transferred through FDI, will be inappropriate to the conditions in the South, and hence less productive (Acemoglu, 2002; Acemoglu & Zilibotti, 1999). The direction of technical change and, therefore, the inappropriateness of the foreign technology used in the South provides a powerful explanation of the increasing income gap across countries. This issue is especially important for the middle income countries trying to catch-up. Although imported technology may contribute to economic growth, the South using inappropriate technology will grow at a lower rate than the North, and the income gap will persist or even rise.

Fu and Gong (this issue) extend the existing literature to the industry level and argue that in a country that has abundant endowments of unskilled and semi-skilled labor, foreign technology may be less appropriate for the labor-intensive low-technology sector than indigenous technology. The appropriateness of foreign technology may increase as the technology-intensity of sectors rises. Since developing countries possess abundant unskilled and semi-skilled labor, indigenous technology will be biased toward this factor. In other words, technologies created in labor-abundant countries may be un-skilled labor augmenting. In low-technology industries that use un-skilled labor intensively, labor-augmenting indigenous technology will be more efficient than foreign technology. In contrast, foreign technology from industrial countries will be skilled-labor augmenting, and it will be more efficient than indigenous technology in the technology-intensive sector that uses skilled-labor intensively.

Moreover, the middle-income countries have accumulated a pool of knowledge and skills, and their factor endowments have become different from those of the least developing countries and of the industrialized countries. Therefore, the large middle-income economies are more likely to generate "intermediate" innovations with medium-level technology intensity than smaller economies with the same degree of capital scarcity (Findlay, 1978). These middle-income countries can reap the gains from investment in such technologies by selling patents, obtaining royalty payments or investing in smaller and less advanced developing countries (Perez & Soete, 1988). Given the disparities in financial and human capital across different regional or economic/social groups in these large middle-income countries, Fu and Gong (this issue) expect that such intermediate technology will be generated by the relative skill and capital-rich group of firms in these economies. Using empirical evidence from a recent Chinese manufacturing firm-level panel dataset for 2001–05, they show that local firms, especially private and share-holding companies, dominate the technological frontier in the low- and medium-technology industries. Indigenous innovation and its diffusion are the driving forces of the dynamic technological capabilities building in the indigenous sector. Instead, foreign firms dominate the high-technology industry. Their study suggests a "two-leg forward" strategy for developing countries.[6]

5. FOREIGN TECHNOLOGY TRANSFER AND INDIGENOUS INNOVATION: COMPLEMENTS OR SUBSTITUTES

What is the relationship between foreign technology transfer and indigenous innovation? Should a developing country rely solely on foreign technology because innovation is costly, risky, and path-dependent, or completely depend on indigenous innovation since foreign technologies do not fit the local socio-economic and technical context? Or should they pursue both strategies with different emphasis but at different development stages and in different industries, as suggested by Aghion and Howitt (2005)?

As discussed earlier, several conditions need to be fulfilled to obtain effective technology transfer to developing countries. A crucial condition is the level of absorptive capacity. Technology transfer can be partial because of the costs and variations in capacity to adopt new technology. The benefits from international knowledge transfer are hence subject to the existence of adequate absorptive capacity of the local firms and organizations—that is the ability of an organization to identify, assimilate, and exploit knowledge from its surrounding environment (Cohen & Levinthal, 1989; Girma, 2005). In turn, absorptive capacity depends on the human capital and R&D expenditures of the receiving country or organization. Cross country studies find that there is a minimum necessary threshold level of human capital (Eaton & Kortum, 1995; Xu, 2000), and smaller firm-size or a lower share of skilled workers may hinder absorptive capacity (Girma, 2005). Another important component of absorptive capacity are the R&D activities carried out by local firms that play the dual role of creating knowledge and promoting learning and absorptive capacity (Aghion & Howitt, 1998; Griffith, Redding, & Reenen, 2004). R&D activities in local universities and research institutions also importantly contribute to a region's (a country's) absorptive capacity. In sum, there are multiple avenues whereby indigenous R&D is necessary to obtain greater gains from foreign technology transfer. Li (this issue) and Fu (2008) both support this hypothesis based on experiences from China. Foreign technology will generate a positive effect on local firms' technological change and upgrading only insofar as sufficient indigenous R&D activities and human capital are present.

On the other hand, would openness to FDI—and the ensuing foreign technology transfer—crowd out local R&D? Sasidharan and Kathuria (this issue) address this major research question and examine the relationship between FDI and domestic firms' R&D in the post-liberalization regime in India. They find that foreign equity participation acts as a disincentive for investment in R&D in most cases but for new local firms. This is consistent with Lokshin, Gils, and Bauer (2008) who suggest that in Europe internal and external R&D are complementary to each other, and that institutional and governance structures play a significant role in this process. Thus, it may well be that in India the new firms born during the liberalization regime with modern institutional and governance structures, are more likely to effectively integrate the benefits from domestic and foreign innovation efforts.

6. CONCLUSIONS

The articles in this Special Section explore in depth the role of indigenous and foreign innovation efforts in technological change and catching up, and their interactions in the emerging economies. The evidence suggests that, despite the potential offered by globalization and a liberal trade regime, the benefits of international technology diffusion can only be delivered with parallel indigenous innovation efforts (Li, this issue; Fu, 2008) and the presence of modern institutional and governance structures and a conducive innovation system (Sasidharan and Kathuria, this issue, Pietrobelli and Rabellotti, this issue). In this sense, indigenous and foreign innovation efforts are complementary. Without proactive indigenous innovation efforts, foreign technology remains only static technology embedded in imported machines which will never turn into real indigenous technological capability. This conclusion is compounded by the expected inappropriateness of Northern technology for countries in the developing South, that calls for greater efforts to develop indigenous innovation crucial for technological change and catch up, especially in the middle income countries (Fu and Gong, this issue). Without indigenous innovation, the income gap between developed and developing countries can never be closed. This needed complementarity of indigenous and foreign innovation efforts is due to several self-reinforcing reasons.

First, technology diffusion and adoption is not costless and unconditional. The speed of diffusion and adoption, and thereby of technological capabilities building, depends on the firms' absorptive capacity and complementary assets. Empirical evidence from the emerging economies illustrates this (Fu, 2008; Li, this issue). Second, only in the presence of local innovation capacity will MNEs adopt a more integrated innovation practice, which has greater linkages with the local economy and thereby enables greater opportunities of knowledge transfer (Franco *et al.*, this issue). Third, the greater use of external knowledge is accompanied by a parallel decrease of the presence of internal R&D departments (Chesbrough, 2003; Howells, James, & Malik, 2004), especially in research-intensive industries (Bönte, 2003). Studies reported in this special issue could not support the hypothesis of positive spillover effects from R&D activities of MNEs on the innovation and technical change of local firms, due to significant disincentives on local firms and crowding out of local R&D (Fu and Gong, this issue). Fourth, the inappropriateness of foreign technology in these emerging markets contributes to explain the poor statistical significance and even the negative effects of FDI spillover. As Lall (2003) suggests, the higher a country moves up the industrial ladder, the more important local capabilities and innovation are. While FDI can facilitate the development of basic operational capabilities, they may be less efficient means of deepening capabilities. Collective indigenous innovation efforts are found to be a major driver of indigenous technical change (Fu and Gong, this issue).

Admittedly, developing countries face a dilemma of resource constraints to meet the high investment costs and high-risk challenges of innovation (Erdilek, 1984; Hoekman, Maskus, & Saggi, 2004). The North–South technology gap in several industries remains remarkably persistent. Experiences from the emerging economies suggest that, in order to maximize the benefits from innovation and accelerate catching-up, the explicit and well-focused encouragement of indigenous innovation and acquisitions of foreign knowledge must work in parallel (Fu and Gong, this issue). Neither autonomous innovations nor FDI-reliant strategies can be used independently (Lall, 2003; Pietrobelli, 2000). Relying solely on one of them would not be optimal for technological capability development and catching up. The Chinese model (and to a lesser degree also the Indian and Brazilian ones) of walking on two legs proposes a strategy to maximize the benefits for the developing country. *How* to select and shape the best combinations at different stages of development and for different countries and industries is a question of utmost relevance for future research. Fu and Gong (this issue) suggest that there are multi-tier choices of technology rather than the simple bi-dimensional North–South divide. Technologies developed in labor-rich emerging economies will be more appropriate to the factor endowments mix in other populous developing countries; and technologies created in land/resource-rich emerging economies will be more appropriate to other land/resource abundant countries. They will also be easier to diffuse and absorb by other local firms. Following this hint, South–South trade and FDI will represent effective vehicles for the diffusion of these technologies, and policies should follow suit consistently. In sum, the encouragement of indigenous R&D and innovation activities remains an indispensable centrepiece of an innovation strategy targeting the assimilation and adaptation of foreign technology and the acceleration of technological learning and capabilities building.

NOTES

1. For surveys of the literature on spillovers from FDI see Görg and Strobl (2001), Blomström and Kokko (1998) and Meyer (2004).

2. South Africa and Russia are often included in this group. However, in this paper we rather focus on the two largest Asian countries and on Brazil, on which new evidence has become available.

3. In 2009 China's GDP grew at 8.7%, and India's at 5.7.

4. These are patents applied for/granted in the US, Europe and Japan.

5. Görg and Strobl (2001), Blomström and Kokko, 1998 and Meyer (2004) are excellent surveys of the literature on spillovers from FDI.

6. This conclusion is also supported by other studies that show how firms have little difficulty in absorbing technological knowledge purchased domestically (Li, this issue).

REFERENCES

Acemoglu, D. (2002). Directed technical change. *Review of Economic Studies, 69*, 781–810.

Acemoglu, D., & Zilibotti, F. (1999). Information accumulation in development. *Journal of Economic Growth, 4*(1), 5–38.

Aghion, P., & Howitt, P. (1998). *Endogenous growth theory*. Cambridge, MA: MIT Press.

Aghion, P., & Howitt, P. (2005). Growth with quality-improving innovations: An integrated framework. In P. Aghion, & S. N. Durlauf (Eds.). *Handbook of Economic Growth* (Vol. 1A, pp. 67–110). Amsterdam: Elsevier.

Aitken, B. J., & Harrison, A. E. (1999). Do domestic firms benefit from direct foreign investment? Evidence from Venezuela. *American Economic Review, 89*(3), 605–618.

Atkinson, A. B., & Stiglitz, J. E. (1969). A new view of technological change. *Economic Journal, 79*, 573–578.

Audretsch, D. (1998). Agglomeration and the location of innovative activity. *CEPR Discussion Papers* 1974.

Audretsch, D., & Feldman, M. (1996). R&D spillovers and the geography of innovation and production. *American Economics Review, 86*(3), 630–640.

Balasubramanyam, V. N., Salisu, M., & Sapsford, D. (1996). Foreign direct investment and growth in EP and IS countries. *Economic Journal, 106*, 92–105.

Barro, R., & Sala-i-Martin, X. (1995). *Economic growth*. New York: McGraw Hill, pp. 186–194.

Basu, S., & Weil, D. N. (1998). Appropriate technology and growth. *Quarterly Journal of Economics, 113*, 1025–1054.

Blomström, Magnus., & Kokko, Ari. (1998). Multinational corporations and spillovers. *Journal of Economic Surveys, 12*, 247–277.

Bönte, W. (2003). Innovation and employment growth in industrial clusters: Evidence from aeronautical firms in Germany. *ERSA conference papers*, ersa03, European Regional Science Association, p. 284.

Breschi, S., & Lissoni, F. (2001). Knowledge spillovers and local innovation systems: A critical survey. *Industrial and Corporate Change, 10(4), 975–1004.*

Buckley, P. J., Clegg, J., & Wang, C. (2002). The impact of inward FDI on the performance of Chinese manufacturing firms. *Journal of International Business Studies, 33*(4), 637–655.

Caves, R. E. (1974). Multinational firms, competition and productivity in host-country markets. *Economica, 41*(162), 176–193.

Chang, Y., Shih, C., Luh, Y., & Wu, S. (2006). *MNE's global R&D strategy in developing countries: A study of foreign-affiliated R&D centres in Taiwan*. Paper presented at IAMOT 2006, Tsinghua University, Beijing, 22–26 May.

Chen, D., Li, J., & Shapiro, D. (2008). *FDI Knowledge Spillovers and Product Innovations of Chinese Firms*. University of Oxford, SLPTMD Working Paper, No. 028.

Chesbrough, H. (2003). The era of open innovation. *Sloan Management Review, 44*(3), 35–41.

Coe, D., & Helpman, E. (1995). International R&D spillovers. *European Economic Review, 39*, 859–887.

Cohen, W., & Levinthal, D. (1989). Innovation and learning: Two faces of R&D. *Economic Journal*, (99), 569–596.

Dahlman, C. (2010). Innovation strategies in Brazil, China and India: From imitation to deepening technological capability in the South. In Xialon Fu, & Luc Soete (Eds.), *The rise of technological power in the South*. London and New York: Palgrave MacMillan.

Dunning, J. H. (1994). Multinational enterprises and the globalization of innovatory capacity. *Research Policy, 23*, 67–88.

Eaton, J., & Kortum, S. (1995). Engines of growth: Domestic and foreign sources of innovation. *NBER Working Papers* 5207, National Bureau of Economic Research, Inc.

Eden, L., Levitas, E., & Martinez, R. J. (1997). The production, transfer and spillover of technology: Comparing large and small multinational as technology producers. *Small Business Economics, 9*(1), 53–66.

Erdilek, A. (1984). International technology spillovers in the Middle East and North Africa. *Management Decision, 22*(2), 45–49.

Fagerberg, J. (1994). Technology and international differences in growth rate. *Journal of Economic Literature, 32*(3), 1147–1175.

Findlay, R. (1978). Relative backwardness, direct foreign investment and the transfer of technology: A simple dynamic model. *Quarterly of Journal of Economics, February*, 1–16.

Fosfuri, A., Motta, M., & Ronde, T. (2001). Foreign direct investment and spillovers through workers' mobility. *Journal of International Economics, 53*(1), 205–222.

Freeman, C., & Soete, L. (1997). *The economics of industrial innovation* (3rd ed.). London: Pinter.

Freeman, R. (2005). Does Globalization of the Scientific/Engineering Workforce Threaten US Economic Leadership National Bureau of Economic Research. *Working Paper 11457*.

Fu, X. (2004). Limited linkages from growth engines and regional disparities in China. *Journal of Comparative Economics, 32*(1), 148–164.

Fu, X. (2008). Foreign direct investment, absorptive capacity and regional innovation capabilities: Evidence from China. *Oxford Development Studies, 36*(1), 89–110.

Girma, S. (2005). Absorptive capacity and productivity spillovers from FDI: A threshold regression analysis. *Oxford Bulletin of Economics and Statistics, 67*(3), 281–306.

Görg, H., & Strobl, E. (2001). Multinational companies and productivity spillovers: A meta-analysis. *Economic Journal, 111*, F723–F739.

Griffith, R., Redding, S., & Reenen, J. V. (2004). Mapping the two faces of R&D: Productivity growth in a panel of OECD industries. *The Review of Economics and Statistics, 86*(4), 883–895.

Griliches, Z. (1979). Issues in assessing the contribution of research and development to productivity growth. *Bell Journal of Economics, 10*(1), 92–116.

Grossman, G. & Helpman, E. (1994). Technology and Trade. *NBER Working Papers* 4926, National Bureau of Economic Research, Inc.

Hoekman, B., Maskus, K. E., & Saggi, K. (2004). Transfer of technology to developing countries: Unilateral and multilateral policy options. *Policy Research Working Papers Series* No. 3332, Washington, DC: The World Bank.

Howells, J., James, A., & Malik, K. (2004). Sourcing external technological knowledge: A decision support framework for firms. *International Journal of Technology Management, 27*(2/3), 143–155.

Hu, A. G. Z., & Jefferson, G. H. (2002). FDI impact and spillover: Evidence from China's electronic and textile industries. *World Economy, 38*(4), 1063–1076.

Jaffe, A. B., Trajtenberg, M., & Henderson, R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations. *The Quarterly Journal of Economics, 108*(3), 577–598.

Javorcik, B. S. (2004). Does foreign direct investment increase the productivity of domestic firms? In search of spillovers through backward linkages. *American Economic Review, 94*(3), 605–627.

Johansson, H. (1994). The economics of export processing zones revisited. *Development Policy Review, 12*(4), 387–402.

Kokko, A., Tansini, R., & Zejan, M. (1996). Local technological capability and productivity spillovers from FDI in the Uruguayan manufacturing sector. *Journal of Development Studies, 32*(4), 602–611.

Krugman, P. (1991). Increasing returns and economic geography. *Journal of Political Economy, 99*(3), 483–499.

Lall, S. (1992). Technological capabilities and industrialization. *World Development, 20*(2), 165–186.

Lall, S. (2003). Foreign direct investment, technology development and competitiveness: Issues and evidence. In S. Lall, & S. Urata (Eds.), *Competitiveness, FDI and technological activity in East Asia, published in association with the World Bank*. Cheltenham, UK: Edward Elgar.

Lall, S. (2001). *Competitiveness, technology and skills*. Cheltenham: Edward Elgar.

Lall, S. (2005). Rethinking industrial strategy: The role of the state in the face of globalization. In K. P. Gallagher (Ed.), *Putting development first. The importance of policy space in the WTO and IFIs* (pp. 33–68). London and New York: ZED Books.

Lall, S., & Urata, S. (Eds.) (2003). *Competitiveness, FDI and technological activity in East Asia*. Cheltenham, UK: Edward Elgar.

Lokshin, B., Gils, A., & Bauer, E. (2008). Crafting Firm Competencies to Improve Innovative Performance, *UNU-MERIT Working Paper Series* 009, United Nations University, Maastricht Economic and social Research and training centre on Innovation and Technology.

Markusen, J. R. (2002). *Multinational firms and the theory of international trade. XXII*. Cambridge, Mass: MIT Press.

Marshall, A. (1920). *Principles of economics*. London: Macmillan and Co., Ltd..

Meyer, K. E. (2004). Perspectives on multinational enterprises in emerging economies. *Journal of International Business Studies, 35*, 259–276.

Narula, R. (2003). *Globalization and technology. Interdependence, innovation systems and industrial policy*. Polity Press.

Nelson, R. R. (1959). The simple economics of basic scientific research. *Journal of Political Economy, 67*, 297–306.

OECD—Organization for Economic Cooperation and Development. (2002). *Science and Technology Industry Outlook*. Paris: OECD.

Perez, C., & Soete, L. (1988). Catching up in technology: Entry barriers and windows of opportunity. In G. Dosi, *et al.* (Eds.), *Technical change and economic theory* (pp. 458–479). London: Pinter.

Pietrobelli, C. (1996). *Emerging Forms of Technological Cooperation: The Case for Technology Partnerships—Inner Logic, Examples and Enabling Environment*. Science and Technology Issues, Geneva: UNCTAD, United Nations.

Pietrobelli, C. (2000). The role of international technology transfer in the industrialisation of developing countries'. In M. Elena, & D. Schroeer (Eds.), *Technology transfer*. Aldershot UK, Burlington USA: Ashgate.

Pietrobelli, C., & Rabellotti, R. (Eds.) (2007). *Upgrading to compete: SMEs, clusters and value chains in Latin America*. Cambridge Mass: Harvard University Press.

Pietrobelli, C., & Saliola, F. (2008). Power relationships along the value chain: Multinational firms, global buyers, and local suppliers' performance. *Cambridge Journal of Economics, 32*(6), 947–962.

Romer, P. (1994). The origins of endogenous growth. *Journal of Economic Perspectives, American Economic Association, 8*(1), 3–22.

Soete, L. (1985). International diffusion of technology, industrial development and technological leapfrogging. *World Development, 13*(3), 409–422.

Stewart, F. (1983). Macro-policies for appropriate technology: An introductory classification. *International Labour Review, 122*(3), 279.

UNCTAD. (2006). *World Investment Report*, Geneva: United Nations.

Willoughby, K. W. (1990). Technology choice. A critique of the appropriate technology movement (Book). *Futurist, 24*(4), 45.

World Bank. (2007). *World Development Report*. Washington DC: World Bank.

World Bank. (2010). *World Development Indicator*. Washington DC: World Bank.

Xu, B. (2000). Multinational enterprises, technology diffusion, and host country productivity growth. *Journal of Development Economics, 62*(2), 477–493.

Zhou, Y. (2006). Features and impacts of the internationalisation of R&D by transnational corporations: China's case. In *Globalisation of R&D and Developing Countries*, New York and Geneva: UNCTAD, United Nations.