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TECHNOLOGICAL UPGRADING IN CHINA AND INDIA: WHAT DO WE KNOW?

by

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PREFACE

Over the past several decades, developing countries have enjoyed an upsurge in growth after two decades of missed opportunities and disappointing performance. Since the beginning of the 1990s, the centre of economic gravity of the world has been progressively shifting from West to East and from North to South. These changes were the result of a combination of skills development and technological upgrading in emerging economies, rising demand for commodities which favoured developing countries specialising in the exports of those commodities and improved fiscal and macroeconomic management.

China and India are regarded as the "locomotives" of this process. These emerging industrial powers are growing at unprecedented annual rates ranging between 6% and 10%. The drivers of this impressive growth are varied, and the two countries follow substantially different development models. However, a common element behind their impressive performance is increased knowledge and accumulated technological capabilities. Rising investments in skills development and in domestic R&D efforts coupled with growing FDI in knowledge intensive activities are supporting Chinese and Indian caching up.

This Working Paper by Jaejoon Woo analyses the re-emergence of China and India as major forces in the world economy, with the objective of detecting the sources of their growth. It finds that FDI inflows and imported capital goods that embody new technology were crucial for explaining technical change, and technological upgrading and diffusion. It also finds that domestic investments in human capital, promotion of skill-intensive industries and rising investment in R&D supported growth and increased the benefit from rising FDIs.

This work not only represents an important contribution to our understanding of structural transformation but also helps shed light on emerging trends and challenges. The author highlights the fact that an "enormous scope for technological catching-up over the next decades to come" exists in both countries. This requires new and better policies in China and India, but it also opens opportunities and challenges for other developing countries. The OECD Development Centre's *Perspectives of Global Development 2013* will look at the changing competitive scenario that developing and emerging economies are facing and will examine how structural change and innovation can be unlocked in the developing world. Preliminary results of that work suggest that countries need to do at least three things: *i)* implement a production development strategy to diversify and upgrade their domestic production structure and increase the commitment of the private sector to innovation; *ii)* overcome skills, infrastructure and financial barriers for innovation and *iii)* increase their participation in global knowledge networks and markets.

The uncertainty of the global scenario, with faltering prospects of growth in OECD countries, and rising demands for more balanced and inclusive development, call for a new approach to development strategies. In this model, knowledge mastering and the capability to deliver innovative solutions are paramount. Past research has helped identify the main drivers of technological change, but more work needs to be done to understand the heterogeneity in patterns of technological upgrading between countries and the policy responses that are needed to support a new innovation-centred development paradigm.

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RÉSUMÉ

Modernisation technologique en Chine et en Inde : Que savons-nous?

Ce papier étudie les sources de modernisation technologique en Chine et Inde. Ce qui est frappant dans la croissance impressionnante de la Chine et, dans une moindre mesure, de l'Inde est que ces pays exportent des produits associés à un haut niveau de productivité qui est bien plus grand qu'un pays de leur niveau de revenu. La structure des exportations de la Chine a fondamentalement changé, se diversifiant en produits intensifs en technologie. La Chine est dorénavant le plus grand exportateur du monde de produits de haute technologie. Les exportations de l'Inde restent significativement moins sophistiquées technologiquement, quoique l'Inde ait connu davantage de succès dans les exportations de services de technologie du commerce ainsi que de l'information et de la communication (TIC). Ce papier présente des preuves empiriques du rôle important des flux entrants d'IDE et des biens de capital importés comprenant la nouvelle technologie pour la croissance de PGF pour un large panel de pays avancés ou en développement sur la période 1970-2007. En ligne avec les preuves longitudinales, données microéconomiques et études de cas, il suggère fortement que les IDE et importations de biens de capital ont contribué à la rapide modernisation de technologie, particulièrement en Chine. Curieusement, cependant, le niveau de PGF en China est bien plus bas qu'espéré au regard de son Indice de Sophistication Technologique des Exportations, faisant naître le doute que la transformation de la structure des exportations vers des produits de haute-technologie est associée avec à une sophistication technologique du contenu national des produits d'exportation. Une explication importante réside dans le rôle de premier plan de la Chine en tant qu'assembleur final de la chaîne de production mondiale. La magnitude du revirement de la position nette des exportations de la China entre les deux catégories, produits intermédiaires et finaux, est saisissante, ce qui implique que les économies développées sont plus ou moins affectées et de façon très différente par la montée de la Chine. Dans l'optique d'améliorer la capacité d'absorber les technologies avancées et les innovations, la Chine et l'Inde ont mis l'accent sur le capital humain, les industries intensives en compétences et les efforts en R&D. Néanmoins, notre analyse montre qu'il reste une place énorme pour le rattrapage technologique dans les prochaines décennies.

Classification JEL : F15, F21, O33, O47, O53

Mots-clés : Modernisation technologique, transfert de technologie, PGF, croissance, classification technologique des exportations, traitement des exportations, chaine mondiale de production.

ABSTRACT

Technological upgrading in China and India: What Do We Know?

This paper studies sources of technological upgrading in China and India. What is striking about the impressive growth of China and (to a lesser degree) India is that they export products associated with a high productivity level that is much higher than a country at their income level. China's export bundle has changed dramatically, diversifying into technology-intensive products. China is now the largest exporter of high-technology products in the world. Exports of India are still significantly less technologically sophisticated, while India has been more successful in exports of business and information technology (IT) services. It presents empirical evidence on the important role of FDI inflows and imported capital goods that embody new technology for TFP growth in a large panel of advanced and developing countries over 1970-2007. Consistent with the cross-country evidence, micro-data and case studies strongly suggest that FDI and import of capital goods have contributed to rapid technological upgrading especially in China. Puzzlingly, however, the TFP level in China is much lower than would be expected from its score on Index of Technological Sophistication of exports, raising a doubt about whether the shift in export bundle towards high-technology products is associated with a technological sophistication of domestic contents of export products. An important explanation appears to be China's prime role as a final assembler of international production network. The magnitude of reversal in net export position of China across the two categories, intermediate and finished goods, is striking, which implies that more and less developed economies are being affected very differently by China's rise. With a view to upgrading the capability to absorb advanced technologies and innovate, China and India have increasingly emphasised human capital, skill-intensive industries and R&D efforts. Nonetheless, our analysis shows that there is still an enormous scope for technological catching-up over the next decades.

JEL classifications: F15, F21, O33, O47, O53

Keywords: technological upgrading, technology diffusion, TFP, growth, technological classification of export, FDI, export processing, international production network

I. INTRODUCTION

The re-emergence of China and India as major forces in the world economy is one of the most important developments in the early 21st century.[1] China's economy has expanded by leaps and bounds, growing at an unprecedented rate of near 10% per year over the last 30 years. The average annual growth rate of India has been 6% during the same period. Since 1980, real GDP per capita has increased 11-fold in China and more than tripled in India, lifting hundreds of millions of people from poverty and improving living standards. Growth has accelerated in recent decades as trade liberalisation and market-oriented reforms have deepened. In 1978, China embarked on market-oriented reforms and opened up to trade and foreign direct investment (FDI), experiencing explosive growth in its industrial sector. The rapid advance in industrial productivity has been facilitated by strong competitive pressures arising from the country's gradual but steady integration into the global market and the incorporation of world-class technology through openness to FDI. In an effort to put its economy on a path of rapid and sustained growth, India embarked on a process of economic reform and progressive integration with the global economy in 1991. India's development path thus far has been considerably different from that of China's, with growth being fueled by the expansion of service industries. Recently, FDI flows to India have grown rapidly. Yet, India's export shares in the global market are still very small, with a modest increase in export of medium- and high- technology products.

The sophistication level of technologies employed in the production often manifests in the quality and variety of the goods. What is striking about the impressive growth of China and (to a lesser degree) India is that they export products associated with a high productivity level that is much higher than a country at their income level.[2] China is now the largest exporter of high-technology products in the world. However, this is closely related to the rise of international vertical specialisation in which China has become a major final assembler in the geographically fragmented production process, while depending crucially on the imported intermediate inputs from advanced economies. From a developing economy's perspective, technological upgrading depends on the extent of adoption and implementation of new technologies that are in use in the advanced countries, that is, technology diffusion. The important mechanisms of technology diffusion include import of capital and intermediate goods that embody technologies, foreign direct investment, export activities, and international vertical specialisation (international production networks).[3] The extent of adoption and assimilation of foreign technologies is in turn

1. See OECD (2010a) on the global macroeconomic implications of the rise of these two Asian giants.
2. See Schott (2008), Rodrik (2006), and Lall *et al*. (2006).
3. See Keller (2004, 2007) and Eaton and Kortum (2001) among others.

influenced by conditions in product and factor markets, and government policies such as trade and competition policies and the protection of intellectual property rights.

The paper examines sources of economic growth and in particular technological upgrading in China and India by adopting a two-pronged approach. First, we investigate the sources of technological change and the channels of technology diffusion in a cross-country analysis. Also, we compare the technological structure of export across countries and over time. To this end, we conduct the growth and development accounting exercises, and present new evidence on the importance of FDI and imported capital equipment in technology transfer in a large panel of advanced and developing countries over 1970-2007. This allows us to put technological upgrading in China and India in a cross-country perspective. Second, we examine each channel of technological diffusion in specific Chinese and Indian contexts, while assembling micro-data evidence and case studies in the literature. In addition, we look into the role of China as a final assembler in the international production network as well as R&D efforts. Thereby, we shed some light on both macro and micro aspects of technological changes in China and India.

The paper proceeds as follows. Section II investigates sources of rapid technological upgrading in China and India, such as total factor productivity (TFP) and technological sophistication of export products. Section III examines channels of technological diffusion such as the role of FDI, import of capital goods, international production networks, and R&D efforts. It provides new cross-country evidence on technology transfer. Section IV concludes, while discussing the implications of rapid technological changes in China and India for the other developing countries in terms of technology, FDI, and required structural reforms.

Summary of main findings

From a growth accounting perspective, the industry- and capital-intensive growth pattern of China's economy is well known. However, strong TFP growth is another key feature of China's rapid growth. This is sharply different from the earlier growth patterns of East Asian miracle economies that are characterised by rapid factor accumulation. It appears not only to reflect the catch-up process and base effect (due to a very low initial TFP level) but also rapid technological upgrading in China. By contrast, India's TFP growth has been modest, but has accelerated lately. Nonetheless, our new estimates show that the TFP levels in China and India are still very low relative to those of the OECD members, indicating an enormous scope for catching-up in the next decades to come.

FDI has long been considered as an important way to access advanced foreign technology. We provide new evidence that inward FDI flows are significantly positively associated with TFP growth in a panel of 90 countries over 1970-2007. FDI appears to be a main source of technological upgrading in China. China is among the world's largest hosts of FDI inflows. Foreign-invested enterprises are primarily engaged in export processing of medium- and high-tech products. A recent surge in Chinese patent applications is also related to FDI. However, FDI flows into India are still lagging behind China, although they have begun to accelerate lately. Imported capital goods that embody new technology are another channel of transmitting knowledge spillovers across countries. Our new econometric analysis presents supporting evidence for this view. There has been an astonishing increase in capital equipment imported into China over 1995-2008 during which technological structure of export products has shifted dramatically towards high-technology categories.

China's export bundle has changed dramatically, diversifying into capital- and technology-intensive products. China's export structure is increasingly more similar to those of high-income countries such as the US, Japan, and Germany than those of Brazil, Russia and other low-income countries. By contrast, exports of India are significantly less technologically sophisticated than in the rest of Asian region, while India has been more successful in exports of business and information technology (IT) services. Our new index of technological sophistication (ITS) confirms the sharp increase in export sophistication in China. It also suggests that technological upgrading is an outcome of long, cumulative processes of learning, and assimilation of advanced technology, and that moving from a low-technology structure to a high-technology one is a challenging goal for many developing countries. The ITS scores have changed little for most of the countries. Puzzlingly, the TFP level in China is much lower than would be expected from its ITS score, raising a doubt about whether the observed increase in export of high-technology products is associated with a technological sophistication of domestic contents of export. This is true, regardless how it is measured (*e.g.* TFP level, domestic value-added of technically sophisticated products, or domestic skill contents of exports). An important explanation for this appears to be China's prime role as a final assembler in the international production network.

The strongest export growth of China has been in high-technology products including office and data processing equipments and telecommunication. This is closely related to the emergence of international production networks, as production stages become increasingly fragmented geographically. Evidence strongly suggests that China plays a primary role as a final product assembler, engaging in processing exports. China's import of manufactures is disproportionally skewed towards parts and components, whereas its export of manufactures is largely in the category of finished goods. In 2007, China's export of finished goods account for 59% of its total manufactures exports and import of finished goods account for 33% of its total import. In sharp contrast, China's import of parts and components account for 66% of its total manufactures import and its export is only 35% of its total export. Although similar patterns are observed in other countries such as the Philippines, Malaysia and Mexico, the magnitude of reversal in net export position of China across the two categories (intermediate and finished goods) is striking. This implies that more and less developed economies are being affected very differently by China's rise. Chinese gains in export shares (particularly in finished goods) come at the cost of other countries that compete head to head with China in third markets. This may provide greater incentives for other countries to move up the technological ladder into the production of more technologically-intensive exports. Yet, countries that produce raw materials, parts and components, and capital equipments utilised heavily in Chinese manufacturing would benefit from China's export growth.

In recent years, China and India have emphasised the skill-intensive industry rather than labour-intensive industry in which they may have a comparative advantage, given their abundant labour endowment. A rapid increase in R&D intensity and focus on higher education are consistent with the goal of upgrading quality and skill contents of production. China has the second largest stock of human resources in science and technology in the world, and is one of the few developing countries whose level of R&D intensity has risen beyond 1% of GDP. India's R&D intensity is getting close to 1% of GDP. However, the increased R&D efforts are not translating into stronger performance in many technological indicators yet. Also, these economies still lag behind the advanced economies in terms of educational attainments. Large increases in foreign R&D investment in Asia, in particular in China and India, have attracted much attention. Looking forward, this shift is expected to continue to the extent that these countries offer a combination of relatively low wages with a large pool of well-trained researchers.

II. TECHNOLOGY AND QUALITY AND VARIETY OF EXPORT PRODUCTS: CHINA AND INDIA IN A CROSS-COUNTRY PERSPECTIVE

II.1. Technology and Total Factor Productivity (TFP)

In order to investigate sources of rapid technological upgrade and increasing sophistication of products in China and India, we focus on important aspects of technology such as TFP and technological structure of export. Let us begin with the growth accounting framework. Taking a neoclassical approach, consider a standard Cobb-Douglas production function:

$$Y = K^{\alpha}(A \cdot H)^{1-\alpha} \tag{1}$$

where Y is aggregate output; K denotes physical capital stock; H is the human-capital augmented labour input; A (TFP) takes the form of labour-augmenting (Harrod-neutral) technological progress. Growth of output will depend on the rate of change of those three factors, and the growth rate of TFP, which is obtained as a residual in the growth accounting, is often ascribed to technological progress (see Box 1).

In recent years, debates over the relative importance between factor accumulation (K and H) and TFP in raising income per capita took a dramatic turn. Several studies have found that more than half of the cross-country variation in both income per capita and its growth results from differences in TFP and its growth, respectively (Hulten and Isaksson, 2007; Caselli, 2005; Parente and Prescott, 2001; Hall and Jones, 1999).[4] See Figure 1a for a scatter plot of labour productivity growth (measured by output per worker) against TFP growth over 1970-2007, and Figure 1b for a scatter plot between the two variables at the level in 2007. The positive correlation between them is striking. This finding suggests that, in order to understand the growth of nations, it is important to develop a better understanding of the forces that shape TFP.

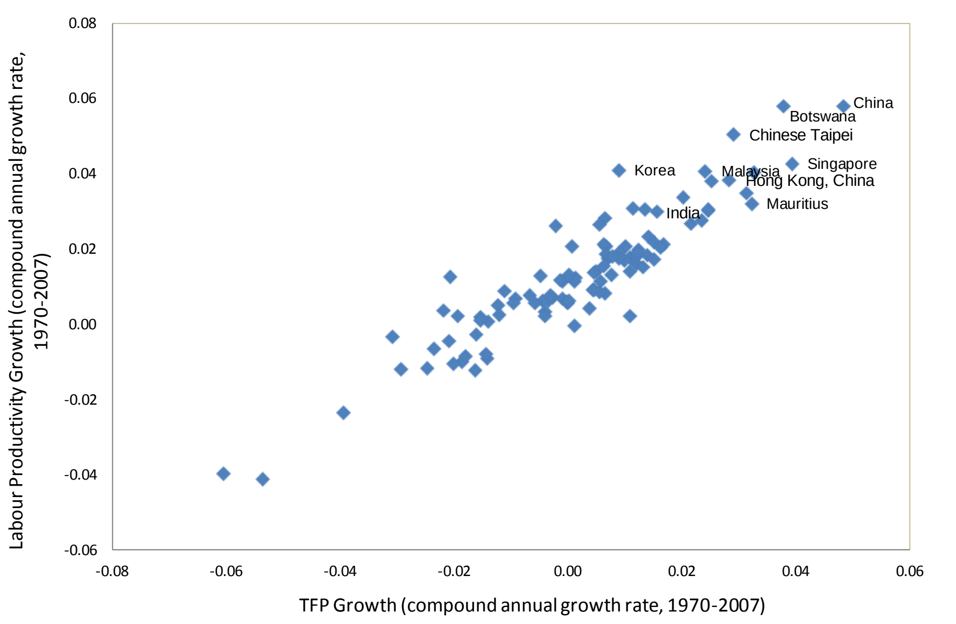
Technological change is an important determinant of TFP. This was Robert Solow (1957)'s original view as well as the view of many economists in the literature (Guinet *et al.*, 2009). Endogenous growth models provide rigorous theoretical frameworks for understanding the economic forces underlying technological change. The models have largely focused on two important types of technological change: *i)* innovation through R&D; and *ii)* technology diffusion through assimilating and adapting advanced foreign technology (see Romer, 1990, 1992; Grossman and Helpman, 1991; Coe *et al.*, 1997; Barro and Sala-i-Martin, 2003 among others).

4. This finding is in sharp contrast with Mankiw *et al.* (1992) who argue that differences in physical and human capital account for most of the observed international differences in income per capita.

Many of the earlier empirical studies focused on the effects on growth of innovation (measured by R&D expenditure or the number of scientists). The evidence on the positive impact on growth of innovation is substantial (Helpman, 2004).

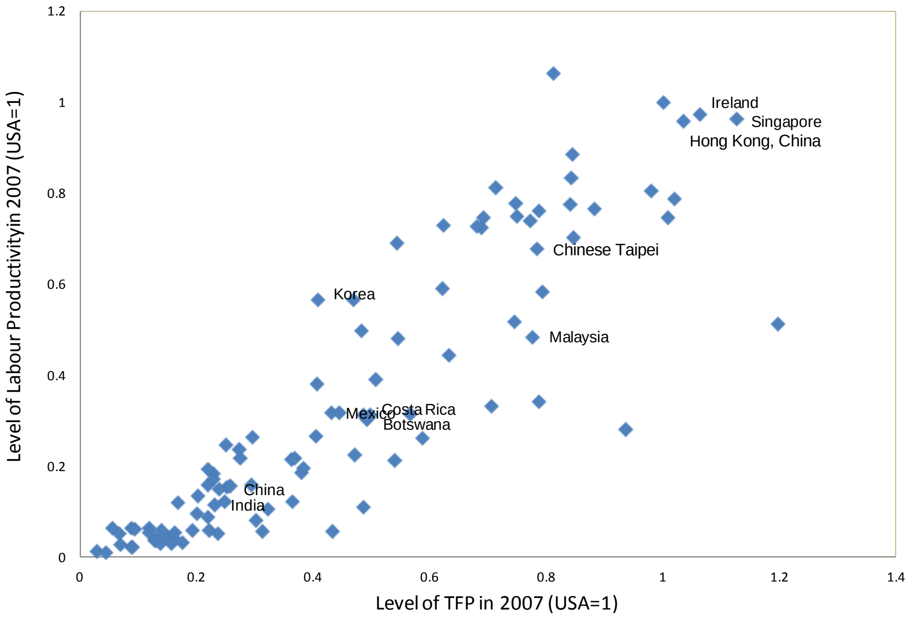
The other channel of technological change, technology diffusion, is relatively more important for developing countries. In a developing country context, technological progress depends on the extent of adoption and implementation of new technologies that are in use in the advanced countries. The important mechanisms of technology diffusion include import of capital and intermediate goods that embody technologies, FDI, export activities (learning by doing, economies of scale), vertical specialisation (global value chain), and technology licensing (see Keller, 2004, 2007; Eaton and Kortum, 1996, 2001 among others). The extent of adoption and assimilation of foreign technologies is in turn influenced by conditions in product markets (including market size), factors (such as skilled labour), and government policies and institutions (such as trade and competition policies and the protection of intellectual property rights).

Figure 1a. TFP Growth and Labor Productivity Growth, 1970-2007



Source: Author's caclulation bsed on Penn World Table 6.3

Figure 1b. Labour Productivity and TFP Levels in 2007 (USA=1)



Source: Author's calculation based on Penn World Table 6.3

Next, we compare TFP and its growth performance of China and India with other countries by using a newly constructed TFP dataset based on the Penn World Table 6.3 (2009). The labour productivity in China and India as measured by output per worker are 16% and 11% of that of US workers in 2007, indicating there is an enormous scope for catch-up (Table 1). The TFP levels as a measure of technology (or overall efficiency) in China and India are 25% and 23% of the US counterpart, respectively. Also, China and India significantly lag behind advanced economies in terms of overall education attainments.[5]

5. The level of physical capital stock per worker in China and India (14% and 8% of the US counterpart, respectively) also indicates a potential for substantial capital accumulation in the future, despite rapid capital accumulation in recent decades.

Box 1. **Growth Accounting**

Taking a standard neoclassical approach, we consider a Cobb-Douglas aggregate production function, $Y = (K)^{\alpha}(AH)^{1-\alpha} = K^{\alpha}(AhL)^{1-\alpha}$, where K denotes the stock of physical capital, H is the human-capital augmented labour input, A (TFP) takes the form of labour-augmenting (Harrod-neutral) technological progress, h (≡H/L) is human capital per worker, and $1-\alpha$ is labour income share. We can conduct a development accounting to get a TFP level. The Cobb-Douglas function can be rearranged into $\frac{Y}{L} = (\frac{K}{Y})^{\alpha/(1-\alpha)} hA$, so that the level of TFP (A) is then obtained as $A = \frac{Y}{L}(\frac{K}{Y})^{-\alpha/(1-\alpha)} h^{-1}$, where $\frac{Y}{L} = \text{output per worker}$.[6]

Also, we can rewrite the aggregate production function in terms of growth rates, $\frac{\dot{Y}}{Y} = (1-\alpha)\frac{\dot{A}}{A} + \alpha\frac{\dot{K}}{K} + (1-\alpha)(\frac{\dot{h}}{h} + \frac{\dot{L}}{L})$, which is known as the growth accounting equation. Note that $\dot{X}/X = \text{growth rate of } X$. The growth rate of TFP ($\dot{A}/A$) is then obtained as a residual after accounting for the contribution to output growth from physical capital (K), human capital (h) and labour input (L). That is, $\frac{\dot{A}}{A} = \frac{1}{1-\alpha}\left[\frac{\dot{Y}}{Y} - \alpha\frac{\dot{K}}{K} - (1-\alpha)(\frac{\dot{h}}{h} + \frac{\dot{L}}{L})\right]$.

In fact, the growth accounting is consistent with a wide range of alternative production functional forms linking the factor inputs and output. It is only necessary to assume a degree of competition sufficient so that the earnings of the factors are proportionate to their factor productivity. Then we can measure TFP growth rates, using the shares of income paid to the factors to measure their importance in the production process as described above (see Caselli, 2005; Bosworth and Collins, 2003 for details). Since consistent measures of factor income shares are often difficult to obtain for individual countries, most studies assume that income shares are identical across time and space. However, Gollin (2002) provides strong evidence in support of such an assumption of constant income shares across time and space, which is consistent with the Cobb-Douglas function approach. Also, Bernanke and Gürkaynak (2001) find no systematic tendency for labour shares to vary with real GDP per capita or the capital-labour ratio nor

6. In our paper, the production function assumes Harrod-neutral technological change, as opposed to Hicks-neutral technical change ($Y = AK^{\alpha}(hL)^{1-\alpha}$). In practice, capital investment is partly an endogenous response to changes in aggregate output such as associated with changes in TFP. This issue can be addressed by assuming Harrod-neutral technical change that would limit capital's contribution to increases in the capital-output ratio (Hall and Jones, 1999). However, it amounts to assuming that capital stock will simply and automatically adjust to all deviations in the growth rate of output induced by TFP changes. This formulation may result in a dominant role for the residual, TFP. If Hicks-neutral technical change were assumed, the TFP growth is simply $\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \alpha\frac{\dot{K}}{K} - (1-\alpha)(\frac{\dot{h}}{h} + \frac{\dot{L}}{L})$. On the other hand, the Hicks-neutral technical change may lead to overstatement of capital's contribution, giving a relatively smaller role for TFP's contribution for the same reason. Nonetheless, the results under the Hicks-neutral technological progress are qualitatively much the same as those presented in the paper.

systematic tendency to rise or fall over time, and most estimated labour income shares lie between 0.6 and 0.8, the average being 0.65. In this paper, we tried both a fixed labour share of 0.65 and actual income shares from Gollin (2002) and Bernanke and Gürkaynak (2001). The results using alternative income share measures are very similar, suggesting that using a fixed labour income share is indeed not a serious problem.

We construct a new data set on TFP for 104 developed and developing countries over 1970-2007. National income and product account data and labour force data are obtained from the Penn World Table (PWT) 6.3 of Heston *et al.*, 2009. To construct the labour quality index for human capital (h), we take average years of schooling in the population over 15 years old from an international data on educational attainment of Barro and Lee (2000). We obtain data on years of schooling in 2005 and 2007 by extrapolation. We follow Hall and Jones (1999) and Klenow and Rodriguez-Clare (1997) to give larger weight to more-educated workers as follows: $h = e^{\phi(E)}$, where E is average years of schooling, and the function $\phi(E)$ is piece linear with slope of 0.134 for $E \leq 4$, 0.101 for $4 < E \leq 8$, and 0.068 for $8 < E$. The rational behind this functional form for human capital is as follows. The wage of a worker with E years of education is proportional to his human capital. Since the wage-schooling relationship is widely believed to be log-linear, this would imply that human capital (h) and education (E) would have a log-linear relation as well, such as $h=\exp(const \times E)$. However, international data on education-wage profiles (Psacharopulos, 1994) suggests that in Sub-Saharan Africa (which has the lowest levels of education) the return to one extra year of education is about 13.4%, the world average is 10.1%, and the OECD average is 6.8%. Thus, Hall and Jones's specification above reconciles the log-linearity at a country level with the convexity across countries. Also, we tried an alternative specification for human capital, assuming an average social return to education of 7% per year of schooling: $h=(1.07)^E$. Again, the results are very similar.

We estimate the capital stock, K, using the perpetual inventory method: $K_t = I_t + (1-\delta)K_{t-1}$, where I_t is the investment and δ is the depreciation rate. Data on I_t are from PWT 6.3 as real aggregate investment in PPP. For many countries in our sample, investment data go back to as early as 1950-1955. We estimate the initial value of the capital stock, say, in year 1950 as $I_{1950}/(g+\delta)$ where g is the average compound growth rate between 1950 and 1960, and δ is the depreciation rate (δ=0.06 is assumed). We further adjust these capital stocks for the portion of residential capital stock that is not directly related to production activity.[7] Batteries of consistency checks suggest that our estimates of TFP growth are reasonable.

7. PWT 5.6 provides data on residential capital per worker as a fraction of non-residential capital per worker for 63 countries. For these countries we use the average ratio of non-residential capital to total capital to impute the non-residential capital stock in our data set. For the remaining countries, we assume that non-residential capital is two-thirds of the total capital, which is about the average value of 0.69 for the countries for which we have data in our country sample.

Table 1. **Comparison of Productivity Level for Selected Countries in 2007 (USA =1)**

Country	Output per worker (Y/L)	Decomposition		
		TFP(A)	Human capital (h)	Physical capital-Output $((K/Y)^{\alpha/(1-\alpha)})$
OECD[a]	0.78	0.79	0.86	1.16
Asia (except Japan)	0.31	0.41	0.67	0.98
Japan	0.69	0.54	0.85	1.51
Singapore	0.96	1.13	0.74	1.15
Hong Kong, China	0.96	1.03	0.83	1.11
Chinese Taipei	0.68	0.78	0.82	1.06
Korea	0.57	0.41	0.95	1.46
Malaysia	0.48	0.78	0.70	0.89
Thailand	0.19	0.22	0.69	1.28
China	**0.16**	**0.25**	**0.66**	**0.95**
Philippines	0.13	0.20	0.8	0.84
Indonesia	0.12	0.25	0.6	0.84
India	**0.11**	**0.23**	**0.6**	**0.83**
Latin America	0.24	0.4	0.66	0.98
Chile	0.52	0.74	0.75	0.93
Argentina	0.39	0.51	0.82	0.94
Costa Rica	0.31	0.48	0.64	1.01
Mexico	0.32	0.43	0.72	1.03
Brazil	0.22	0.47	0.59	0.81
Colombia	0.19	0.38	0.59	0.83
Sub-Saharan Africa	0.09	0.24	0.48	0.72
South Africa	0.34	0.79	0.66	0.66

Notes: The average of 22 OECD member countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, USA, United Kingdom.

Source: Author's calculation using data from Penn World Table 6.3.

While the levels of the TFP are still very low, China and (to a lesser degree) India have experienced strong TFP growth in the last decade. Growth rates of output in China and India have accelerated to 9.52% and 7.95% per year during 2000-07 up from 7.42% and 4.53% per year during 1970-2000, respectively (Table 2). In 2000-07, the contribution of TFP to output growth in China is remarkable at 5.23% per year, compared to that of physical capital growth at 3.36% per year.[8] In fact, the contribution of TFP to output growth (5.21% per year) was already more important than capital growth (3.49% per year) in 1990-2000. During 1970-2000, the contribution

8. The estimates of TFP growth depends partly on the underlying assumption on the capital income share (α) and whether the technological progress is Harrod-neutral versus Hicks-neutral, as discussed earlier. Bosworth and Collins (2008), IMF (2006) and our paper use a capital income share of near 0.4, while He and Kujis (2007) use 0.5.

of TFP and that of physical capital stock to output growth are about the same (2.65% and 2.89% per year, respectively). Overall, the contribution of TFP is 3.14% per year the entire period of 1970-2007, which is consistent with the estimates of China's TFP growth in the literature that are in the range of 3-4% per year for various time periods (*e.g.* He and Kuijs, 2007; OECD, 2010b). While the industry- and capital-intensive growth pattern is well-known, strong TFP growth is another key feature of the Chinese economy. This sharply contrasts with the earlier growth patterns of East Asian miracle economies (such as Hong Kong, China; Korea; Singapore; Chinese Taipei and Thailand) that were primarily driven by factor accumulation, rather than TFP growth. It may not only reflect the catch-up process due to the initially low TFP level but also rapid technological upgrading in China. It is noteworthy that the contribution of labour input and human capital to output growth during 2000-07 is about half of that in 1970-2000. This seems to reflect very sluggish growth in employment (barely 1% per year), despite the explosive growth in the number of undergraduate and graduate students in the last decade.

In India, growth of TFP has accelerated to 2.94% per year in 2000-07, sharply up from 0.76% and 0.57% per year in 1990-2000 and 1970-2000, respectively.[9] Also, the contribution physical capital to growth has increased to 2.86% per year in 2000-07 up from 1.98% and 1.84% per year in 1990-2000 and 1970-2000, respectively. Labour input and human capital have contributed about 2% points to output growth throughout the entire period, 1970-2007.

Interestingly, the relative importance of TFP in output growth has risen and that of physical capital stock has fallen noticeably in East Asian miracle economies with an exception for Chinese Taipei, compared to those of 1970-2000: TFP growth accounts for 25-57% of output growth in 2000-07, compared to 6-32% in 1970-2000. Physical capital growth accounts for 15-41% of output growth in 2000-07, in contrast to 35-55% in 1970-2000. This reflects a significant decline in investment after the 1997 Asian financial crisis. Also, many of Latin American and Sub-Saharan African countries have posted strong economic growth in 2000-07 and positive TFP growth on average for the first time in decades. Many resource rich countries in the regions have benefited from strong growth worldwide in the run-up-to the global crisis as well as from the rise of China and India which has generated substantial increase in demand for raw materials (OECD, 2010a). In sharp contrast, most of these countries had experienced very low or negative TFP growth amid anaemic economic growth in the earlier decades (*e.g.* the "lost decade" in Latin America after the sovereign debt crisis in the early 1980s).

9. Again, the TFP growth estimate is comparable to that of Bosworth and Collins (2008) who estimate the TFP growth in India to be 2.3% per year in 1993-2005 – they assume the Hicks-neutral technological progress in the aggregate production function.

Table 2. **Growth Accounting for Selected Countries: 1970-2000 and 2000-2007**

(per annum)

Country	**Growth of Output (Y) (% per annum)**	**Contributed to output growth by**			**Growth of output per worker (Y/L) (% per annum)**
		TFP (A)	**Labour (L) and Human capital (h)**	**Physical capital (K)**	
2000-07 Period					
OECD (average)	2.51	0.37	0.97	1.17	1.51
Asia (except Japan)	4.89	1.48	1.85	1.56	2.77
Japan	1.29	0.8	0.09	0.40	1.52
Singapore	5.5	2.1	2.33	1.06	3.11
Hong Kong, China	4.72	2.69	0.92	1.11	3.44
Chinese Taipei	3.68	0.93	1.22	1.53	2.34
Korea	4.18	1.24	1.26	1.67	2.86
Malaysia	5.16	1.75	2.17	1.25	2.63
Thailand	4.96	2.81	1.34	0.81	3.93
Philippines	4.81	1.75	2.20	0.86	2.06
Indonesia	4.46	1.75	2.03	0.68	2.49
China	**9.52**	**5.23**	**0.93**	**3.36**	**8.56**
India	**7.95**	**2.94**	**2.16**	**2.84**	**5.66**
Latin America	3.76	0.88	1.97	0.92	1.39
Chile	4.64	0.89	1.68	2.08	2.65
Argentina	3.99	1.77	1.61	0.62	1.99
Costa Rica	4.71	0.56	1.92	2.23	2.25
Mexico	2.39	-0.53	1.71	1.21	0.3
Brazil	3.35	0.57	2.22	0.56	0.93
Colombia	4.51	1.43	1.81	1.27	2.31
Peru	5.13	1.34	2.88	0.92	1.95
Sub-Saharan Africa	4.39	1.13	1.87	1.39	2.02
South Africa	4.40	1.70	1.44	1.26	2.99
Average, 104 countries	3.97	1.05	1.67	1.25	2
1970-2000 Period					
OECD (average)	2.92	0.60	1.13	1.18	1.78
Asia (except Japan)	5.61	0.80	2.28	2.52	2.97
Japan	3.17	0.31	0.91	1.94	2.27
Singapore	8.26	2.66	2.75	2.85	4.55
Hong Kong, China	6.54	1.64	2.20	2.7	3.94
Chinese Taipei	7.98	2.11	2.12	3.76	5.68
Korea	7.15	0.42	2.83	3.90	4.39
Malaysia	7.77	1.52	2.73	3.52	4.42
Thailand	6.18	1.35	2.04	2.79	3.77
Philippines	3.96	-0.31	2.62	1.65	1.04
Indonesia	6.13	0.49	2.37	3.27	3.23
China	**7.42**	**2.65**	**1.88**	**2.89**	**5.18**
India	**4.53**	**0.57**	**2.1**	**1.86**	**2.39**
Latin America	2.91	-0.62	2.25	1.27	0.22
Chile	4.04	1	2.03	1.01	1.52
Argentina	1.95	-0.74	1.82	0.87	-0.05
Costa Rica	3.85	-0.88	2.76	1.97	0.31
Mexico	3.92	-0.85	3.19	1.59	0.25
Brazil	3.98	-0.36	2.53	1.82	0.68
Colombia	3.79	-0.62	2.87	1.54	0.23
Peru	2.13	-1.46	2.99	0.6	-1.4
Sub-Saharan Africa	2.78	-0.82	2.23	1.37	0.06
South Africa	2.78	-0.39	2.08	1.09	0.09
Average, 104 countries	3.39	-0.18	2.03	1.54	1.06

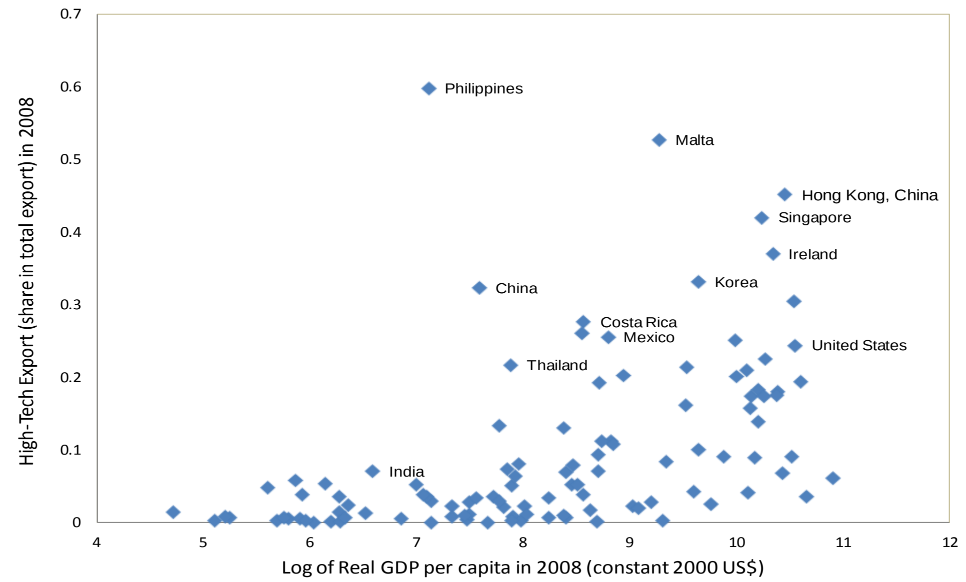
Source: Author's calculation using data from Penn World Table 6.3.

II.2 Technological Structure of Export

The sophistication level of technology employed in the production manifests in quality and variety of goods and services, which can be directly observable from the export structure. In this section, we examine the technological structure of export and export performance of developed and developing countries including China and India over 1985-2008. What is striking about the impressive growth of two emerging giants in Asia, China and India, is that they export products associated with a high productivity level that is much higher than a country at their income levels (Rodrik, 2006; Schott, 2008). In particular, China has been increasingly diversifying its exports into complex, capital- and technology-intensive products, although its exports are still largely labour-intensive.

Richer countries tend to export more high-tech products than poorer countries (Figure 2). However, China and (to a much lesser degree) India stand out in terms of a much greater high-tech export share relative to their low per capita income level. It is worthwhile to note that high-tech products make up nearly 60% of the Philippines' total exports, which is higher than any country and region (See Haltmaier *et al.*, 2007 about the Philippines electronic sector and the role of global supply chain).

Figure 2. High-Tech Export and GDP per capita in 2008



Source: Author's calculation based on UN COMTRADE (2009) and WDI (2009)

China has been pursuing a two-pronged strategy, rather than pursuing an export-growth strategy predicated on specialisation according to its apparent comparative advantage in low-skill and labour-intensive products. While they capitalise on its abundant labour by promoting job-creating labour-intensive manufactures, they also pursue rapid upgrading of their economy by producing and exporting higher-technology products (OECD, 2006).

Now we compare the technological sophistication of export products across countries and over time. The changes in sophistication of products can be viewed as reflecting the technological capability of an economy, although a country may have the technology to produce certain products and yet may or may not specialise in them as other factors affect its comparative advantage. The trade pattern of a country is influenced by many factors including factor endowments, technology, and geographical agglomerations associated with increasing returns to scale and externalities. Yet, technology plays an important role in determining the dynamic comparative advantage. Given the required access to foreign advanced technology and learning process, not many developing countries have succeeded in upgrading the quality and expanding varieties of export products, such as shifting from low-technology, low-skill and labour-intensive products to high-technology and high-skill products. In this regard, China's export growth with a tremendous increase in the product variety is special. While China was present in 9% of all manufacturing product categories in 1972, it was present in 70% of categories by 2001 (Schott, 2008).

We consider the following technological classifications of export structure: primary products (PP), agricultural resource-based manufactures (RB1), other resource-based manufactures (RB2), low-technology textile manufactures (LT1), low-technology manufactures of other products (LT2), medium-technology automotive products (MT1), medium-technology process goods such as chemicals and basic metals (MT2), medium-technology engineering products (MT3), high-technology electronics (HT1), and other high-technology products (HT2). See Box 2.

Box 2. **Technological Classification of Export**

There are various ways to categorise products by the levels of technology. A popular methodology (Lall, 2000) is to distinguish among primary products, resource-based manufactures, low-technology manufactures, medium technology manufactures, and high-technology manufactures. It improves upon previous classifications from OECD (1994). The technological classifications can provide valuable information on different levels of technology used in disaggregated export activities and their upgrading over time. In this paper, we use export data from the most comprehensive data set, UN COMTRADE, at the 3-digit SITC, Rev.3. We follow the classification from Lall (2000) that is adapted in accordance to SITC, Rev.3 from Rev.2 by Haltimaier *et al.*, 2007.

However, there are some drawbacks. The classification at this 3-digit level sometimes puts together products at the different levels of technological complexity under the same category. For example, telecommunication apparatus includes highly advanced mobile telephone technology as well as a simple plastic telephone set. Importantly, the sharp rise of international production network (global value chain) makes the technological classification complicated. The aggregate trade statistics does not tell about the process involved in the global value chain supply across different locations (we will return to this issue later). Take the case of iPod, which is assembled in China using 451 generic parts from different countries and is exported to the US and other countries. In trade statistics, the Chinese export value for a unit of 30GB video iPod in 2007 was USD 299. But the best estimate of the value added attributable to producers in China was only USD 4, with the bulk of value being in the concept and design of the iPod at Apple headquarters in the US and the remaining value added coming from the US, Japan and other countries (Varian, 2007). Finally, the export values do not show technological upgrading over time within each product category. With these caveats, we examine the technological levels of major exports of countries in our sample.

Technological classifications are as follows:

- Resource-based (RB) products tend to be simple and labour-intensive (*e.g.* food or leather processing), and competitiveness advantages in these products generally rise from natural resource endowments. Some segments are characterised by skill- and capital-intensive technologies. A further distinction is made into RB1 (agro-based products such as processed foods/meats, vegetable oils, and beverages) and RB2 (others such as petroleum, cement, ore concentrates).
- Low-technology (LT) manufactures tend to have stable, well-diffused technologies that are often embodied in the capital equipment. The low end of the range has relatively simple skill requirements. This category includes low-technology products based on simple technologies in high-quality segments where brand names, skills, design and technological sophistication are very important. A further distinction is made into LT1 (textile, garment, footwear) and LT2 (simple metal parts/structures, furniture, toys, and plastic products). LT1 group of products has undergone massive relocation from rich to poor countries, with assembly operations shifting to low-wage areas and complex design and manufacturing functions remaining in the advanced countries.
- Medium-technology (MT) products comprise of the bulk of skill- and scale-intensive technologies in capital goods and intermediate products. They tend to have complex technologies, with moderately high levels of R&D, advanced skill needs and lengthy learning process. Those in the engineering and automotive sub-groups have extensive supply networks, and need considerable interactions between firms to reach best practice technological efficiency. A further distinction is made into MT1 (automotive products such as automobiles and parts), MT2 (processing industries such as chemicals and basic metals), and MT3 (engineering products such as engines, motors, industrial machinery, and ships).The relocation of labour-intensive processes to low-cost countries is not spread yet.
- High-technology (HT) products have advanced and fast-changing technologies, with high R&D investments and primary emphasis on product design. The most advanced technologies require sophisticated technology infrastructures, high levels of specialised technical skills and close interaction between firms and between firms and research institutions. Some of the products like electronics have a final labour-intensive assembly stage which has been massively relocated to low-cost countries as a part of the rising international production networks. In recent years, China has been dominant as a final assembler in the production networks. A further distinction is made into HT1 (electronics including office/data processing/telecommunications equipments and electrical products) and HT2 (pharmaceuticals, aerospace, optical/precision equipments).

Table 3 shows the world leading fifteen exporters across three technological categories (high-, medium-, and low-technology) in 1995 and 2007. China's export performance is striking. In 2007, China was the largest exporter of high- and low-technology products, accounting for 15% and 19% of total exports in the world, respectively.[10] Compared to year 1995, China made the biggest gains in medium- (from 16th to 4th rank) and high-technology (from 13th to 1st rank) categories. China is also dominant in low-technology exports, accounting for 19% of total exports in 2007. By contrast, the Indian export share of the world total is very small. In 2007, its export shares in high- and medium-technology categories were 0.3% and 0.09% of world total, respectively.[11]

10. In 2004, China became the world's leading exporter of ICT (information communication technology) products (OECD, 2006).

11. However, India has been more successful in exports of business services and of information and IT services (Bosworth and Collins, 2008).

Table 3. **World Leading 15 Exporters of High- Medium- and Low-Technology Products**

	High-Tech			**Medium-Tech**			**Low-Tech**		
Year 2007 ranking	Country	Export (USD mil)	Share (%)	Country	Export (USD mil)	Share (%)	Country	Export (USD mil)	Share (%)
1	China	409663	15	Germany	610066	15	China	384474	19
2	United States	311634	12	United States	411103	10	Germany	170388	9
3	Germany	236260	9	Japan	394413	10	Italy	133030	7
4	Hong Kong, China	154828	6	China	280454	7	United States	114216	6
5	Japan	149454	6	Italy	214286	5	Hong Kong, China	95087	5
6	Singapore	141202	5	France	203565	5	France	79670	4
7	Korea	123216	5	United Kingdom	150728	4	Belgium	66352	3
8	France	110759	4	Korea	149775	4	United Kingdom	60152	3
9	Chinese Taipei	105678	4	Belgium	142932	4	Japan	59785	3
10	Netherlands	103404	4	Canada	122496	3	Netherlands	45874	2
11	United Kingdom	79066	3	Netherlands	110402	3	Chinese Taipei	43639	2
12	Malaysia	72529	3	Spain	104734	3	Spain	40519	2
13	Belgium	69451	3	Mexico	97099	2	Korea	40239	2
14	Mexico	63951	2	Hong Kong, China	69831	2	Turkey	38144	2
15	Switzerland	50764	2	Chinese Taipei	64103	2	India	37797	2
	Total Above	2181860	81	Total Above	3125988	77	Total Above	1409365	71
	World Total	2688522		World Total	4066613		World Total	1973202	
1995									
1	United States	164090	17	Germany	241379	15	Germany	78242	9
2	Japan	138202	15	Japan	224550	14	Hong Kong, China	74554	9
3	Germany	80115	8	United States	195911	12	Italy	74387	9
4	Singapore	63115	7	France	100861	6	China	69525	8
5	United Kingdom	62163	7	Italy	92041	6	United States	60473	7
6	France	52763	6	United Kingdom	75903	5	France	44412	5
7	Hong Kong, China	38437	4	Canada	67109	4	Japan	37887	4
8	Korea	38391	4	Belgium/Luxembourg	61319	4	United Kingdom	35485	4
9	Chinese Taipei	36899	4	Korea	43920	3	Chinese Taipei	33272	4
10	Netherlands	31743	3	Netherlands	42723	3	Belgium/Luxembourg	30653	4
11	Malaysia	30235	3	Hong Kong, China	41892	3	Korea	27599	3
12	Italy	22542	2	Spain	38651	2	Netherlands	22557	3
13	China	19350	2	Switzerland	34340	2	Spain	15521	2
14	Canada	18716	2	Mexico	31506	2	Thailand	15192	2
15	Mexico	16366	2	Chinese Taipei	30220	2	Canada	14794	2
	Total Above	813127	86	Total Above	1322324	84	Total Above	634555	75
	World Total	944710		World Total	1570713		World Total	846480	

Source: Author's calculation based on UN COMTRADE (2009), SITC Rev 3. See Box 2 for technological classification.

Table 4 presents the largest 15 exporters among non-advanced economies. China is the number one in all three categories. India is now among the top 15 exporters for high- and low-technology products, but its export shares in 2007 are close to those in 1995. Across all three categories, Chinese gains in export shares appear to come at the cost of other countries. Other major exporters of medium and high technology products such as Hong Kong, China; Korea; Singapore; Chinese Taipei; Malaysia and Mexico lost some ground. Figures 3a and 3b compare the export shares across ten technological sub-categories between 1995 and 2007 for China and India, respectively. In the case of China, there is a notable move out of agricultural, apparel, textiles, footwear and toys and into electronics, telecommunication, and office machines with the strongest export growth in electronics and electrical products (HT1) and engineering products (MT3). Similarly, India experienced a decline in its export shares of primary and low-technology products. However, the increase in higher-technology product share has been modest.

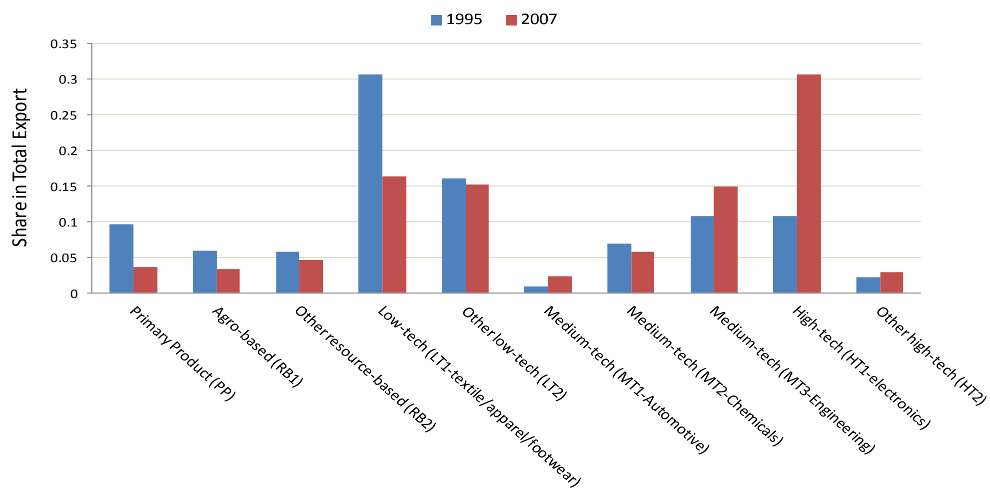
Table 4. Leading 15 Exporters of High- Medium- and Low-Technology Products among Non-Advanced Economies[a]

	High-Tech			Medium-Tech			Low-Tech		
Year 2007 ranking	Country	Export (USD mil)	Share (%)	Country	Export (USD mil)	Share (%)	Country	Export (USD mil)	Share (%)
1	China	409663	31	China	280454	22	China	384474	38
2	Hong Kong, China	154828	12	Korea	149775	12	Hong Kong, China	95087	9
3	Singapore	141202	11	Mexico	97099	7	Chinese Taipei	43639	4
4	Korea	123216	9	Hong Kong, China	69831	5	Korea	40239	4
5	Chinese Taipei	105678	8	Chinese Taipei	64103	5	Turkey	38144	4
6	Malaysia	72529	6	Poland	55468	4	India	37797	4
7	Mexico	63951	5	Singapore	54225	4	Poland	30738	3
8	Thailand	37989	3	Czech Rep.	52068	4	Mexico	28344	3
9	Philippines	31946	2	Thailand	45513	4	Czech Rep.	24897	2
10	Hungary	27328	2	Brazil	39666	3	Thailand	23176	2
11	Czech Rep.	24525	2	Turkey	38038	3	Viet Nam	18168	2
12	Poland	13418	1	Hungary	36376	3	Singapore	17502	2
13	Brazil	11516	1	Russia	31536	2	Indonesia	17076	2
14	Slovak Rep.	9825	1	Malaysia	28608	2	Malaysia	17058	2
15	India	8771	1	Slovak Rep.	25844	2	Brazil	14050	1
	Total Above	1236320	95	Total Above	1068560	82	Total Above	830390	82
1995									
1	Singapore	63115	23	Korea	43920	15	Hong Kong, China	74554	21
2	Hong Kong, China	38437	14	Hong Kong, China	41892	14	China	69525	20
3	Korea	38391	14	Mexico	31506	10	Chinese Taipei	33272	9
4	Chinese Taipei	36899	13	Chinese Taipei	30220	10	Korea	27599	8
5	Malaysia	30235	11	China	27687	9	Thailand	15192	4
6	China	19350	7	Singapore	23540	8	India	11798	3
7	Mexico	16366	6	Malaysia	14304	5	Mexico	11702	3
8	Thailand	13790	5	Brazil	12094	4	Turkey	10474	3
9	Israel	3599	1	Thailand	9423	3	Indonesia	10249	3
10	Philippines	2852	1	Czech Rep.	7166	2	Singapore	8576	2
11	Indonesia	1790	1	Poland	5566	2	Poland	7626	2
12	Czech Rep.	1785	1	Indonesia	4806	2	Malaysia	7396	2
13	Brazil	1611	1	South Africa	4578	2	Brazil	6951	2
14	India	1433	1	Turkey	4066	1	Czech Rep.	6713	2
15	Hungary	1410	1	Israel	3956	1	Pakistan	6043	2
	Total Above	271063	97	Total Above	264724	88	Total Above	307671	87

Note: Advanced economies are defined to include the OECD member nations as of 1990, excluding Turkey that is conventionally classified as an emerging economy. Thus, non-advanced economies include some of the current OECD members such as Korea, Mexico, Czech Rep, and Slovak Rep., *etc*.

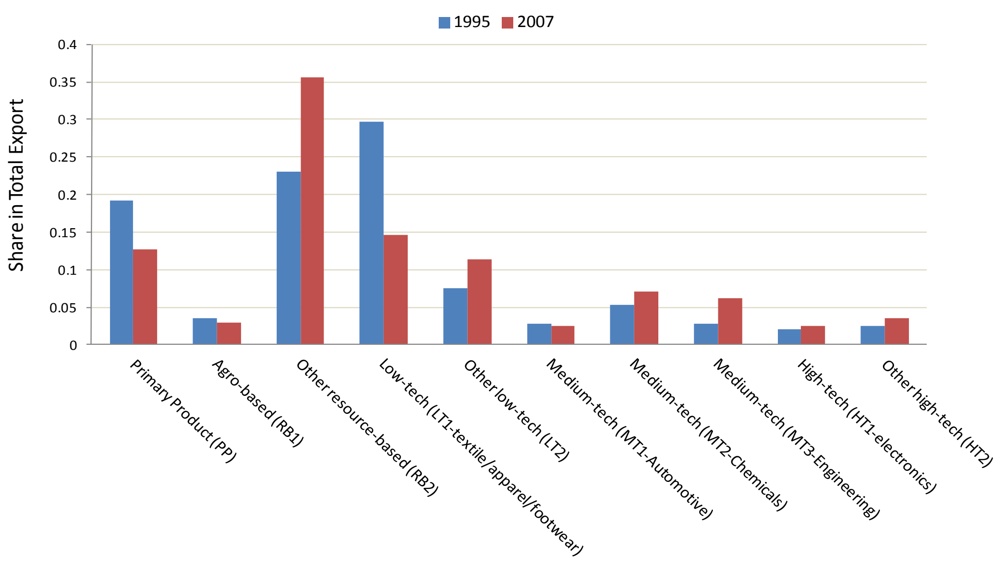
Source: Author's calculation based on UN COMTRADE (2009), SITC Rev 3. See Box 2 for technological classification.

Figure 3a. Composition of Export Products in China



Source: Author's calculation based on the UN COMTRADE database 2009

Figure 3b. Composition of Export Products in India



Source: Author's calculation based on the UN COMTRADE database 2009

As documented so far, China's export bundle has changed dramatically towards capital- and technology-intensive products. To what extent is the technological sophistication of export products associated with TFP? To address this question, we construct an index of technological sophistication (ITS), which is higher the greater the percentage of each country's exports in the more technologically advanced categories. Specifically, the index is obtained by assigning lower values to the lower-technology categories and higher values to higher-technology categories: 1

for primary products (PP), 2 for resource-based manufactures (RB1, RB2), and 3 for low-technology products (LT1, LT2), 4 medium technology (MT1, MT2, MT3), and 5 for high-technology (HT1, HT2). The percentage of exports in each category is multiplied by the assigned value, and these are summed and divided by 100. The resulting index ranges from 1 to 5, with higher values indicating greater technological sophistication.

Table 5 shows the ITS scores for selected countries in 1995 and 2007. Asian economies tend to specialise in higher-technology exports, relative to Latin American and Sub-Saharan African economies. The rapid rise in China's export of medium- and high-technology products is reflected by an increase in the ITS score to 3.75 in 2007 from 3.13 in 1995. By contrast, export products of India and Indonesia are significantly less sophisticated. The ITS scores have little changed over 1995-2007. In fact, the ITS scores have not changed much in many countries, which suggests that technological upgrading is an outcome of long, cumulative processes of learning, and assimilation of more advanced technology, and hence moving from a low-technology structure to a high-technology one is a challenging goal for many developing countries.[12] In this respect, it is remarkable that the Philippines's ITS score jumped up from 1.93 in 1995 to 4.11 in 2007 thanks to a sharp increase in export share of high-technology electronics HT1 (from 16% to 61%). Equally impressively, Costa Rica's ITS also jumped up from 1.66 in 1995 to 3.11 in 2007 where the biggest export share gains were made in high-technology electronics HT1 (from 0.8% to 28%) and medium-technology engineering category MT3 (from 2.9% to 13.7%). Brazil, Mexico, Mauritius and South Africa also have bigger presence in higher-technology categories than in the rest of their regions.

12. The decline in Japan's ITS is mainly due to a shift away from high-tech electronics category HT1 (28% in 1995 to 17% in 2007), which seems to be associated with the rise of international production network and relocation of production facilities to China and other Asian countries in the past decades.

Table 5. **Index of Technological Sophistication for Selected Countries in 1995 and 2007**

Country	Index of Technological Sophistication in 1995	Index of Technological Sophistication in 2007
OECD	2.92	2.96
Asia (except Japan)	3.09	2.95
China	**3.13**	**3.75**
Hong Kong, China	3.53	3.95
India	**2.50**	**2.61**
Indonesia	2.19	2.22
Japan	3.98	3.69
Korea	3.78	3.88
Malaysia	3.58	3.47
Philippines	1.93	4.11
Singapore	3.98	3.68
Chinese Taipei	3.80	3.94
Thailand	3.16	3.34
Latin America	1.98	2.16
Argentina	2.05	2.06
Brazil	2.53	2.49
Chile	1.55	1.58
Colombia	1.81	2.07
Costa Rica	1.66	3.11
Mexico	3.37	3.25
Peru	1.45	1.53
Sub-Saharan Africa	1.62	1.82
Mauritius	2.74	2.75
South Africa	1.82	2.44

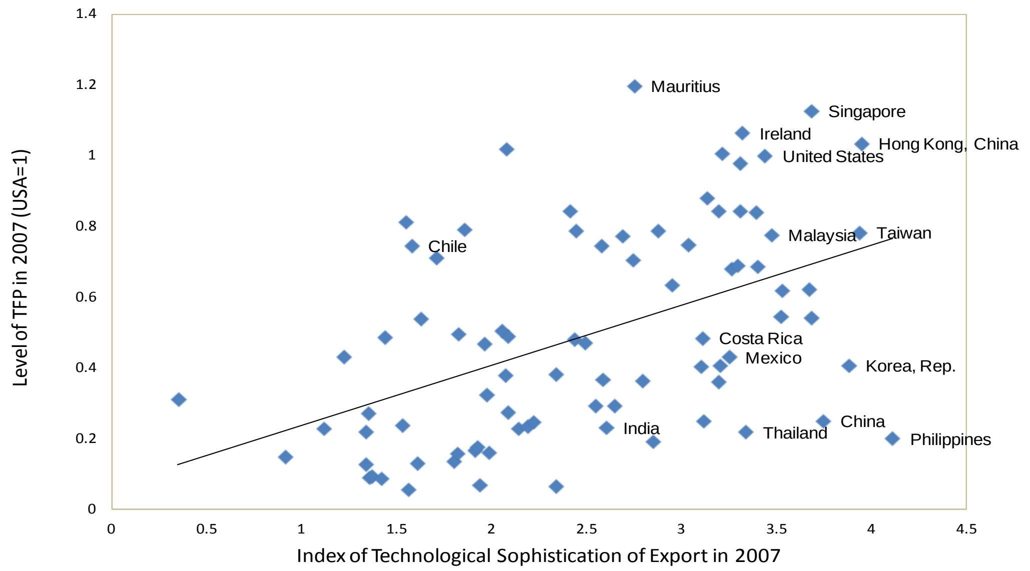
Source: Author's calculation based on UN COMTRADE (2009) database.

There is a relatively strong positive relationship between ITS and TFP (Figure 4). Countries that have greater technological sophistication of their export products tend to have higher levels of TFP. Export activities in higher-technology industries can be associated with technology upgrading through economies of scale, learning-by-doing, and exposure to new advanced technology. Conversely, countries with higher levels of technology tend to specialise in exporting higher-tech products. Given the consensus view that technology is an important determinant of TFP, it is not surprising to find this positive relationship. To our best knowledge, however, this paper is the first to present such evidence. Upon a close inspection, we find that China's TFP level is way too low relative to its ITS score. Since China's ITS score is 3.75, we would expect China to have TFP at 70% of the US level according to the OLS regression. However, China's TFP is only 25% of the US counterpart![13] One important explanation on this

13. Consistent with this puzzling observation, Xu (2010) argues that although many of China's exported goods belong to sophisticated categories, they may well be the low-quality varieties. Without considering the product quality dimension, therefore, one would overestimate the sophistication of China's exports as recent studies (e.g., Schott, 2008; Rodrik, 2006) have found that China is special in exporting highly sophisticated goods not comparable with its income level.

appears to be related to the dominance of processing export in China, that is, China's prime role as a final assembler in the international production network. We will discuss this issue later. Nonetheless, reflecting dramatic changes in export sophistication, TFP growth, as opposed to its level, has been strong in China.

Figure 4. Index of Technological Sophistication of Export and TFP, 2007



Fitted line: TFP=0.07+0.17*ITS, where t-statistics are in parentheses, R^2 = 0.23.
(0.78) (4.96)
Source: Author's calculation

Finally, we look at the correlation of Balassa index between a country in question and other countries as another way of examining technological level of exports. The Balassa index is based on the concept of revealed comparative advantages (RCA) which are measured by the ratio of the share of a country's export of good *i* in its total export relative to the share of country's export in the entire world export. Table 6 shows correlation of the Balassa index between China and major countries as well as between India and those countries at the 1-digit level of SITC for 1986 and 2005. It is evident that China's export structure is increasingly more similar to those of high-income countries such as the United States, Japan, and Germany than those of Brazil, Russia and other low income countries. In other words, types of exported goods from China are increasingly overlapped with those of the United States, Japan and Germany.[14] However, the opposite was true in 1986. In contrast, the Indian export structure has been largely

14. Based on HS 9-digit level classifications, Wang and Wei (2010) also find that China's export structure is already more similar to those of the high-income countries than to those of Brazil, Russia and middle-income countries. However, they do not find strong evidence that China already has a similar export structure to France, Japan and other high-income countries, although there is a clear trend in that direction. See Fontagne *et al*. (2007) for similar evidence and Goldstein *et al*. (2006) for a comparison of China and India with low-income countries.

stagnant, remaining similar to what it was in 1986 (the correlation coefficient between 1986 and 2005 Balassa index for India is 72). This is consistent with our earlier observation on China's extraordinary export performance in medium- and high-technology products, and the stagnant nature of India's export performance.[15]

Table 6. **Correlation of the Balassa Index across Major SITC categories for China and India**

	China			India	
	1986	2005		1986	2005
China	-3		India	72	
US	-27	25	US	-13	32
Japan	-49	62	Japan	-30	-14
Germany	-71	46	Germany	-31	-24
Italy	-24	42	Italy	15	-24
Brazil	25	-45	Brazil	64	45
Indonesia	67	-38	Indonesia	-22	-9
India	37	17	China	37	17

Note: Correlation coefficients (*100) between the Balassa index for either China or India and other countries listed in the first column in each table.

Source: Gros (2008), original data from UN COMTRADE data

However, one should be cautious in interpreting export data. The emergence of international production networks ("unbundling production stages" across different locations) and the dominant role of China as a final assembler in the production networks (known as processing export) have made it very difficult to correctly interpret the results based on conventional trade statistics. For example, both the United States and China may export laptop computers, but Chinese manufacturers may import the most sophisticated parts and components, such as processors (CPU) made by Intel or ADM in the United States and LCD panel by Samsung in Korea. That is, Chinese firms may specialise in the labour-intensive production stage while the final product is classified as a high-technology item (see Box 2 for an illustration based on the case of Apple's iPod).

Moreover, China and advanced economies may export the same product lines, but they may export different varieties within each product line, with China exporting varieties of lower quality. Despite the dramatic shift of export structure toward more sophisticated high-technology products, the skill content of China's manufacturing exports seems to remain at a relatively low level (we will have more to say about this later). On balance, this observation is consistent with our earlier finding that the level of TFP in China is still very low.

15. For a detailed analysis of India's trade and trade policy, see Kowalski and Dihel (2009) among others.

III. CHANNELS OF TECHNOLOGY DIFFUSION: FDI, IMPORT OF CAPITAL GOODS, INTERNATIONAL PRODUCTION NETWORK AND R&D EFFORTS

III.1 Foreign Direct Investment (FDI)

FDI has long been considered as an important way to access advanced foreign technology. Beyond adding more capital to a host country, FDI can be a conduit to the production technology, cutting edge of R&D, and management expert, while boosting market competition and generating spillovers and externalities to local firms in the host economy.[16]

FDI in China and India

China has attracted a large amount of FDI inflows since its opening to the world in 1979, and is now among the world's largest hosts of FDI inflows. On the other hand, FDI into India has just begun to accelerate more recently (Figure 5). Since the early 1980s, FDI has made a significant contribution to domestic capital formation in China, although its share of domestic investment has declined steadily after reaching a peak of 17% in 1994. In 1995-2009, on average inward FDI flows accounted for about 9.6% and 4% of gross fixed capital formation in China and India, respectively.

Hong Kong, China is indisputably the most important source of FDI in China. In 2008, Hong Kong, China, invested USD 41 billion in China, accounting for 44.4% of the total.[17] Other major sources of FDI include Chinese Taipei, United States, South Korea, Singapore, Japan, and more recently tax havens such as British Virgin Islands, and the Cayman Islands.[18] In recent years, an increasing share of FDI came from global companies in the OECD countries such Motorola, Siemens, and Samsung. Nearly 70% of FDI in China is in the manufacturing sector.

16. FDI is usually defined as an investment involving a long-term relationship and reflecting a lasting interest in and control by a resident entity in one economy (foreign direct investor or parent enterprise) of an enterprise resident in a different economy (FDI enterprise or affiliated enterprise or foreign affiliate). The FDI categories include controlling stakes in acquired foreign firms and greenfield investment (construction of new production facilities). Once an FDI investment is established, all subsequent financial transactions between the parent and affiliate are classified under FDI, including intra-firm assets and liabilities.

17. Data are from China Statistical Yearbook 2009.

18. These two islands account for 20.7% of total FDI inflows into China in 2008. Much of FDI from these tax havens are actually redirected to China by Chinese and foreign investors. Tax havens are popular choice for incorporation of high-technology start-up enterprises in China itself. Creation of an offshore vehicle facilitates the financing of new ventures in China. Thus some of these FDI flows from tax havens may reflect domestic Chinese investment. See Naughton (2007) for details.

In the early 1980s, China's FDI policies were mainly characterised by setting up new regulations to permit joint ventures between foreign investors and local partners and setting up Special Economic Zones (SEZs).[19] During this period, FDI inflow was low and remained roughly constant. Since 1986, China started to further open up to FDI and adopted more favorable policies to encourage FDI inflow. Foreign investors were given preferential tax treatments, duty-free import of inputs, and streamlined business licensing procedures. In the 1990s, Chinese government allowed wholly foreign-owned enterprise as a new entry mode of FDI. During the past few years, wholly foreign-owned enterprises have become the most popular form of entry mode of FDI to China, representing more than 2/3 of total FDI in 2009. Most recently, the government started to allow, and in some cases even encourage, foreign investors to merge with or acquire domestic firms. As a result, more and more new FDI projects take the form of merger or acquisition. In many cases, the target firms are either state owned enterprises or other leading and promising companies.

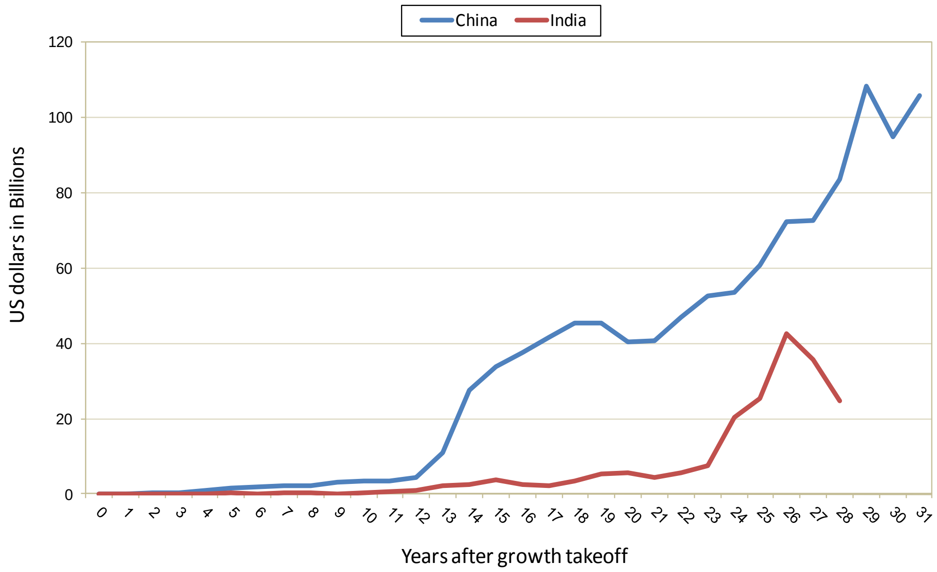
One of the primary goals of China's FDI policies is to address its technological backwardness by promoting technology transfer to China, especially from multinational companies – with its high savings rate China is hardly in need of foreign savings, and is trading market access in return for technology. Indeed, promotion of technology transfer is of the key ingredients of the *Guiding Directory on Industries Open to Foreign Investment* first promulgated in 1995. Since the mid-1990s, China has been encouraging FDI to flow into cutting-edge, technology-oriented industries such as electronics, information technology, bioengineering, new materials, and aviation and aerospace, as well as establishing local R&D centres (technology or industry parks).[20] This should help generate horizontal spillovers via such channels as labour turnovers and demonstration effect, as well as vertical spillovers.

A policy designed specifically to promote backward linkage effect of FDI is the so-called local content requirement, which requires a foreign investor to purchase a certain amount of intermediate input from local suppliers as opposed to from international markets. For instance, during the 1990s China required that the local content rate of all cars made in China be at least 40% and must increase to 60% in a year and to 80% in two years after operation of a project. In 2007, China issued its new set of guidelines for FDI detailing sectors in which it will promote, restrict or ban foreign investment. The National Development and Reform Commission and the Ministry of Commerce said that the new guidelines will help put FDI to better use to spur innovation, promote industrial restructuring and ease regional imbalance.

19. See Fung *et al.* (2004) and Naughton (2007) about FDI trends and policies in China.

20. About two-thirds of China's inward FDI has gone into manufacturing, and the country's foreign-invested enterprises now account for 60% of pharmaceuticals output, 75% of medical, precision and optical output, 88% of electronic and telecommunications and 96% of computer and office equipment (OECD, 2010a).

Figure 5. FDI Inflows to China and India Since Growth Takeoff



Note: The growth takeoff year for China is 1979 and for India 1982 (Hausmann, Prichett, Rodrik 2005)
Source: UNCTAD, Foreign Direct Investment Database (2011)

Outward FDI can also provide access to foreign technology (*e.g.* acquisition of Arcelor by Mittal steel, and IBM PC business unit by Lenovo). After the Chinese government substantially relaxed outward FDI regulations in 2004, the outward FDI accelerated. The latest figure shows USD 68 billion of FDI outward flow in 2010, accounting for 5% of total world outward FDI flows. Recently, India's outward FDI flows have sharply increased to reach USD 14.6 billion (near 6% of GDP) in 2010.

III.1.1 Cross-country Studies

Empirical research on the role of FDI in economic growth has been growing recently. However, it has largely focused on the effect of FDI on per capita income growth (*e.g.* Borensztein *et al*., 1998; Alfaro *et al*., 2004; Blonigen and Wang, 2005). A few earlier studies report the positive effect of FDI on income growth is only conditional on having the right initial conditions such as human capital (Borensztein *et al*., 1998), outward-looking trade policy (Balasubramanyan *et al*., 1996) and financial development (Alfaro *et al*., 2004).[21] Thus, it became a popular view that the effect of FDI on income growth is *only* contingent on the recipient country's capability to absorb foreign technology. Blonigen and Wang (2005) argue that inappropriate pooling of developed countries with developing countries is responsible for estimation of insignificant effects of FDI with respect to per capita GDP growth in some of the earlier studies. Then, they find positive significant effects of FDI on per capita GDP growth in a sample of developing countries only.

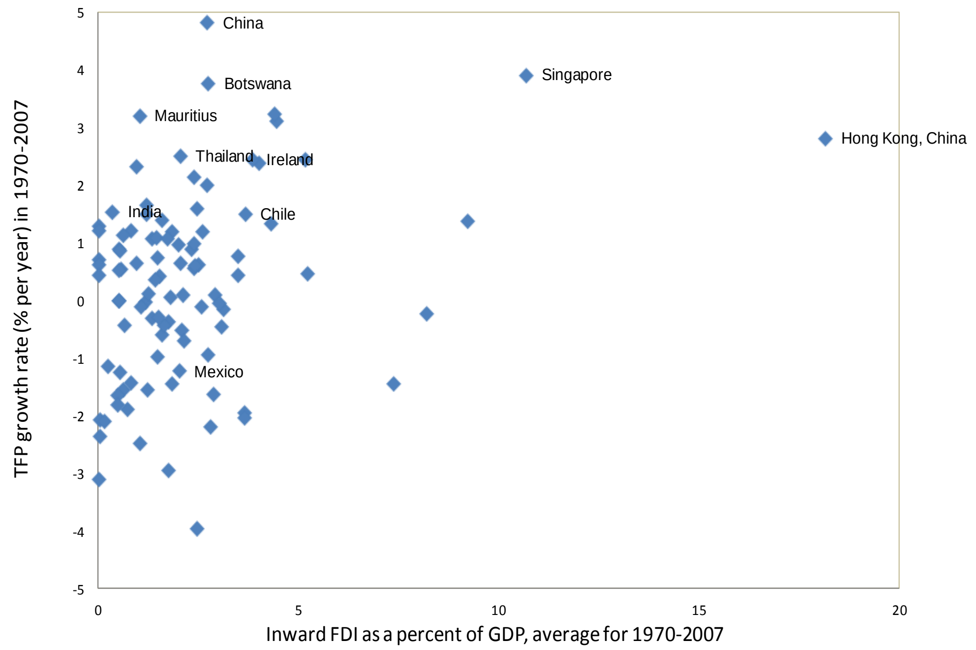
21. Also, see Carkovic and Levine (2005) and Melitz (2005).

Given the importance of technological advance/diffusion as a key determinant of TFP in endogenous growth theory, there are surprisingly very few studies on FDI and TFP in the literature. In a panel of a large number of countries for 1970-2000, Woo (2009) presents the first evidence of positive direct effect of FDI on TFP growth, and shows that various robustness checks including estimation methods, and different samples (developed versus developing) yield largely the same result.[22] Interestingly, he reports that FDI that is originated in OECD countries has stronger positive effects on TFP growth in developing countries. Intuitively, one can expect a stronger technological diffusion from advanced economies to developing countries. Conversely, FDI taking place between countries with similar technological levels may reflect factors other than technological diffusion process, such as market penetration, circumventing trade restrictions, and offsetting other advantages given to domestic firms. Consistent with the above result, there is strong micro-data evidence that FDI flows into China from non-HMT (non-Hong Kong, China, Chinese Taipei, Macao) have positive horizontal and backward technological spillovers that are not found in FDI from HMT (Lin *et al*., 2009).

The positive relationship between TFP growth and FDI Inflows is evident in the scatter plots (Figures 6a and 6b). Figure 6a is based on FDI inflows to a country from abroad (% of the recipient country's GDP) from the IMF's International Financial Statistics (IFS) data, whereas Figure 6b is based on FDI inflows from 22 traditional OECD countries only which is taken from the OECD International Development Statistics that provides geographical distribution of financial flows from DAC (development assistance committee) donor countries.

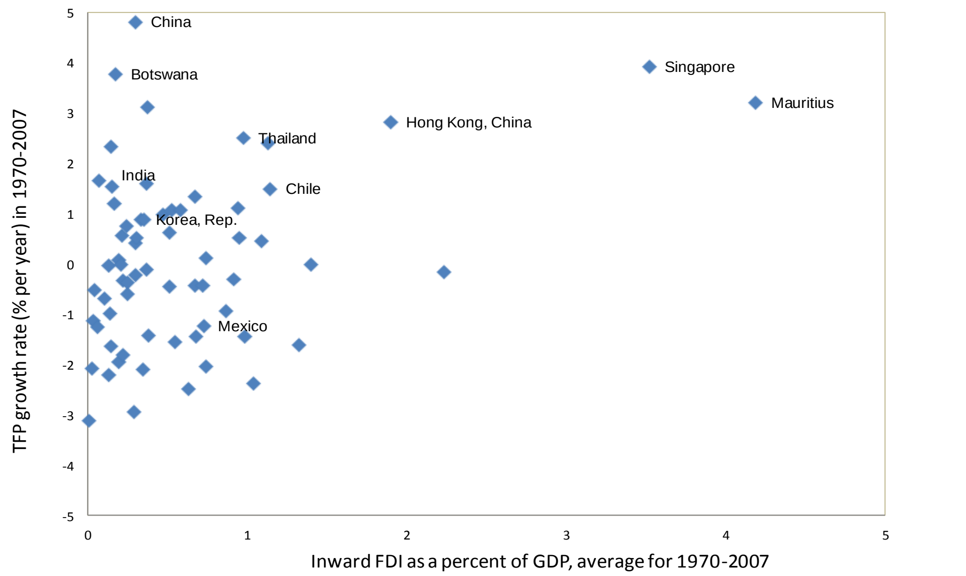
22. Similarly, Kose *et al*. (2009) also find that de jure capital account openness has a positive effect on TFP growth and present evidence that FDI and portfolio equity liabilities boost TFP growth while external debt is actually negatively correlated with TFP growth. Related, Coe *et al*. (1997) study the effects of imported machinery and equipment on TFP level for 77 countries in the period of 1971-1990. In a panel of 19 OECD countries, Scarpetta *et al*. (2002) report evidence that stringent regulatory settings in the product markets and strong employment protection have negative effects on TFP growth at the industry level.

Figure 6a. TFP Growth and FDI Inflows, 1970-2007



Source: Author's calculation based on PWT 6.3 (2009) and International Finance Statistics (2009)

Figure 6b. TFP Growth and FDI Inflows from OECD DAC Countries, 1970-2007



Source: Author's calculation based on PWT 6.3 (2009) and International Finance Statistics (2009)

Next, we present new evidence on the positive effects of FDI on TFP growth for a panel of 90 (developed, emerging, and developing) countries in the period of 1970-2007, taking advantage of our new data set on TFP based on Penn World Table 6.3. To estimate the effects of FDI on TFP growth, we employ four different estimation methods: pooled OLS, robust regression (which addresses the outlier problem), fixed-effects (FE) panel regression, and system GMM (SGMM) dynamic panel regression (see Box 3).

Table 7 presents the panel regression results. Columns (1)–(4) show the results for the entire sample using the inward FDI data from IFS. The coefficients of the initial TFP level are all significant at the 1% level and have the expected sign (−). In fact, the initial TFP level is strongly negatively correlated with TFP growth in subsequent years even when TFP growth is regressed on the initial TFP level only, which indicates unconditional convergence unlike the case of per capita income growth that only exhibits conditional convergence. The OLS and FE estimators are likely to be biased in the opposite direction in the context of lagged dependent variables in short panels, with OLS biased upwards, and FE downwards. The *consistent* GMM estimator should lie between the two (Bond, 2002). In the growth regressions, this means that the OLS understates the convergence rate (reflected by the coefficient of initial TFP), while the FE estimator overstates it. Consistent with this reasoning, the OLS coefficient of initial TFP is -1.18, whereas the FE coefficient is -6.04. The SGMM coefficient of initial TFP (-1.51) is between those two estimates, indicating that the SGMM estimate in Column (4) is likely to be a *consistent* parameter estimate of the convergence rate.[23] The coefficients of years of schooling are positive and significant at the 1-5% in the OLS and robust regressions, but lose statistical significance in the FE and SGMM regressions. The coefficients of initial population, initial government size, and growth of terms of trade are all of the expected sign in the OLS and robust regressions, but they take a wrong sign in the FE and SGMM regressions.

The coefficients of FDI are all significant at 1-10% and of expected (+) sign in all four estimation methods. According to the coefficients of FDI, a 1% of GDP increase in inward FDI is associated with an increase in TFP growth of 0.25-0.34% points. Columns (5)–(8) show the regression results for developing countries only, which are very similar to those for the entire sample. Yet, all the coefficients of FDI are now significant at 1%, and the magnitude of impact of FDI is also greater. A 1% of GDP increase in inward FDI is associated with an increase in TFP growth of 0.35-0.4% points. Finally, Columns (9)–(12) are based on the FDI inflows originating in the OECD countries. All the coefficients of FDI are significant at 5-10%. The estimated positive impact on TFP growth of a 1% of GDP increase in FDI from the OECD ranges from 0.34 to 0.46% points per year.

23. Consistency of the system GMM estimator depends on the validity of the instruments. We consider two specification tests, suggested by Arellano and Bover (1995) and Blunedell and Bond (1998). The first is a Hansen J-test of over-identifying restrictions, which tests the overall validity of the instruments by analyzing the sample analog of the moment conditions used in the estimation process. This indicates that we cannot reject the null hypothesis that the full set of orthogonality conditions are valid (p-value=0.12). The second test examines the hypothesis that the error term εit is not serially correlated. We use an Arellano-Bond test for autocorrelation, and find that we cannot reject the null hypothesis of no second-order serial correlation in the first-differenced error terms (p-value=0.83).

Box 3. Panel Regression on TFP growth

The baseline specification for TFP growth regression is as follows:

$$\text{TFPgrowth}_{it} = \text{constant} + \alpha\ln(\text{initial TFP relative to US})_{it} + \beta\ln(\text{human capital})_{it} + \gamma\ln(\text{population})_{it}$$
$$+ \lambda(\text{government share})_{it} + \delta(\text{FDI})_{it} + \phi X_{it} + \eta_i + \varepsilon_{it},$$

where *i* and *t* denote the country and time, η_i a country-specific fixed effect, and ε_{it} is an unobserved error term. TFP growth is the average TFP growth for each non-overlapping ten-year period during 1970-2007 (*i.e.* 1970-80, 1980-90, 1990-2000, 2000-07). First, we expect the catching-up process to occur in the TFP growth. Countries with a lower level of initial TFP will imitate more quickly than those with a higher initial level of TFP because these countries are farther away from the technology frontier, and hence the absorption of low technology will be relatively easier (Barro and Sala-i-Martin, 2003). The catching-up term, representing the distance from the technological frontier, is proxied by log of TFP relative to the US value (*i.e.* $\ln(TFP_i/TFP_{US})$).

The sensitivity of OLS coefficients of growth regressors to inclusion of other conditioning variables is well-known (Durlauf *et al.*, 2005 and references therein). Thus, we focus on a small "core set" of explanatory variables which are mostly initial conditions (to avoid the reversed causality as well) that have been identified as having significant explanatory power in the growth regression (*e.g.* Sala-i-Martin *et al.*, 2004), and evaluate the importance of FDI conditional on inclusion of the core set. We include initial human capital and population size in the regression. Countries with an abundance of human capital and large country size (capturing potentially large market extents and aggregate scale effects) have a greater ability and incentive to engage in innovation activities (Grossman and Helpman, 1991). We proxy initial human capital by the log of average years of schooling in the population over age 15 in the initial year from Barro and Lee (2000), and as a proxy for country size the log of initial population from PWT 6.3. We also control for the initial government size measured by government consumption share of GDP. The term FDI_{it}, which is measured as average of FDI inflows (percentage of GDP) over the relevant time period, is the variable of our main interest. Finally, X_i represents other variables including terms of trade growth.

In estimating TFP growth regression, we employ four different methods: pooled OLS, robust regression, fixed-effects (FE) panel, and system GMM (SGMM) dynamic panel regression. In the pooled OLS and robust regression, regional dummies for Asia, Latin America, sub-Saharan Africa as well as time period dummies are included. Robust regression is used to address leverage points and outliers. It is an iterated re-weighted least squares regression in which the outliers are dropped (if Cook's distance >1) and the observations with large absolute residuals are down-weighted. As one can see from Figures 6a and 6b, some countries receive relatively much larger amounts of FDI inflows. The OLS estimates tend to be sensitive to outliers, either observations with unusually large errors or influential observations with unusual values of explanatory variables. Thus, it is important to make sure that some of our results are not unduly driven by outlier observations. Also, we ran the regression while dropping some of these countries such as Hong Kong, China; Singapore and Mauritius from the sample. The results are similar (not reported to save space).

In both FE and SGMM regressions, unobservable country-specific fixed effects are explicitly controlled for (through within transformation in FE and differencing in SGMM regression). A fundamental issue in the empirical growth literature is the endogeneity problem. Although we are interested in the effects of FDI on TFP growth, the potential problem is that TFP growth and FDI flows might be jointly determined by a third variable(s). Given the difficulty of finding appropriate external instrumental variable(s) for FDI, we address the endogeneity issue by using the SGMM approach of Arellano and Bover (1995) and Blundell and Bond (1998), which uses suitable lagged levels and lagged first differences of the regressors as instruments (see Bond, 2002; Roodman, 2009). This approach has recently gained popularity, and is widely used in a variety of different contexts. In general, the dynamic panel GMM can generate too many instruments, which may overfit endogenous variables and run a risk of a weak-instruments bias. The system GMM that is used in this paper is generally more robust to weak instruments than the difference GMM. Given this potential weak instruments problem, one recommendation when faced with a weak-instrument problem is to be parsimonious in the choice of instruments. Roodman (2009) suggests restricting the number of lagged levels used in the instrument matrix or collapsing the instrument matrix or combining the two. The reported SGMM results in our paper are obtained by combining the "collapsed" instrument matrix with lag limits up to two. In addition, we also ran regressions using lagged values of FDI flows to check on potential reversed causality from TFP growth to FDI inflows. The results turn out to be largely the same, so we do not report to save space.

III.1.2 Micro-Data Analyses and Case Studies

There are a large number of micro-data (firm- or plant-level) analyses and case studies on FDI, technology transfer and productivity (*e.g.* Harrison and Rodriguez-Clare, 2009; Moran *et al*., 2005; Keller, 2004). The studies tend to focus on three aspects of technology transfer (spillovers or externalities) in relation to FDI: *i)* own-plant effect – whether firms with foreign equity participation systematically have higher productivity or TFP than other domestic firms; *ii)* horizontal spillovers – whether foreign ownership in a sector positively affects the productivity of domestic firms in the same sector. Such spillovers can occur through demonstration effect, labour turnover and competition effect. *iii)* vertical spillovers (backward versus forward) – whether positive externalities are stemming from the relationships of foreign enterprises with domestic suppliers or customers. Backward spillovers can occur if domestic suppliers to downstream foreign firms benefit from contacts with the firms to increase productivity. Forward spillovers can occur if foreign firms that are located domestically supply inputs that embody new technologies or processes.

Most research has focused on finding whether there are technology spillovers (positive externality) from FDI. However, probably the most important contribution that foreign firms make is the own-plant effect – direct effect on the plants with foreign investment. Firms with foreign equity participation typically have higher labour productivity or higher levels of TFP. Based on the Chinese firm-level data, Hu and Jefferson (2002), Du *et al*., 2008 find that joint ventures in China exhibit not only higher productivity levels than other enterprises but also higher productivity growth.

When it comes to the horizontal spillovers, recent studies that control for the fixed effects typically tend to find either insignificant or negative horizontal spillover effects on domestic enterprises that do not have foreign partnerships – Aitken and Harrison (1999) for Venezuela, Djankov and Hoekman (2000) for Czech Republic, Lopez-Cordova (2002) for Mexico, and Hu and Jefferson (2002) for China (electronics and textile industries). This insignificant or negative effect seems to be associated with "market-stealing" effect, that is, foreign-invested enterprises can increase intensity of competition and can hurt domestic firms at least in the short run by reducing their market share and output. Also, it could be related to the fact that foreign firms have no incentive to transfer technology to competitors within the same industry. On balance, it seems that the market-stealing effect (more than) offsets any positive technological spillovers within the same industry.

However, this incentive to transfer technology may be different in the case of vertical spillovers. The foreign enterprises may have an incentive to transfer technology to their suppliers through backward or forward linkages. Javorcik (2004), based on firm-level data from Lithuania, present evidence consistent with positive backward spillovers from FDI taking place through contacts between foreign affiliates and their local suppliers in upstream sectors. Interestingly, spillovers are associated with projects with shared domestic and foreign ownership but not with fully owned foreign investments.[24] Blalock and Gertler (2003) also find positive backward spillovers for Indonesia, Lopez-Cordova (2002) for Mexico, and Liu (2002), and Lin *et al*., 2009 for China. This result is particularly important for China because it is closely related with international production networks, which we will discuss later.

Table 8 summarises the main findings on the effects of FDI from two studies based on Chinese firm-level data, Hu and Jefferson (2002) and Lin *et al*., 2009. As mentioned earlier, these studies find insignificant or negative horizontal spillovers on domestic firms within the same industry from FDI. Yet, Hu and Jefferson (2002) report strong positive own-plant effects, whereas Lin *et al*. (2009) find strong positive backward and forward spillovers. In relation to the result of insignificant or negative (net) horizontal spillovers, they investigate the issue further by distinguishing between FDI from Hong Kong, China; Macao; Chinese Taipei (HMT) and FDI from non-HMT countries (mostly OECD countries). They find that HMT-invested firms generate negative horizontal spillovers, while non-HMT foreign invested firms tend to bring positive horizontal spillovers, which seem to cancel each other at the aggregate level. One possible explanation is that HMT FDI tends to enter labour intensive industries such as garments, footwear, and light electronics, and produce close substitutes to products of Chinese domestic firms, which results in direct competition with domestic firms. By contrast, non-HMT firms are more technologically advanced and engaged in international production networks, which is related to another interesting finding that the backward spillovers effect is significant only for non-HMT FDI, not for HMT FDI.

24. Almeida and Fernandes (2007) find in a firm-level data of 43 developing countries (including China) that foreign-owned subsidiaries rely mostly on the direct transfer of technology from their parents and that firms that import intermediate inputs are more likely to acquire new technology from their machinery suppliers.

Table 7. **Panel Regression of TFP Growth on FDI for Period of 1970-2007 (ten-year panel)**
Dependent Variable: TFP growth rate (% per annum)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Explanatory Variables	**OLS[a]**	**Robust[b]**	**Fixed-Effects Panel[c]**	**System GMM[d]**	**OLS**	**Robust**	**Fixed-Effects Panel**	**System GMM**	**OLS**	**Robust**	**Fixed-Effects Panel**	**System GMM**
	Full sample	**Full sample**	**Full sample**	**Full sample**	**Non-advanced**	**Non-advanced**	**Non-advanced**	**Non-advanced**	**Non-advanced**	**Non-advanced**	**Non-advanced**	**Non-advanced**
Initial TFP relative to USA	-1.175***	-1.124***	-6.039***	-1.508***	-1.162***	-1.134***	-5.862***	-2.770***	-1.418***	-1.264***	-6.488***	-3.501***
(log)	(0.317)	(0.23)	(0.651)	(0.54)	(0.397)	(0.291)	(0.74)	(0.809)	(0.412)	(0.311)	(0.698)	(0.813)
Initial years of schooling	0.963**	0.797***	0.912	0.972	0.873*	0.775**	1.030	0.182	1.008**	0.967***	-0.022	1.16*
(log)	(0.377)	(0.267)	(0.876)	(0.675)	(0.459)	(0.343)	(0.960)	(0.828)	(0.488)	(0.361)	(1.039)	(0.644)
Initial population (log)	0.178	0.16	-2.055*	-0.011	0.218	0.278**	-2.273*	0.241	-0.097	-0. 049	-0.901	-0. 332
	(0.139)	(0.104)	(1.092)	(0.486)	(0.180)	(0.141)	(1.165)	(0.508)	(0.189)	(0.136)	(1.217)	(0.664)
Initial government size (%	-0.024	-0.027	0.004	-0.131**	-0.024	-0.029	-0.014	-0.164**	-0.024	-0.035	0.005	-0.203**
of GDP)	(0.019)	(0.017)	(0.038)	(0.058)	(0.019)	(0.021)	(0.039)	(0.066)	(0.022)	(0.022)	(0.037)	(0.079)
Terms of trade growth	0.011	0.027	0.042	-0.035	0.012	0.048	0.036	-0.000	0.005	0.042	0.032	0.034
(percent)	(0.057)	(0.032)	(0.043)	(0.052)	(0.063)	(0.04)	(0.050)	(0.049)	(0.066)	(0.041)	(0.053)	(0.052)
Inward FDI (% of GDP)	0.308***	0.277***	0.338***	0.251*	0.347***	0.358***	0.398***	0.351***				
	(0.074)	(0.062)	(0.077)	(0.131)	(0.098)	(0.082)	(0.112)	(0.118)				
Inward FDI from OECD									0.387**	0. 339*	0.37*	0.455*
(% of GDP)									(0.182)	(0.177)	(0.214)	(0.246)
Arellano-Bond test for AR(2), p-value				0.83				0.48				0.15
Hansen Test of Joint Validity of instruments				0.12				0.57				0.64
No. of Instruments				45				45				45
No. of Obs.	338	338	338	338	244	244	244	244	254	254	254	254
No. of countries	90	90	90	90	65	65	65	65	68	68	68	68

Note: The panel is comprised of four 10-year periods for each country, if data permit. Heteroskedasticity and country-specific autocorrelation consistent standard errors are reported in parentheses. Levels of significance are indicated by asterisks: *** 1%, ** 5%, * 10%. An intercept term is included in each regression. See Appendix for the list of countries included in the sample.

a: Pooled OLS. Regional dummies (Asia, Latin America, Sub-Saharan Africa) and time period dummies are included.

b: Robust estimation (to address leverage points and outliers). Iterated re-weighted least squares regression in which the outliers are dropped (if Cook's distance >1) and the observations with large absolute residuals are down-weighted.

c: Fixed-effects (within) panel regression. Country-specific fixed effects are controlled for (through within transformation).

d: System GMM dynamic panel estimation (Arellano and Bover, 1995; Blundell and Bond, 1998). Country-specific fixed effects are controlled for (differenced out).

Table 8. Estimates of FDI effects on TFP/Productivity in China from Firm-Level Data

Studies/Data	Regression Equation	Estimates of Coefficients				Estimation Method
		Own-Plant Effects (β_1)	Horizontal Spillovers (β_2)	Vertical Spillovers		
Hu and Jefferson (2002): Firm-level data from survey of large and medium enterprises by Chinese National Statistical Bureau, 1995 and 1999	(1)	1.42*	-0.76**			OLS/Pooled/Electronics
	(2)	0.72***	-0.04			OLS/ Difference between 1995 & 1999/ Electronics
	(3)	1.06*	-0.42			OLS /Pooled/ Textiles
	(4)	0.31	-0.11			OLS/ Difference between 1995 & 1999/ Textiles
			Horizontal Spillovers	**Backward**	**Forward**	
Lin, Liu, and Zhang (2009): Firm-level data covering all manufacturing firms in China, 1998-2005	(5)		-0.035	0.513***	1.714***	Fixed-effects panel on dependent var., lnY
	(6)		-0.086	1.357***	4.560***	Fixed-effects panel on dependent var., lnTFP
	(7)		-0.025	0.197***	0.664***	Random-effects panel on dependent var., lnY
	(8)		-0.091	1.329***	2.799***	Random-effects panel on dependent var., lnTFP
	(9)		**Non-HMT Horizontal**	**Non-HMT Backward**	**Non-HMT Forward**	Fixed-effects panel on dependent var., lnTFP, with controlling for sources of FDI (HMT versus non-HMT) separately
			0.318**	2.402***	5.361***	
			HMT Horizontal	**HMT Backward**	**HMT Forward**	
			-0.706***	-0.277	3.345***	
	(10)		**Non-HMT Horizontal**	**Non-HMT Backward**	**Non-HMT Forward**	Random-effects panel on dependent var., lnTFP, with controlling for sources of FDI (HMT versus non-HMT) separately
			0.550**	1.993***	3.288***	
			HMT Horizontal	**HMT Backward**	**HMT Forward**	
			-0.876***	0.216	2.454**	

Note 1: Levels of significance are indicated by asterisks: *** 1%, ** 5%, * 10%.

Note 2: the benchmark regression specification is typically as follows:

$$Y_{ijt} = \text{constant} + \beta_1 DFI\_Plant_{ijt} + \beta_2 DFI\_Sector_{jt} + \beta_3 DFI\_Plant_{ijt} * DFI\_Sector_{jt} + \beta_4 \mathbf{X}_{ijt} + \varepsilon_{ijt},$$

where Y_{ijt} is log output for plant i in sector j at time t, DFI_Plant is share of foreign equity participation at the plant level, DFI_Sector is the foreign equity participation averaged over plants in the sector. The vector X can control for input use, so that Y_{ijt} can be interpreted as TFP. Alternatively, the dependent variable can be TFP. The coefficient β_1 measures whether firms with foreign investment are more productive than domestic plants. If the productivity advantages of foreign forms spill over to domestic firms, the coefficient β_2 should be positive.

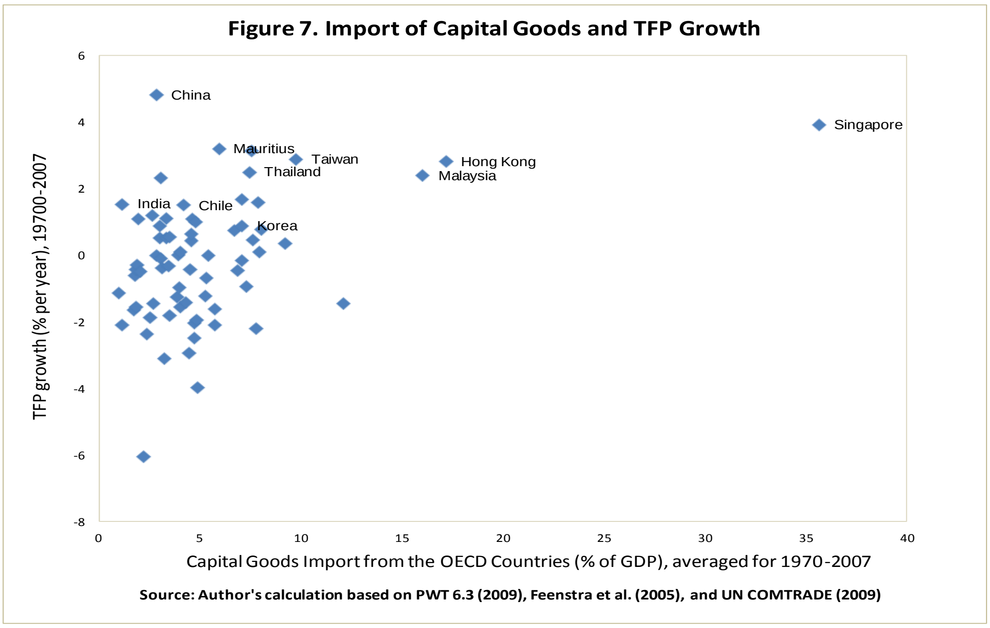
III.2 Import of Capital Goods

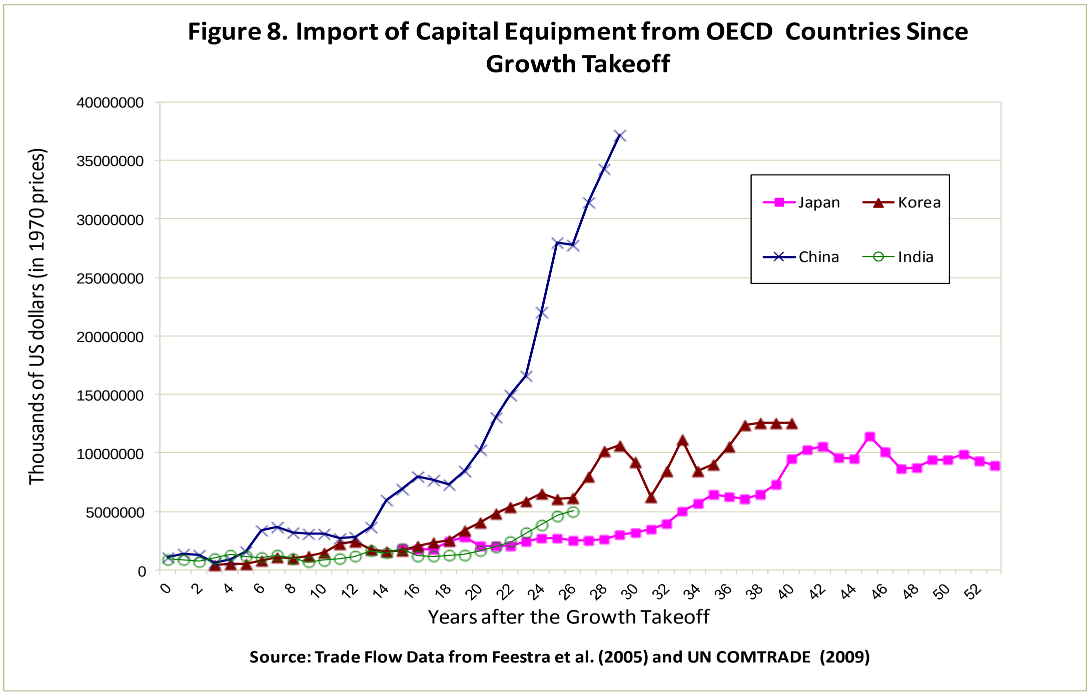
Technological advances, in the form of production of capital equipment and R&D activity, are highly concentrated in a small number of advanced economies. Most of developing countries import the bulk of their machinery and equipment. Imported capital goods that embody new technology can be a crucial mechanism for transmitting knowledge spillovers across countries, although only a few countries do much of the R&D activities. A number of studies present supporting evidence that import of capital goods is a significant source of technology diffusion. (*e.g.* Coe and Helpman, 1995; Coe *et al.*, 1997; Eaton and Kortum, 2001; Woo, 2004; Almeida *et al.*, 2007).

Table 9 presents the panel regressions of TFP growth on import of capital goods from 22 OECD countries, using the same regression specification and four different estimation methods as in the case of FDI. [25] The coefficients of import of capital goods are all significant at the conventional level and of the expected positive sign. The estimated coefficients suggest that a 1% of GDP increase in import of capital goods is associated with an increase in annual TFP growth of 0.11-0.15% points in the entire sample and 0.1-0.21% points in the developing country sample (see Figure 7 for a scatter plot of import of capital goods (percentage of GDP) from 22 OECD countries against TFP growth in 1970-2007).

Figure 8 shows an astonishing increase in capital equipment import from OECD countries by China over the period of 1995-2008, during which the technological structure of export has shifted dramatically towards high-technology categories. It increased by 368% between 1995 and 2008 (equivalently, 16th to 29th year since growth takeoff). For India, it went up by 205% in 1995-2008. From the 16th to 29th year since growth takeoff, Korea experienced a comparable increase of 422% in the annual capital import. However, the size of the absolute amount of capital equipment import to China is truly unprecedented.

25. Here we follow Eaton and Kortum (2001) regarding the definition of capital goods. They include farm and garden machinery, construction and mining equipment, computer and office equipment, other non-electric machinery, household appliances, household audio and video, electronic components, other electrical machines, instruments and apparatus. 22 OECD member countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, USA, United Kingdom.





III.3 Intra-Industry Trade and International Production Networks

The strongest export growth of China has been in high-technology products including office and data processing equipments and telecommunication. This is closely related to the rapid emergence of international production networks, as production stages become increasingly fragmented geographically (see OECD 2007a).[26] China has played a primary role as a final product assembler, using capital equipments and intermediate goods (which include primary goods, parts and components and semi-finished goods) imported from other advanced countries within international production networks.

These developments in China raise some important questions. How much of the rapid technological sophistication of export structure in China is real? Is China producing most of the value-added of the high-technology products or is it merely assembling duty-free imported parts and components for re-export (processing trade)? What is the role of foreign-invested enterprises in technological shifts toward high-technology products? Does the participation in production networks help upgrade quality of its products because they typically require the local producers to meet international quality standards? To address these issues, we first examine the primary role of China as a final assembler in the production networks. Then, we look into types of exporters engaged in processing exports and high-technology development zones in China.

26. Advancement in production technology has allowed for "unbundling of production stages" into different tasks that can be performed in different locations. Technological innovations in communication and transportation have improved the speed, efficiency, and coordination of geographically dispersed production processes. This has facilitated establishment of "service links" to combine various fragments of the production process in a timely and cost-efficient manner (Jones and Kierzkowski 2001).

Table 9. **Panel Regression of TFP Growth on Import of Capital Goods for Period of 1970-2007**

Dependent Variable: TFP growth rate (% per annum)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Explanatory Variables	**OLS[a]**	**Robust[b]**	**Fixed-Effects Panel[c]**	**System GMM[d]**	**OLS**	**Robust**	**Fixed-Effects Panel**	**System GMM**
	Full sample	**Full sample**	**Full sample**	**Full sample**	**Non-advanced**	**Non-advanced**	**Non-advanced**	**Non-advanced**
Initial TFP relative to USA (log)	-1.333***	-1.152***	-6.548***	-1.819***	-1.111***	-1.105***	-6.109***	-3.15***
	(0.349)	(0.222)	(0.778)	(0.508)	(0.399)	(0.294)	(0.828)	(0.828)
Initial years of schooling (log)	1.023***	0.82***	0.622	1.841***	0.889*	0.841**	0.519	1.275**
	(0.384)	(0.260)	(0.966)	(0.439)	(0.465)	(0.346)	(1.034)	(0.591)
Initial population (log)	0.111	0.111	-1.316	0.027	0.09	0.150	-0.983	0.011
	(0.142)	(0.106)	(1.173)	(0.433)	(0.201)	(0.151)	(1.261)	(0.689)
Initial government size (% of GDP)	-0.019	-0.021	0.023	-0.122**	-0.020	-0.032	-0.001	-0.145
	(0.022)	(0.017)	(0.045)	(0.057)	(0.022)	(0.021)	(0.043)	(0.093)
Terms of trade growth (percent)	-0.018	-0.007	0.029	-0.032	-0.004	0.010	0.032	0.015
	(0.058)	(0.031)	(0.046)	(0.055)	(0.067)	(0.04)	(0.052)	(0.066)
Import of capital goods from OECD	0.105***	0.107***	0.147**	0.105**	0.093***	0.099**	0.109*	0.211**
(% of GDP)	(0.025)	(0.031)	(0.064)	(0.044)	(0.031)	(0.040)	(0.064)	(0.094)
Arellano-Bond test for AR(2), p-value				0.71				0.98
Hansen Test of Joint Validity of instruments				0.10				0.12
No. of Instruments				45				45
No. of Obs.	347	347	347	347	248	248	248	248
No. of countries	91	91	91	91	65	65	65	65

Note: The panel is comprised of four 10-year periods for each country, so that data permitting, each country has four observations. Heteroskedasticity and country-specific autocorrelation consistent standard errors are reported in parentheses.
Levels of significance are indicated by asterisks: *** 1%, ** 5%, * 10%. An intercept term is included in each regression.
See Appendix for the list of countries included in the sample.
a) Pooled OLS. Regional dummies (Asia, Latin America, Sub-Saharan Africa) and time period dummies are included.
b) Robust estimation (to address leverage points and outliers). Iterated reweighted least squares regression in which the outliers are dropped (if Cook's distance >1) and the observations with large absolute residuals are down-weighted.
c) Fixed-effects (within) panel regression. Country-specific effects are controlled for (through within transformation).
d) System GMM dynamic panel estimation (Arellano-Bover 1995). Country-specific effects are controlled for (differenced out).

III.3.1 Processing Export and China as a Final Assembler

The international production network consists of vertical production chains where the various stages are optimally located across different countries so that total production costs can be lowered (Box 4).[27] In order for the fragmentation of production process to be economical, the cost of service links connecting production blocks (such as transport costs, telecommunication cots and coordination costs) should be low enough. Advances of information and communication technology (ICT) have substantially reduced the service link costs. East Asian countries are substantially different in terms of labour costs and technological levels. Thus, there is a huge scope for potential gains from the production fragmentation process in the region (Ando and Kimura, 2003).

During the past decades, firms from Hong-Kong, China; Chinese Taipei; Japan; South Korea and other Asian economies have relocated their labour-intensive industries to China, while firms from the United States and Europe operating in the NIEs (newly industrialised economies including Hong Kong, China; Singapore; Korea; Chinese Taipei; and Thailand) have also moved their operations to China. A triangular trade pattern has emerged with Japan and other NIEs exporting capital and sophisticated intermediate goods to less developed countries like China, which then process them for exports destined to the United States, Europe and back to the NIEs. Trade balance of China in HT1 (high-technology products) illustrates this triangular pattern well. China reports trade surpluses with the United States and the EU-15 and yet trade deficits with other Asian countries such as Chinese Taipei, Korea, Japan (Figure 9). In 2007, total trade surplus of China is largely due to LT (low-technology) exports such as textile, garment, footwear, and toy, rather than high-technology (HT) exports despite their strong growth in recent years (Figure 10). Similarly, low-tech exports are a main contributor to overall trade surplus in India and Indonesia, but medium- and high-tech exports make a negative contribution to trade balance.

There is strong evidence that China's primary role in the production network is a final product assembler. Compared to other countries, China represents an extreme case in that its import of manufactures is disproportionally skewed toward parts and components (Figure 11a), whereas its export of manufactures is largely in the category of finished goods (Figure 11b). In 2007, China's export of finished goods account for 59% of its total manufactures exports and import of finished goods account for 33% of its total import. In sharp contrast, China's import of parts and components account for 66% of its total manufactures import and yet its export is only 35% of its total export. Although similar patterns are observed in the Philippines, Malaysia, Mexico, Hungary and Czech Republic, the reversal of net export position of China across the two categories, intermediate goods and finished goods, is striking.[28]

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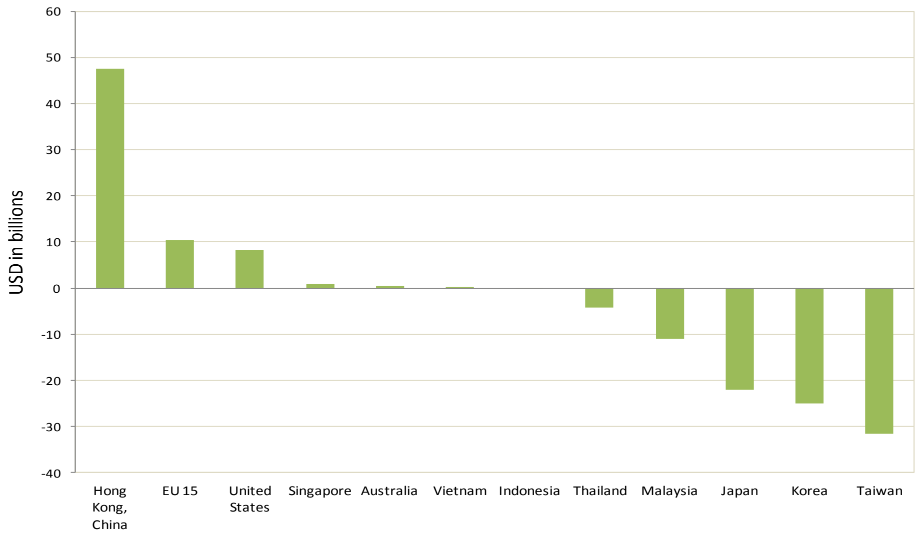
27. As for the fragmentation theory, see Jones and Kierzkowski (1990) and Deardorff (2001) among others.

28. However, the OECD (2006) argues that China's ICT firms are not merely assembling and re-exporting to OECD countries, but are also increasingly competing in aspects of the production process that use skilled labour and demand higher-technology inputs, citing that growth in high-technology imports largely lags growth in high-technology exports and interpreting that as evidence of increasing domestic value-added.

Therefore, advanced and less advanced economies are being affected very differently by China's rise. Chinese gains in export shares (particularly in finished goods) come at the cost of other countries that compete head to head with China in third markets. At the same time, this may provide the greater incentive for other countries to move up the technological ladder into the production of more technologically-intensive, less labour-intensive exports. However, countries that produce raw materials, parts and components, and capital equipments that are utilised heavily in Chinese manufacturing benefit from China's export growth (see OECD, 2010a; Eichengreen *et al*., 2007).[29]

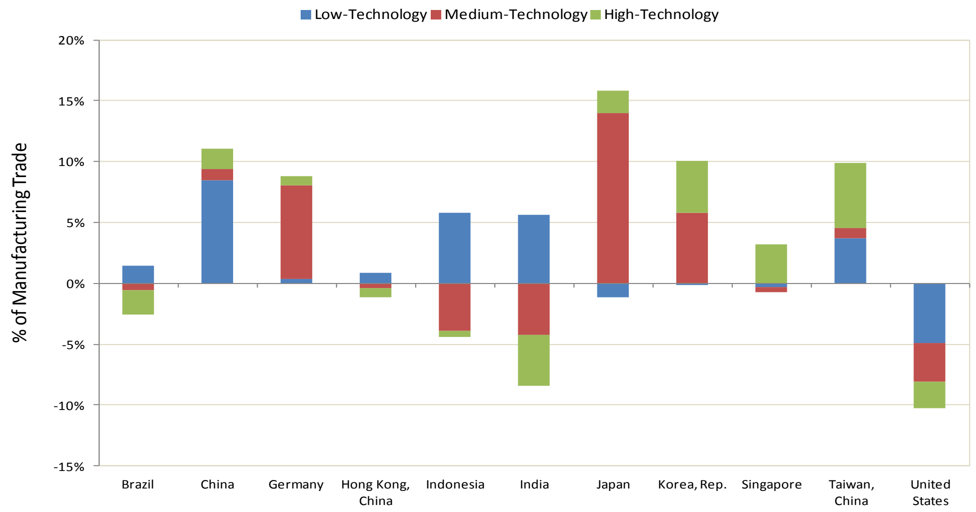
Figure 9. China's Trade Balance with Trade Partners on High-Tech Products (HT1), 2007



Source: Author's calculation based on UN COMTRADE (2009) data

29. China and India can potentially provide access to technology for other developing countries at lower cost. In the case of China, exports of capital goods to low- and middle-income countries rose from USD 1.6 billion in 1990 to USD 114 billion in 2008 (OECD, 2010a).

Figure 10. Contributions to Manufacturing Trade Balance (% of Manufacturing trade), 2007



Source: Author's calculation based on UN COMTRADE (2009) data

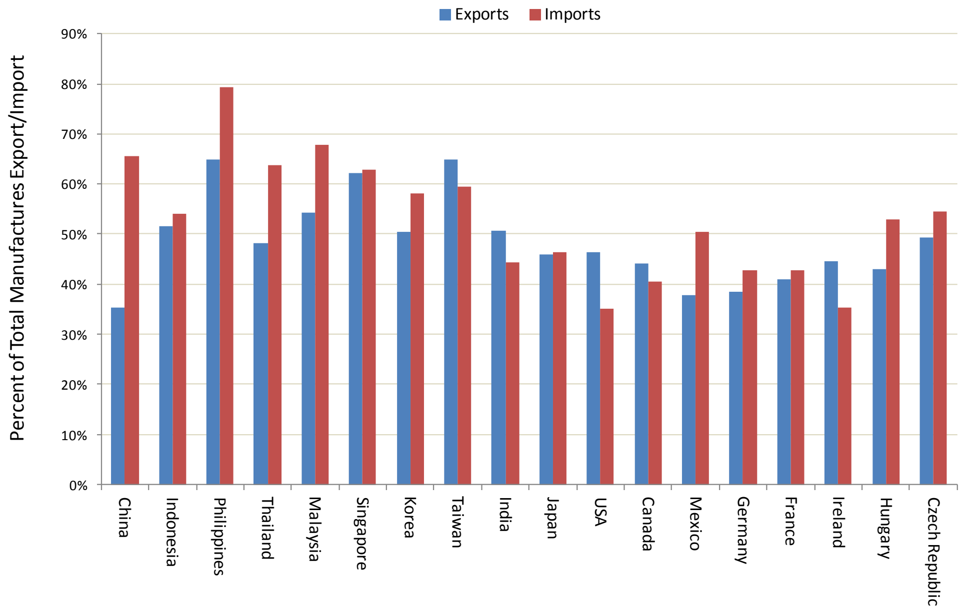
Note: The "contribution to the trade balance" is the difference between:

$$(X_i - M_i) - (X - M)\frac{(X_i + M_i)}{(X + M)}$$

where $(X_i - M_i)$ = observed industry trade balance, and $(X - M)\frac{(X_i + M_i)}{(X + M)}$ = theoretical trade balance

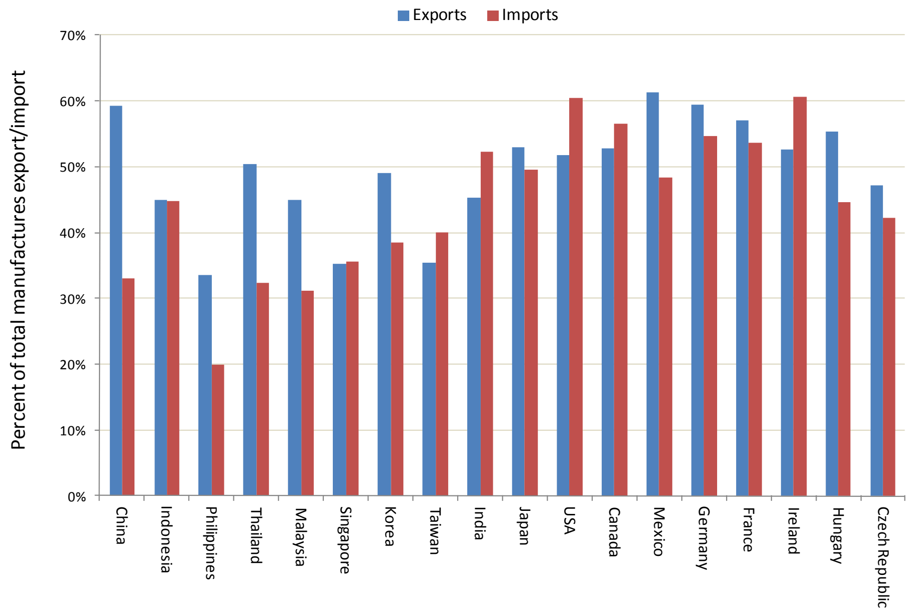
If there were no comparative advantage or disadvantage for any industry *i*, a country's total trade balance (surplus or deficit) should be distributed across industries according to their share in total trade. A positive value for an industry indicates a structural surplus and a negative one a structural deficit.

Figure 11a. Parts and Components - Export and Import in Selected Countries, 2007



Source: UN COMTRADE (2009)

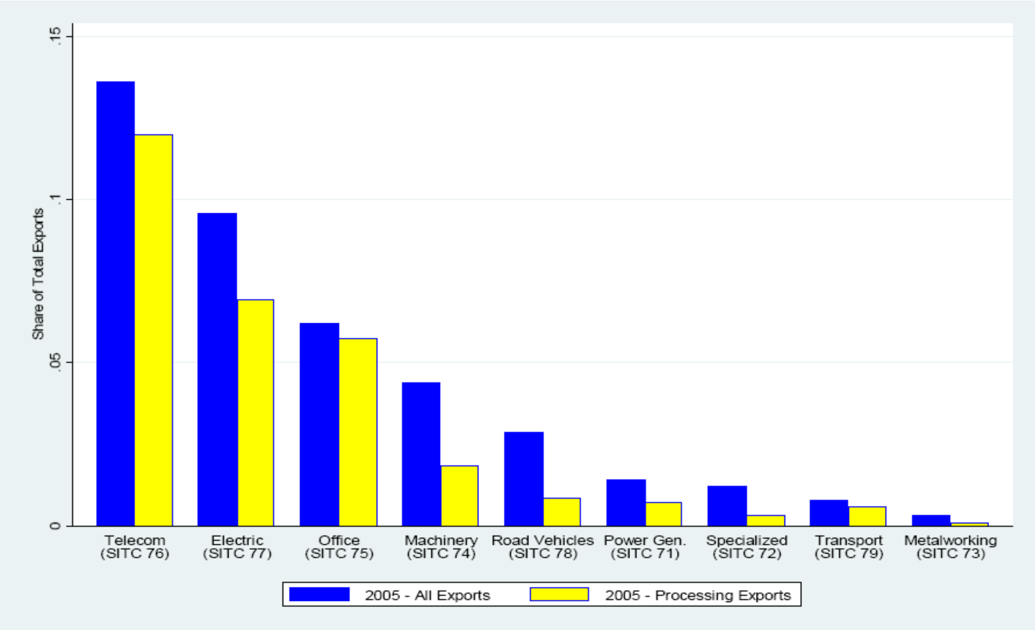
Figure 11b. Finished Goods - Export and Import, 2007



Source: UN COMTRADE (2009)

The processing exports account for more than 50% of China's exports every year at least since 1996 (Koopman *et al.*, 2008). See Figure 12. According to Dean *et al.*, 2007, imported inputs account for between 52 to 76% of the value of processing exports. Similarly, Koopman *et al.* (2008) find that domestic value-added as a share of Chinese exports is about 50% on average. Yet, there is a substantial variation across sectors. Technically sophisticated sectors such as computers and telecommunications tend to have much lower domestic value-added in the range of 20% or less (similar conclusion reached in Krugman, 2008). Low-skill labour intensive sectors exhibit a high share of domestic content in China's exports. Foreign-invested firms (wholly owned or Sino-foreign joint venture firms) tend to have a relatively low share of domestic content in their exports. However, we do not find a similar pattern in India, which is consistent with the smaller role of manufacturing industry relative to service industry as well as its still limited integration with the rest of the world (see OECD, 2009a about India's trade integration).

Figure 12. **Machinery Exports and Processing Exports in China**



Note: Column headings include the following industries based on HS 2-digit classifications:

SITC 71: Boilers, turbines, internal combustion engines, and power generating machinery.
SITC 72: Agricultural machinery, civil engineering and contractors' equipment, printing and bookbinding machinery, and textile and leather machinery.
SITC 73: Lathes, machines for finishing and polishing metal, soldering equipment, metal forging equipment, and metal foundry equipment.
SITC 74: Heating and cooling equipment, pumps, ball bearings, valves for pipes, and nonelectrical machines.
SITC 75: Typewriters, photocopiers, and data processing machines.
SITC 76: Television receivers, radio receivers, and sound recorders.
SITC 77: Equipment for distributing electricity, electro-diagnostic apparatus, and semiconductors.
SITC 78: Automobiles, trucks, trailers, and motorcycles.
SITC 79: Railroad equipment, aircraft, ships, boats, and floating structures.

Source: Amiti and Freund (2010)

Box 4. **International Production Network**

Globalisation process during the last decades is associated with the rapid emergence of international production network as production processes become increasingly fragmented geographically. The advance of information and communication technology (ICT) has made it possible to slice up the value chain and perform activities in any location that can help reduce costs. The globalisation of value chains results in the physical fragmentation of production, where the various stages are optimally located across different sites as firms find it advantageous to source more of their inputs globally. This phenomenon has also been referred to in the literature as global value chains or vertical specialisation. International production network allows intermediate and final production to be outsourced abroad, leading to increased trade through exports and imports, and to a rapidly growing volume of intermediate inputs being exchanged between different countries. In 2003, 54% of world manufactured imports were classified as intermediate goods (which includes primary goods, parts and components and semi-finished goods).

The international production network has also resulted in increasing intra-industry trade (*i.e.* trade within the same industry, including the trade in intermediate goods at various stages of production). While a substantial increase in intra-industry activities is observed in almost all countries, it is particularly noticeable in Asia (Ando and Kimura, 2003). High and medium-high technology industries are on average generally more internationalised than less technology-intensive industries. This difference results partly from the growing complexity of many high technology products; firms no longer have all the required knowledge in-house and increasingly have to look outside.

The international production network is motivated by a number of factors. One is the desire to increase efficiency, as growing competition in domestic and international markets forces firms to become more efficient and lower costs. One way of achieving that goal is to source inputs from more efficient producers, either domestically or internationally, and either within or outside the boundaries of the firm. Other important motivations are entry into new emerging markets and access to strategic assets that can help tap into foreign knowledge. Notwithstanding these anticipated benefits, engaging in global value chains also involves costs and risks for firms. See OECD (2007a) for a good discussion on global value chains.

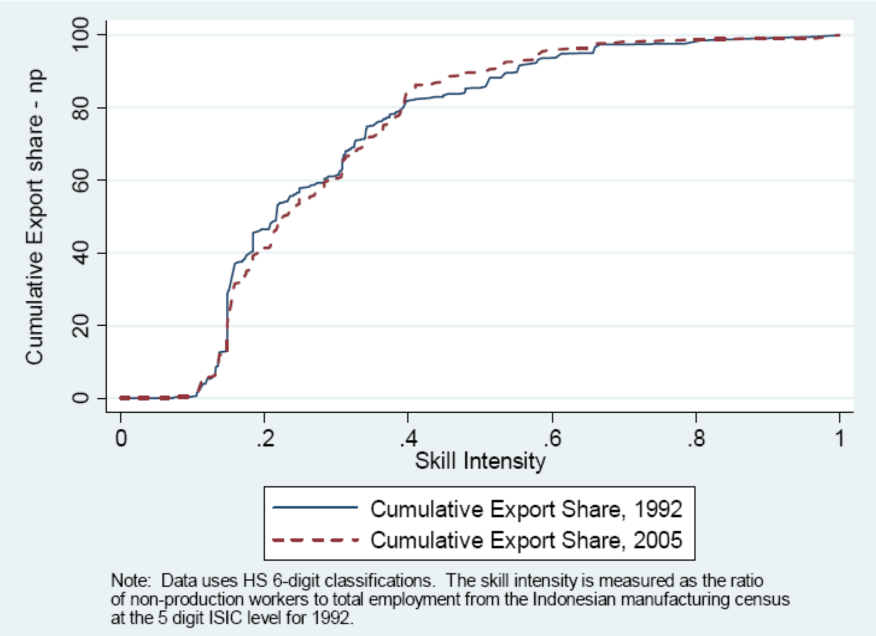
III.3.2 Skill Content of Export: Processing Export versus Non-Processing Export

Regarding the increasing level of sophistication of China's export products, one controversial issue is whether the increased sophistication has been associated with an increase in domestic skill contents of its exports. Amiti and Freund (2010) find the skill content of China's exports has increased: in 1992, 20% of the least skill-intensive industries produced 55% of China's export. By 2005, the export share of these industries has fallen to 32%. However, this may be due to China importing intermediate inputs with higher skill content that it assembles for exporting. They show that the skill intensity of China's non-processing manufacturing exports in 2005 remains unchanged at the level of 1992, suggesting that China continues to specialise in labour intensive goods, once we account for the processing exports (Figure 13).

However, this does not prove that there is no technological progress in China. It does not say anything about within-industry skill upgrading in processing and non-processing export industries. Moreover, there is evidence on knowledge spillovers from FDI in China, and that foreign-invested enterprises are predominantly engaged in processing export in China. Thus, we cannot conclude from their study that there is no skill upgrading in China's non-processing exports. Nonetheless, technological changes seem to be largely associated with processing export activities, rather than non-processing exports. Using unit value as another yardstick of sophistication level of variety, Chinese varieties tend to have lower unit values in general (Schott, 2008; Wang and Wei, 2010). Again, there is substantial heterogeneity across industry and locations in China. Private Chinese firms produce lowest unit values, whereas foreign-invested firms engaging in export processing and located in high-tech development zones produce highest unit values.

Next we look into the export activities by the producer location (export processing zones and high-tech industrial zones), producer ownership (wholly foreign-invested firms, Sino-foreign joint ventures, or domestic firms), and customs type (processing or non-processing trade).

Figure 13. **The Skill Intensity of China's Manufacturing Exports Excluding Processing Export**



Source: Amiti and Freund (2010)

The Chinese authorities (central, regional and local government levels) have actively promoted quality upgrading of China's product structure, through tax and other policy incentives, which has contributed to proliferation of special economic and technological development zones, such as special economic zones, export processing zones, and high-tech zones (Box 5). Their share in China's exports has risen from less than 6% in 1995 to 25% in 2005.

Table 10 shows a breakdown of China's exports into processing trade, normal trade, and others according to exporters' customs declarations. Processing exports come in three different forms: *i)* export processing zones; *ii)* high-tech development zones; and *iii)* processing exports from outside any policy zones. Collectively, their share in the country's total exports has increased from 43% in 1995 to 52% in 2005. It is noteworthy that processing exports in high-tech zones have substantially increased from 3.2% in 1995 to 11.8% in 2005. While export processing zones have gained some modest share from zero to 4.6% over the same period, processing exports outside policy zones have declined a bit from 39.8% to 35.6%. This fact in combination of the finding that export sophistication is strongly associated with processing exports suggests that policy zones set up by the central and local governments may have encouraged firms to upgrade quality of their products to a higher level and contributed to greater sophistication of China's exports. Although export processing zones may also have contributed to the rising sophistication of export products and rising unit values, their magnitude is relatively small.

In terms of ownership, foreign-invested firms in China play a major role in exports. The share in China's total exports by wholly-owned firms and by Sino-foreign joint ventures has continuously increased from 31.5% in 1995 to 58.2% in 2006. These foreign-invested firms are dominant in processing exports and therefore may produce much more sophisticated products than domestic firms (Figure 14). Either wholly or partly foreign-owned firms account for 100% of exports from export processing zones, 95% processing exports out of high-tech zones, and 67% of processing exports outside the policy zones in China (Wang and Wei, 2010).

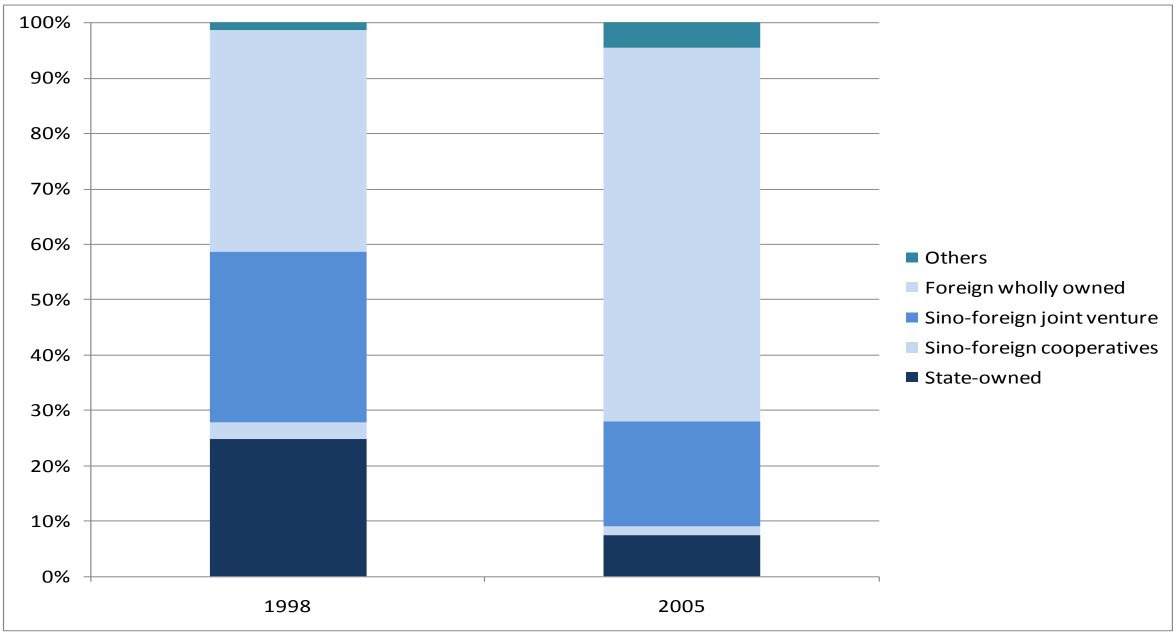
Table 10. **Share of Processing Trade and Policy Zones' Production in China's Total Exports, 1996-2005**

Year (1)	Special Economic Zones (2)	Exports Processing Zones (3)	Processing exports in High-tech Zones (4)	Normal exports in High-tech Zones (5)	Processing Exports Outside Policy Zones (6)	Normal Exports Outside Policy Zones (7)	All Other Exports[a] (8)
1995	10.6	0	3.2	2.1	39.8	42.1	2.2
1996	8.7	0	3.9	1.8	45.2	38.3	2.0
1997	8.8	0	4.6	1.7	43.9	39.0	1.9
1998	8.2	0	5.5	1.9	45.5	36.9	1.9
1999	7.0	0	6.4	2.2	45.5	37.0	1.9
2000	7.1	0	7.0	2.6	43.3	38.2	1.8
2001	6.8	0.1	7.4	2.8	43.0	38.0	1.9
2002	6.2	0.7	8.0	3.0	42.2	37.6	2.3
2003	5.3	2.4	9.5	3.4	39.6	37.1	2.7
2004	4.4	3.6	11.0	3.6	37.7	36.4	3.2
2005	4.3	4.6	11.8	3.6	35.6	36.8	3.5
1996-2004 average	6.3	1.3	8.0	2.8	41.7	37.4	2.4

Note: a) This category includes international aid, compensation trade, goods on consignment, border trade, goods for foreign contracted projects, goods on lease, outward processing, barter trade, warehouse trade, and entrepôt trade by bonded area.

Source: Wang and Wei (2010), original data based on official trade statistics from the China Customs Administration.

Figure 14. **Chinese High-Tech Exports by Ownership of Firms**



Source: OECD (2008)

Box 5. **Special Economic and Technological Development Zones in China**

China has established a number of special economic zones where more incentive policies have been applied since 1979, as a part of its development strategy. Five special economic zones (SEZs) have been set up and are distinguished from other special economic areas. They include all of Hainan province, three cities (Shenzhen, Zhuhai, and Shantou) in Guangdong province, and a city (Xiamen) in Fujian Province. Other special economic zones were subsequently created are much smaller geographically, and classified as Economic and Technological Development Zones (ETDZs) that offer many of the same provisions as SEZs, Export Processing Zones (EPZs), and High and New Technology Industry Development Zones (HNTIDZ) that often serve as an international R&D hub for science-related and high technology, such as biotechnology and information technology and provide co-location opportunities for start-up firms along with business development or technology support services. Some of these special incentive zones and areas fall within the five SEZs. China's SEZs offer lower tax rates, fewer and simplified administrative and customs procedures, duty-free import of components and supplies, and building infrastructure and utilities at a subsidised rate.

Among these policy zones, ETDZs and HNTIDZs are tax-favoured enclaves established by central or local governments (with the approval of the central government) to promote development of sectors that could be considered "high and new tech" by some imperfectly-defined criteria. There are differences in theory between the two types of zones. In practice, however, the line between the two is often blurred. Which firms should go into which type of zone is somewhat arbitrary. The share of ETDAs and HNTIDZs in China's exports has grown steadily, from only 4.3% in 1995 to 15.4% in 2005. Dedicated export processing zones (whose exports are exclusively in processing trade) were established starting in 2001 and are present in only 26 cities currently. In national aggregate, only 4.6% of exports come from all the export processing zones taken together, by 2006.

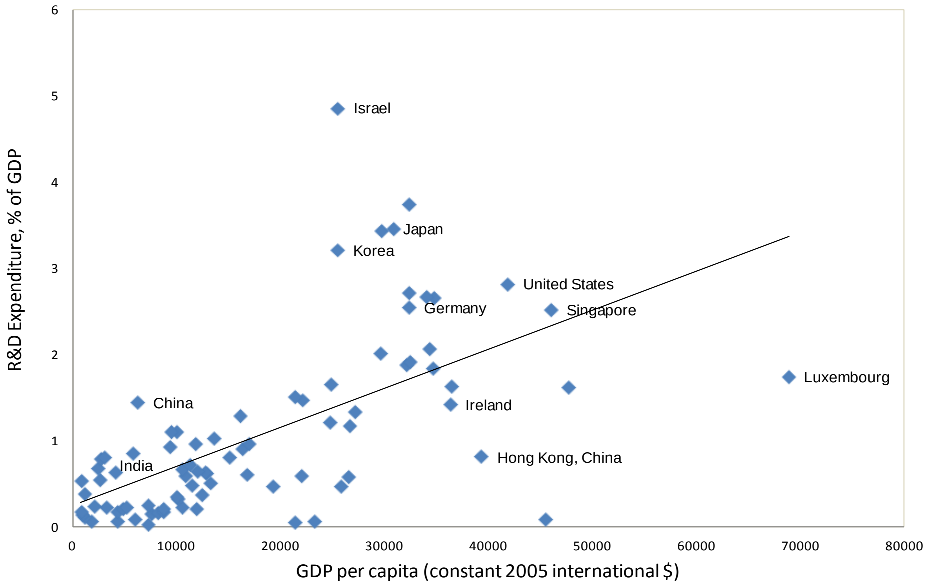
III.4 Upgrading the Technological Capabilities: R&D Efforts and Human Capital

China and India have increasingly emphasised the skill-intensive industry rather than labour-intensive industry in which they may have a comparative advantage, given their greatest factor endowment, a surplus of labour. A rapid increase in R&D intensity is consistent with the goal of upgrading the quality and skill contents of products. R&D intensity of China, measured by R&D expenditure as a percentage of GDP, was about 0.5% for much of the 1990s, then substantially rising to 1% in 2000 and further to 1.5% in 2007. It is set to rise to 2% by 2010, according to the government's objectives – against the OECD average of 2.2% (OECD, 2010b). China is one of the few low or low-middle income countries whose level of R&D intensity has risen beyond 1%. For India, it was 0.8% in 2007 (Figure 15). The market oriented reforms of China's R&D system since 1985 have resulted in industry's share of general expenditures on R&D (GERD) rising to 69% in 2006, making China's R&D funding structure resemble that of advanced OECD countries. However, it is not yet translating into stronger performance in many technological indicators (Figure 16).[30]

Human capital is fundamental for the ability to adapt to new technology and to innovate. Recently, China has been focusing on higher education. The focus on tertiary education differentiates the Chinese case from other countries that stressed primary and secondary education at similar stages of development. The number of undergraduate and graduate students in China has been grown at approximately 30% per year since 1999, and the number of graduates at all levels of higher education in China has approximately quadrupled in the last 6 years (Li *et al.*, 2008). China has the second largest stock of human resources in science and technology (HRST) in the world, just after the United States (having pulled ahead of Japan in 2000). A substantial share of China's university graduates has degrees in science and engineering – at 41.3%, the share is almost twice as high as the leading OECD country. Some studies (*e.g.* Wang and Wei, 2010) find that improvements in human capital along with government policies in the form of tax-favoured high-tech zones have been key determinants of China's rising export sophistication. Nonetheless, the overall level of tertiary education attainment is still quite low, even by developing countries standards. China and India substantially lag behind the advanced economies in terms of overall educational attainments. Figure 17 shows years of schooling of population over age 25 as a measure of human capital for selected countries in 1950-2010. The number of researchers per person employed is also very low, reaching only about one-tenth of Finland's level, the highest in the world. This is also true of India (Table 11).

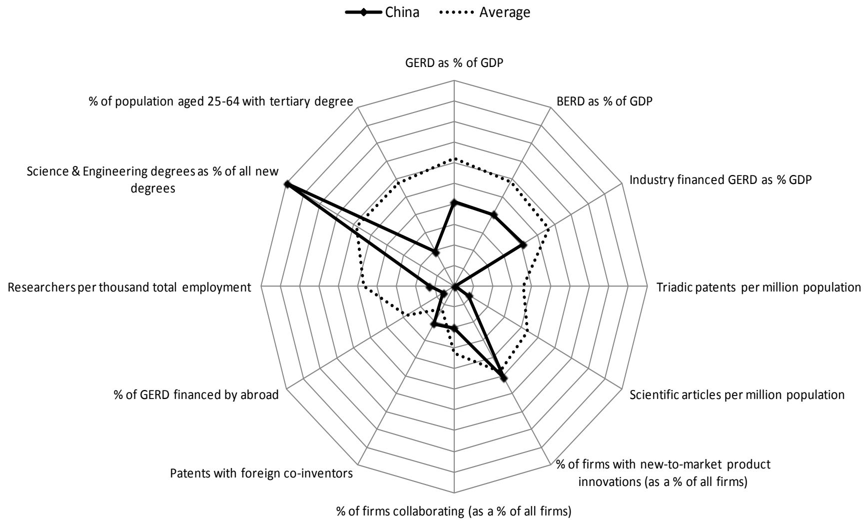
30. China's Medium and Long term S&T Strategic Plan (2006-2020) provides a blueprint for further developing Chinese innovation capacities and for reaching the objective of being an innovation-oriented country by 2020.

Figure 15. R&D Expenditure (% of GDP) and GDP per capita, 2008/09



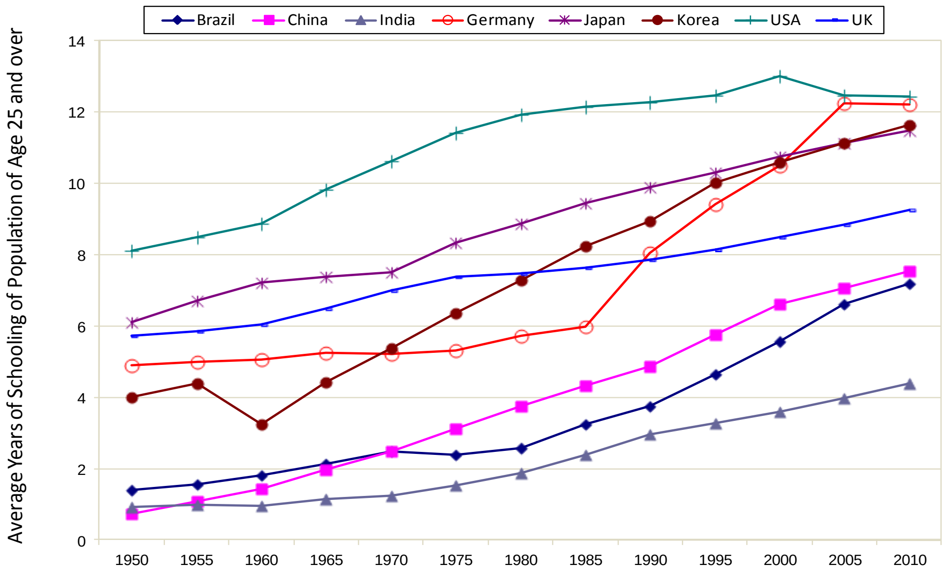
Note, For China and India, the R&D expenditure figures are for 2007
Source: World Development Indicator (2011)

Figure 16. Science and Innovation Profile of China



Source: OECD (2010c)

Figure 17. Years of Schooling of Population of Age 25 and Over



Data: Barro and Lee (2010)

Table 11. **Researchers in R&D and Students in Science and Engineering**

Country	Researchers in R&D[a]	Researchers in R&D per Million People	Enrollment Ratio in Natural Science & Engineering[b]
China	1 411 380	1 071	53
India	149 892	137	23.9
Japan	712 063	5 573	62.2
Korea	224 213	4 627	43

Notes:
a) The figures for China, Japan, and Korea are in 2007 and for India in 2005.
b) Ratio of undergraduate and post-graduate enrolment in natural science & engineering to the total in 2006.
Source: World Development Indicators (2010), Science and Engineering Indicators (2010).

Domestic and foreign applications for patents in China have increased 9 times and 8 times, respectively, between 1995 and 2005. More recently, Chinese applications for foreign patents have increased rapidly, accounting already for 3% of applications filed with World Intellectual Property Organisation's Patent Cooperation Treaty (PCT) (see OECD, 2007b for a detailed review of China's innovation system and policy). However, production of triadic patent families and scientific articles is still very low on a per capita basis.[31] Foreign inventers still own a large share of invention patents granted in China, and foreign-owned firms account for an increasing share of China's high-tech exports.

31. In absolute numbers, China entered the top 15 for the number of triadic patent families in 2005, and it accounted for 5.9% of worldwide scientific articles in 2005, up from 1.6% in 1995, thus taking 5th place behind the United States, Japan, Germany, and United Kingdom.

The share of GERD funded from abroad is also low in China. However, motivated by the availability of quality HRST and a large domestic market, inflows of foreign R&D investment to China have increased strongly in the past years, and foreign funding is estimated to account for 25% of business expenditure on R&D (BERD) in China. This trend of foreign R&D investment is set to continue, as China is considered the prime destination for future R&D investment by multinational firms. While foreign ownership of Chinese inventions held abroad is still high, at 47%, it has decreased from 55% in the early 1990s, owing in part to a marked increase in domestic patenting activity.[32]

R&D investment abroad by multinational firms has grown strongly as multinational enterprises' strategies focus on global technology sourcing. This involves building networks of R&D globally in order to tap into local knowledge and develop sources for new technology development. While most R&D internationalisation still takes place within the OECD area, developing countries are increasingly attracting R&D centres, although these remain relatively small in a global perspective (see OECD 2007c for more on internationalisation of business R&D activities). Large increases in foreign R&D investment in Asia, in particular in China and India, have attracted much attention in recent years. This shift is expected to continue to the extent that these countries offer a combination of relatively low wages with a large pool of well-trained researchers.

32. As for the patent surge in China, Hu and Jefferson (2009) find that foreign direct investment along with legislative changes favouring patent holders and ownership reform that clarified the assignment of property rights prompted Chinese firms to file for more patent applications. Although rising R&D intensity in China tracks with patent activity, it explains only a small fraction of the patent explosion.

IV. CONCLUDING REMARKS

The paper has examined sources of technological upgrading in China and India by assembling new cross-country evidence as well as micro-data evidence and case studies in the literature. First, the overall technological level in these economies is still low compared to that of the OECD Members, regardless how it is measured (*e.g.* TFP level, domestic value-added of technically sophisticated products, or domestic skill contents of exports), which suggests a substantial scope for technological catching-up in the future. Evidence clearly shows that technological upgrading is taking place at a rapid pace in China, while it is rather slow in India. Strong TFP growth is a key feature of China's rapid growth. It appears not only to reflect the catch-up process but also rapid technological changes. Consistent with this observation, China's export bundle has been diversifying into complex, capital- and technology-intensive products. This has been an important driver of growth at the breakneck rate and an increasing threat to advanced countries. On the other hand, India's TFP growth has been modest, and accelerated lately. Also, exports of India are significantly less technologically sophisticated than in the rest of Asian region, although India has been more successful in exports of business services and of information and IT services.

Second, our new evidence from a panel regression on TFP growth confirms the importance of FDI and import of capital goods in the technology diffusion process from advanced to less developed countries. China is not an exception in this regard. FDI appears to be a main source of technological upgrading in China, bringing advanced production technology, cutting edge of R&D, and management expert, and generating spillovers and externalities to local firms. Also, foreign-invested enterprises are primarily engaged in processing exports of medium- and high-tech products in the international production network.

Third, China's extraordinary export performance in medium- and high-technology products, which is often perceived to be a threat to advanced economies, is closely linked to the emergence of an extensive international production network in Asia. China has been playing a primary role as a final product assembler in the network, using capital equipments and intermediate goods imported from other advanced economies. This appears to be an important explanation for the puzzle of why the measured overall technological level of the economy is much lower than the technological sophistication of exports. Our analysis also suggests that more and less developed countries are being affected very differently by China's rise. Chinese gains in export shares particularly in finished goods come at the cost of other countries that compete head to head with China in third markets, providing the greater incentive for other countries to move up the technological ladder into the production of more technologically intensive and less labour-intensive exports. By contrast, countries that produce raw materials, parts and components, and capital equipments utilised heavily in the Chinese manufacturing can benefit from China's export growth.

Fourth, technological upgrading is an outcome of long, cumulative processes of learning, and assimilation of more advanced technology, and hence moving from a low-technology structure to a high-technology one is a challenging goal for many developing countries. The success story of China and India teaches us a valuable lesson for these countries. It is beyond doubt that foreign trade and openness to FDI has played a significant role in the phenomenal economic performance in China and (to a lesser degree) in India where the reform started a decade later. With market-oriented reforms and opening to trade and FDI deepening, growth has accelerated in both economies. China's advance in industrial productivity have been facilitated by competitive pressures arising from the country's gradual but steady integration into the world economy and the incorporation of advanced technology through openness to FDI. China's strategic decision to open to FDI and trade can be viewed as a way of addressing its technological backwardness – in effect, trading access to its large and growing market in return for technology. Since the mid-1990s, China has been encouraging FDI flow into technology-oriented industries, such as electronics, IT, and bioengineering, as well as establishing local R&D centres.

Technological upgrading however is not an automatic outcome of opening to trade and FDI, as the earlier experiences of trade and capital account liberalisations in Latin America demonstrate. China's pattern of production and exports would have looked different if China simply pursued an export-growth strategy predicated on specialisation according to its apparent comparative advantage in low-skill and labour-intensive products. There have been increasingly deliberate efforts to promote technological progress through government policies. For example, China has established a number of special economic zones (SEZs) including high technology industry zones. The SEZs have offered lower tax rates, simplified administrative and customs procedures, duty-free import of components and supplies and subsidised utilities. Also, China and India have increasingly emphasised the capability to absorb technologies and generate new ones by encourage investment in human capital and R&D activities. Human capital is not only a fundamental determinant of the capacity to innovate but also can facilitate technological diffusion. Indeed, improvements in human capital along with government policies in the form of tax-favoured high-tech zones are found to be determinants of China's rising export sophistication.

Finally, from a developing economy's perspective, technology upgrading depends on the extent of adoption and assimilation of foreign technologies that is influenced by domestic conditions in product markets, factors (such as skilled labour), and government policies and institutions (such as trade and competition policies, and regulatory framework). The challenges facing many developing countries are to establish a transparent, broad and effective policy environment that is conducive to investment in skills and technology, and to build the institutional capacities to implement them. They also need to pursue sound macroeconomic policies geared to sustained high economic growth, price stability and sustainable external accounts. Such a stable and effective policy environment not only provides incentives for improvements of skills and innovation but also equips the country better to benefit from opening to FDI and trade.

Appendix Table A1. **List of Countries in the Sample of Tables 7 and 9**[33]

The sample of 90 countries is dictated by the availability of data in Penn World Table 6.3 and international data on educational attainment, which would be needed to compute TFP (total factor productivity). The classification of countries in terms of advanced and non-advanced economy group follows the convention in the literature. In particular, the advanced economy group includes 21 traditional OECD member countries, which excludes Hungary, Korea, and Mexico, *etc*.

21 Advanced Economies (traditional OECD member nations)

	Country		Country		Country
1	Australia	8	Greece	15	Norway
2	Austria	9	Iceland	16	Portugal
3	Canada	10	Ireland	17	Spain
4	Denmark	11	Italy	18	Sweden
5	Finland	12	Japan	19	Switzerland
6	France	13	Netherlands	20	United Kingdom
7	Germany	14	New Zealand	21	United States

69 Non-Advanced Economies

	Country		Country		Country
1	Algeria	24	Guyana	47	Paraguay
2	Argentina	25	Haiti	48	Peru
3	Bahrain	26	Honduras	49	Philippines
4	Bangladesh	27	Hong Kong, China	50	Poland
5	Benin	28	Hungary	51	Romania
6	Bolivia	29	India	52	Rwanda
7	Botswana	30	Indonesia	53	Senegal
8	Brazil	31	Iran	54	Singapore
9	Bulgaria	32	Israel	55	South Africa
10	Cameroon	33	Jamaica	56	Sri Lanka
11	Central African Republic	34	Jordan	57	Sudan
12	Chile	35	Kenya	58	Swaziland
13	China	36	Korea, Republic of	59	Syria
14	Colombia	37	Malawi	60	Tanzania
15	Costa Rica	38	Malaysia	61	Thailand
16	Cyprus	39	Mali	62	Togo
17	Dominican Republic	40	Mauritius	63	Trinidad &Tobago
18	Ecuador	41	Mexico	64	Tunisia
19	Egypt	42	Mozambique	65	Turkey
20	El Salvador	43	Nicaragua	66	Uganda
21	Ghana	44	Niger	67	Uruguay
22	Guatemala	45	Pakistan	68	Venezuela
23	Guinea-Bissau	46	Papua New Guinea	69	Zambia

33. In Table 9, 91 countries are in the sample in which Swaziland and Tanzania (shown in the country list) are excluded, whereas Chinese Taipei, Democratic Republic of Congo, and Sierra Leone (not shown in the list) are included due to data availability.

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