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Science, technology and innovation for sustainable development*Background report by Keun Lee* and John Mathews⁺*

Abstract

The paper argues that science, technology and innovation (STI) play a critical role in expediting transition to a sustainable mode of development. Latecomer nations suffer from several disadvantages as they attempt to catch-up with the technological leaders, but they can enjoy latecomer advantages, if appropriate strategies are formulated and executed. One of the key concepts is leapfrogging, whereby the latecomers absorb what the technological leaders have to offer and leap to a new environment-friendly techno-economic paradigm. To facilitate such leap, the current intellectual-property-rights regimes need to evolve to one that fosters technology diffusion and greater use of intellectual property.

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Contents

1. Introduction	1
2. Issues and challenges in sustainable development	3
2.1 The middle-income trap, poverty trap, and the adding-up problem.	3
2.2 The challenge of environment- and climate-friendly development.	5
2.3 Intellectual Property Rights (IPRs): Incentives or barriers to innovation?	6
3. The search for a new paradigm of development.	8
3.1 New strategic thinking about development	8
3.2 From removing the binding constraint to creating the growth poles/drivers	8
3.3 Potential of STI in catching-up development	9
4. Necessity and feasibility of new growth models	12
5. Learning from cases of stage-skipping and leapfrogging	15
5.1 Telephone switches in China and Korea vs. Brazil and India	15
5.2 Biofuels in Brazil	16
5.3 Solar thermal heating in rural China and solar power in Nigeria	17
5.4 From black to green development in Mozambique	18
6. Specific strategies and policies for sustainable development	20
6.1 Building technological capability in three stages and the role of public laboratories.	20
6.2 Using incentives to kick-start environment-friendly technological trajectories	24
6.3 IP strategies for latecomer firms.	25
7. Concluding remarks and suggestions for the international community	26
References	29

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Science, Technology and Innovation for Sustainable Development

Keun Lee and John Mathews

1. Introduction

In June 2012, the United Nations Conference on Sustainable Development met in Rio de Janeiro just 20 years after the first conference in 1992 had adopted a far-reaching strategy on sustainable development. The new “Rio+20” strategy, as outlined in the conference outcome document “The future we want” (and adopted by the UN General Assembly a month later, in July 2012) shows continuing commitment by the United Nations Member States to sustainable development in three dimensions, namely promotion of an economically, socially and environmentally sustainable future for our planet and for present and future generations. Special note was taken of the continuing deterioration in the global environment and the failure of past strategies to halt the fossil-fuel based “business as usual” trajectory found in both developed and developing countries.

Among the three dimensions of sustainable development, economic sustainability is concerned with poverty reduction and more directly related to the Millennium Development Goals (MDGs). Social sustainability concerns equity and has recently been formulated as emphasis on inclusive development. The third dimension, environmental sustainability, concerns the ecological and resource crises faced today which threaten the development prospects of countries around the world. While all three dimensions are relevant, economic sustainability is particularly vital to developing countries as many of them tend to be stuck in poverty or in middle-income traps as their growth is not sustained¹. This paper is concerned primarily with the interaction between the economic and environmental dimensions, and investigates the role of STI in enabling developing countries to reach their potential and catch up with advanced countries, while respecting the social inclusion goals that are promoted in the MDGs.

Advancing a nation’s STI capacity and its effective application in economic activities are essential factors for expanding peoples’ capabilities and achieving sustainable development. Globalization has implied increased competition among producers/countries and further stressed the importance of STI for the dynamic transformation of economies and for sustaining growth. For example, the rapid development of digital technologies and their accelerated use in hardware (computers, mobile phones, etc.) and in production processes have changed many aspects of people’s daily lives and enhanced prospects for development. Countries and individuals lacking the capacity to access, adapt and fully utilize these technologies have lagged behind the STI frontier, while the productivity and welfare gaps between the haves and have-nots have widened.

For most developing countries, the underlying strategic objective in the area of STI is to promote technological catch-up with leading countries (the leader), which include not only developed countries, but also some other developing countries. This catch-up process involves acquiring, mastering and adapting new products, technologies or managerial structures previously developed by the leader and, eventually, breaking into new markets, and expanding and consolidating participation in those markets. For many least

1 United Nations Committee for Development Policy, *The United Nations Development Strategy Beyond 2015* (United Nations publication, Sales No. E.12.II.A.3)

developed countries (LDCs) that do not possess a minimal technological base to start or advance in the catch-up process, external assistance may be required to enable them to establish a minimum technological platform from which the process can be initiated. The initial success of the catch-up would make it possible for countries—LDCs and otherwise—to climb up the ladder in the global technological hierarchy and eventually to participate in the generation of knowledge and new technology.

These considerations call for an examination of the role of technology in economic development, and the role of STI policies in the context of national development strategy as well as the potential contribution of international cooperation in the area of technology transfer and capacity-building. In this regard, the success of East Asian countries can be attributed to the priority given by their national development strategies to policies aimed at enhancing long-term growth prospects, including policies on technology, human capital and institutional development. STI policies were undertaken with a view towards creating or strengthening strategic industries through tax concessions, subsidies and trade protection.

However, countries trying to catch up at present face new challenges and opportunities that the East Asians did not face. First, policies to promote structural change in the economy increasingly need to be consistent with the introduction of technologies that rely on clean energy and adapt to climate change². Second, more rapid technological progress than before implies that the targets for catching up and development are constantly moving and that market opportunities change quickly in today's world. Thus, promoting sectors based on mature technologies, while offering a good platform for promoting manufacturing, may not lead to catch-up (Pérez, 2001). Accordingly, the requirements to access and apply new technologies and to capture market opportunities may be more difficult to meet than before. Third, the inability of the conventional fossil-fuelled industrial model to scale up and provide a sound source of income and wealth for all the world's inhabitants has to be confronted, and an alternative sustainable model of development needs to be created³. This means, in effect, that developing countries need to avoid carbon lock-in approaches that constrain the uptake of renewables and low-carbon technologies in the advanced world, while securing advantages from the adoption of renewables. Brazil is a case in point, as the country has been using bioethanol from sugar cane as a domestically developed alternative fuel. Fourth, intellectual property rights are now ruled by the TRIPS agreement and also increasingly by regional and bilateral free trade agreements (FTAs), which may restrict the range of policy options available for developing countries. These patent-based regimes are not necessarily compatible with the technological development stage of many developing countries and may deter innovation in these countries (Kim, Mani and Mu, 2012).

The main objective of the present paper is to examine what policy measures—both at the domestic and international level—are effective in facilitating technological catch-up or leapfrogging by developing countries. The analysis will be based on the experience of some successful developing countries while paying due consideration to the new challenges and opportunities in the twenty-first century. The focus will be not only on policies for advancing STI, but also on their application in the upgrading and transformation of production structures in developing countries to drive job creation and poverty reduction in accordance with the MDGs. In the context of the greening of development strategies and the role played by STI, our objective is to demonstrate how developing countries can formulate policies to access and utilize the accumulated knowledge related to the transition from a fossil-fuel based development trajectory to a new, sustainable trajectory and generate latecomer advantages for them.

2 See Report of the Committee for Development Policy on its fourteenth session (12-16 March 2012), Official Records of the Economic and Social Council, 2012, Supplement No. 13, E/2012/33.

3 Report of the Committee for Development Policy on its fourteenth session, *op. cit.*

In what follows, section 2 reviews the issues and challenges related to these two dimensions of economic and environmental sustainability. Section 3 discusses the role of STI in addressing these challenges, while section 4 discusses the necessity and feasibility of switching to an alternative growth paradigm. Section 5 analyses and derives lessons learned from selected country experiences where STI strategies have been used in actual contexts. Section 6 discusses specific policy strategies in building up capabilities of developing countries, as well as how to use STI in dealing with the challenges in sustainable development. Section 7 concludes by presenting some policy recommendations for the international community to assist developing countries in the promotion of the acquisition of technological capabilities.

2. Issues and challenges in sustainable development

2.1 *The middle-income trap, poverty trap, and the adding-up problem*

While some latecomer economies have been having remarkable success in catching-up, many others have not been able to join the “catch-up club” (Lee, 2013a). Despite the large amounts of development aid and policy reforms along the lines of the Washington Consensus, poverty and the widening gap between rich and poor countries still prevails. Some have blamed this disappointing outcome on poor institutional conditions in these economies, including insecure property rights, poor governance and rule of law (Knack and Keefer, 1995). The recent literature on economic development has debated the relative importance of institutions, policy, and geography as competing determinants of economic growth or as factors responsible for the reversal of fortune between former colonies and others. A stream of research, such as works by Acemoglu et al., (2001), Rodrik et al., (2004) and Acemoglu (2012), has verified the importance of institutions. However, the cross-national empirical literature has failed to establish a strong causal link between any particular design feature of institutions and sustained economic growth (World Bank, 2005). Furthermore, Glaeser et al., (2004) proposed human capital as a more robust variable for explaining long-run economic growth. In the meantime, the Commission on Growth and Development acknowledged the importance of government activism and industrial policy, while expressing caution over hasty liberalization and privatization initiatives (Commission on Growth and Development Report, 2008).

Recently an increasing number of scholars have been paying attention to the fact that many developing countries were able to show growth spurts for a certain period of time (usually less than a decade) but were unable to sustain it over a longer period (Jones and Olken, 2005; Hausman et al., 2005; and Rodrik, 2006). We view this question of sustaining growth especially important for middle-income countries (MICs) because many countries were able to grow and attain middle-income status but subsequently failed to go on to achieve high-income status. While there have been many studies on the poverty trap and its relevance for low-income countries, few empirical studies have focused on sustaining economic growth beyond the middle-income level⁴.

We find instances in Latin American countries, such as Brazil and Argentina, where growth more or less stalled during the 1980s and the 1990s (Lee and Kim, 2009, table 1; Pause, 2009). These countries have arguably been caught in what could be called a middle-income country trap—defined as a situation where MICs struggle to remain competitive as new countries with low-cost, high-volume production take over their market shares in sectors where they had enjoyed a significant presence. MICs struggle to move forward

4 This issue of the middle-income trap has attracted increasing attention in a number of recent studies, including one by the World Bank (2010), as well as by Griffith (2011), Eichengreen and others (2011) and Pause (2009).

but lack the capacity and capabilities to shift to advanced industries⁵. In contrast, several other countries moved beyond the middle-income status over the two decades and joined the “rich country” club. Examples of these include Korea and Taiwan, whose per capita income increased three times that of Latin American countries during the 1980s and the 1990s.

This trend of declining growth rates as a country moves on from lower-middle income to upper-middle income level suggests that sustaining catch-up growth becomes more difficult when a country is closer to the technological frontier. How can we explain the difficulties faced by middle-income countries, and what would be the possible breakthrough in this difficult situation? The trend also raises the important question of how a few countries, such as Korea and Taiwan, were able to escape this trap and continue their catching-up trajectory.

As verified in Lee and Kim (2009), the answer appears to lie in the level of expenditure on R&D and related innovation capabilities. Country panel analysis shows that during the first transition from low- to middle-income level, basic factors like institutions and primary/secondary education are significant, whereas in the upgrading from middle- to high-income stage, factors like tertiary education and technological innovation begin to play a significant role.

This econometric finding is consistent with the descriptive data. Lee and Kim (2009) show that in the early 1980s, measures such as R&D-to-GDP ratio as well as the number of patents registered in the United States recorded similar levels in Asian countries (Korea and Taiwan, for example) and Latin American countries, such as Brazil and Argentina. However, twenty years later or by the early 2000s, while the Asian countries passed the threshold of 1 per cent ratio of R&D to GDP and filed about 6,000 US-registered patents, the Latin American countries’ R&D intensity rarely reached 1 per cent, while their filing patents in the United States never exceeded 500. The Latin American countries appeared to be caught in the middle-income trap.

Growth beyond the middle-income level is important because without a clear prospect for further development, countries have fewer incentives to promote growth beyond a certain level of income. Economic growth in MICs is important in terms of both poverty reduction and environmental sustainability, given that about 70 per cent of the world’s poor live in these countries and that countries cannot switch to green technologies without achieving a certain minimum income level.

Growth of the current low-income countries may be more possible and sustained as the so-called adding-up problem is attenuated. The adding-up problem happens when a number of countries flood the market with similar goods, usually requiring low or simple technologies and processes that they tend to be good at producing. Thus, relative prices of these kinds of goods decrease, making these sectors less profitable (Spence, 2011). Only when more successful MICs move on to the next stage of making and selling higher value-added or high-end goods will they leave room for the less successful and/or new entrants in the market (low-income countries) to continue to sell low-end goods and maintain their footing on the development ladder.

5 There has been a broad discussion of the “middle-income country trap”, and particularly regarding the issue as to whether China might be able to avoid such an impediment (for example, Lin and Treichel, 2012).

From this view, it is very important for China to move as quickly as possible beyond the specialization in low-end or labour-intensive goods to higher-end goods so that other latecomer countries may avoid the continuing competition with Chinese goods, which seems to be happening already. In fact, such succession has happened in Asia with the Korean and Taiwanese firms taking over the places left by the Japanese companies, and in turn, as these two moved further, the next tier countries moved into the places left by Korea and Taiwan⁶.

In general, sustaining economic growth—although not sufficient—is a necessary condition for job growth and poverty reduction in developing countries. As seen above, STI is crucial in accelerating and sustaining growth, but has played a limited role in these economies. We will address how to improve this situation in the following sections.

2.2 The challenge of environment- and climate-friendly development

While sustaining economic growth is vital for poverty reduction, job creation and avoiding the middle-income trap, the world has reached the stage that the environmental costs of economic growth have to be seriously reconsidered (United Nations Committee for Development Policy, 2012). In other words, trade-offs between the economic and environmental dimensions of sustainable development can no longer be dismissed as the increase in the level of human activity is now threatening to surpass Earth's capacity as a source of resources and as a receptacle for carbon emissions (United Nations Committee for Development Policy, 2012; Vos, 2013).

While it results from both natural factors and human activities, climate change is a major challenge. Human activities contribute to climate change through emissions of greenhouse gases (GHGs), with carbon dioxide (CO₂) being the most common. Energy use is the main source of CO₂ emissions, followed by land use change and deforestation. Power generation and cement production generate most of the GHG emissions in China⁷. The impacts of climate change, such as sea level rise, changes in weather regimes, etc., affect livelihoods and welfare. Developing countries are expected to shoulder at least 75 per cent of the potential global economic losses brought about by climate change, while having relatively limited capacity to respond (Opschoor, 2013).

In general, environmental unsustainability has distributional consequences, as poor groups and countries depend more on the direct use of natural resources to secure livelihoods. At the same time, 1.4 billion people are “energy poor”, that is, lacking access to forms of modern energy or electricity in particular, which in turn is hampering their economic opportunities (Vos, 2013). Environmental pressures (including on natural resources) are driven by population dynamics, economic growth and technological change, and thus there are three basic routes to reducing environmental pressures: reduced population growth, slower economic growth or technological innovation. Given that reducing population growth implies a wide range

6 A relevant question would be whether there is room for both rising MICs and the existing high-income countries, as MICs move forward in relevant market segments. One might reason that there is not be enough room for both groups of countries and more trade disputes might happen. Despite this, one can also note that the successful catching-up economies tend to specialize more in shorter-cycle, technology-based sectors, while existing advanced countries tend to remain strong in long-cycle sectors. For additional information see Lee (2013a and 2013b).

7 For instance, Vos (2013) indicates that, at present, 90 per cent of energy is generated through brown technologies that utilize fossil fuels, with this type of production being responsible for about 60 per cent of carbon dioxide emissions. On China's electric power sector transformation and its GHG emissions, see John Mathews and Hao Tan, “China's industrial energy revolution: renewable targets just became even more demanding”, *The Asia Pacific Journal*, vol. 10, No. 52 (December 2012), available from <http://www.japanfocus.org/-Hao-Tan/3874>.

of ethical considerations, and we need economic growth for poverty reduction and jobs, the least controversial way of tackling unsustainability should be to rely on the potentials of STI.

Traditionally, it is thought that countries of the North are the suppliers of eco-friendly innovations and capable of employing these technologies in their national plans. However, with increasing cross-border flows of information about environmental technologies and the growing technological capacities of countries in the South, it has become possible for these countries to integrate eco-friendly technologies into their national development strategies, so that they can pursue both economic catch-up and environmental sustainability (Walz and Krail, 2012). Indeed, eco-friendly innovations are seen as a possible field in which latecomers might more rapidly achieve a leading position, thanks to lower path dependency or lock-in. An example might be the wind turbine industry, which used to be dominated by European firms but has now seen significant and successful entry by firms from China and India. Although China relied heavily on European firms for most of the components, supplies, and equipment at the early stages of development of this industry, it localized much of the production process owing to local procurement practices and domestic content requirement policies (Lema et al., 2012). We see this as an option for other developing countries as well.

Policy frameworks need to be designed so as to promote widespread use of available eco-friendly technologies. Because many such technologies are still evolving and far from commercial maturity, Governments may need to temporarily set rents at levels that make investments in these technologies “artificially” attractive (Altenberg and Engelmeier, 2012). Temporary rents allow for testing new technologies, learning, and building up economies of scale that are necessary for commercial success. Solar energy technologies are a prominent example. While solar energy is climate-neutral and abundant, solar energy cannot yet compete with fossil fuels, especially as long as environmental costs are not accounted for.

2.3 Intellectual Property Rights (IPRs): Incentives or barriers to innovation?

How to achieve the right balance between incentive provision for knowledge generation and access to knowledge has long been the source of conflicting views on the role of Intellectual Property (IP) in the economic well-being of human society. History has witnessed a pendulum between more and less protection of IPRs (Reichman, 2009). Since the 1980s, the period for pro-protection bias had driven the IP field with the agenda of global harmonization of the IP regime and TRIPs. Recent decades, however, have seen a revived concern for the anti-competitive effects of IP overprotection. Such turnaround has led to the formulation of the WIPO development agenda and 45 recommendations⁸. This shifting emphasis from more protection to increased access to IP has coincided with a newly emerging innovation paradigm such as the rise of open innovation where a wide range of innovation activities is systematically encouraged to exploit synergies both within and outside an entity (Lee et al., 2013).

Generally speaking, developing countries are concerned with the utilization and commercial use of IPs for the development of their societies. While protection of knowledge provides innovators with economic incentives, such incentives are to be given more priority at the later stage of economic development where countries enjoy a higher level of technological capabilities.

⁸ See World Intellectual Property Organization, The 45 adopted recommendations under the WIPO development agenda, available from <http://www.wipo.int/ip-development/en/agenda/recommendations.html>.

Although there is some evidence of the IPR effects on economic growth, particularly with regard to patent protection (Kanwar and Evenson, 2003), the evidence is mixed. Some studies have dealt with the impact of IPRs contingent on certain conditions, stages of economic development or capabilities (Kim et al., 2012; Falvey et al., 2006; Schneider, 2005). A general conclusion is that the impact of IPRs on economic growth depends on many other factors that vary over time from country to country, including the stage of development (Fink and Maskus, 2005). More recent studies, furthermore, point out that an IP system is only one of the many factors that affect economic growth, and developing countries, in particular, confront factors that are more critical or binding for economic growth than IPRs (Odagiri et al., 2010). This latter statement is supported by the experiences of successful catching-up economies that have achieved growth without strong protection for IPRs. Also, simply raising the level of IPR protection would not encourage more innovation expenditure or additional efforts in the context of developing countries where innovation capabilities are lacking. In other words, more stringent IPR protection leads to higher R&D expenditure only when there are pre-existing R&D capabilities, which is not the case in typical developing countries.

Furthermore, strong IP enforcement may seriously reduce the catching-up probability of latecomer firms, especially SMEs from developing countries. In fact, Lee and Kim (2010) and Odagiri et al., (2010) cite stories of such firms having trouble with IPR lawsuits by forerunning companies, though bigger firms in developing countries have had relative success in overcoming the barriers after some troubles. Moreover, while anti-dumping suits were the main tools of trade disputes between countries in the past, IP litigation has become the most rapidly increasing area for trade dispute (Lee et al., 2013). The increased patent litigations over fragmented IPRs and the emergence of patent trolls are also a matter of concern for policymakers in both developed and developing countries because these create numerous regulatory and antitrust issues, and threaten the wider usage of IP for innovation and knowledge creation.

In general, latecomer firms currently face more difficult challenges than in the past. This problem is more serious and burdensome for SMEs with limited financial and human resources which may have to respond to litigations from forerunning companies. In circumstances where firms' capabilities, especially SMEs, are weak, there can be a case for the active role of the government and public research institutes. This should be an important policy agenda. Countries should be allowed certain room to tailor their own IP system to their specific needs. In general, developing countries at earlier stages of development could be encouraged to adopt a petit patent (utility models) system⁹, in addition to regular invention patents. This secondary IP system has turned out to be successful in the past and for countries currently successful in catching-up, such as China, Japan, Korea and, most recently, in Thailand after 1999 (Kim, Mani and Mu, 2012).

9 While patents protect innovations of relatively high inventiveness, utility models protect those of relatively low inventiveness. Patents are granted for inventions that are novel, non-obvious, and have industrial applicability, and are typically granted for 20 years. Utility models are second-tier protection for minor inventions, such as devices, tools and implements. Processes or methods of production are typically excluded. Under the utility model, the duration of protection is typically six to ten years. The application process is often more simple and less costly than the full patent system. Thus, in practice, utility models are sought for small, marginal innovations which may not meet the patentability criteria (Kim and others, 2012). According to WIPO, 58 economies and regions provide utility model protection. (See World Intellectual Property Organization, How do you turn inventions into profit-making assets of your SME?, available from http://www.wipo.int/sme/en/ip_business/importance/inventions.htm [accessed 16 January 2013]).

3. The search for a new paradigm of development

3.1 New strategic thinking about development

Development is, in essence, a process of capability building, not of optimization. The difference in income levels across countries comes basically from differences in capabilities in many aspects, including the capability to produce and sell internationally competitive products for a prolonged period of time. We can reason, then, that neoclassical economics cannot provide a good theoretical framework for sustainable development because it is all about optimization or optimal uses of (existing) resources. It also implicitly assumes that all resources are accessible and we only have to consider how to utilize them most efficiently. But, in reality, the access to the resources is limited for most of the developing countries and thus they do not have luxury to allocate the resources optimally. For them, the more critical issue is how to build up such capabilities, especially the private sector (Lee and Mathews, 2010).

In this view, the existing framework of official development assistance (ODA) is limited in helping developing countries to upgrade their industrial structures to ease the adding-up problem, because it tends to focus on the public infrastructure and encourage the participation of the NGOs in the implementation of aid programmes and projects, rather than on the capacity-building of private firms and entrepreneurship strengthening. A famous example involving a donor giving out anti-mosquito nets but leading to the collapse of the local private business producing and selling the nets illustrates this point (Moyo 2009).

3.2 From removing the binding constraint to creating the growth poles/drivers

Binding constraints refer to those economic distortions whose removal would make the largest contribution to economic growth. Hausmann et al., (2008, p. 331) suggest to undertake a diagnostic analysis to detect where the most significant constraints on economic growth are located (hence, where the greatest return is) and then to address them by adequate policies. But the stark reality in developing countries is that there are far too many obstacles or binding constraints. A binding constraint that has often been identified is the poor infrastructure for commercial investment, or “doing business” climate. For example, many studies on the so-called investment climate report a wide range of deficiencies in several areas, from telecommunication, transportation, and energy supply to corruption prevention, regulatory framework, etc. However, the idea that if you remove those constraints growth will automatically take off sounds somewhat naïve (Lin, 2012). It is naïve in that sense that these concepts still do not put the capabilities of the private sector at the center of the discussion. In other words, the priority should be not only on improving the business climates but also on directly cultivating capabilities in the private sector. As it evolves, the private sector will come up with its own ideas on how the investment climate should be improved and what the priority areas are.

If there is only one universal binding constraint for developing countries, it should be the hard currencies. Robust growth is completely dependent on investment, and only hard currencies can pay for the investment goods that are most likely to be imported and are produced locally in developing countries. Despite the importance of export growth, the recent development literature tends to only emphasize the relevance of openness measured by the trade-to-GDP ratio. However, several empirical studies do not find evidence of openness as a determinant of growth (Lee and Kim, 2009).

Along this line of thought, it has been suggested that developing countries should select and specialize in a few specific sectors or industries as growth poles or growth drivers (United Nations Committee for

Development Policy, 2012). Initially, it can be tourism, labour-intensive manufacturing, or primary products although it is recognized that the industrial structure needs to be diversified and upgraded along the stage of development. Focusing on a few growth poles is important because resources are limited and therefore need to be mobilized in a few strategic areas. Improving the business environment can also be done first in these targeted sectors, rather than in every sector. In what follows, we examine how STI can contribute to enhance the possibility of upgrading the capabilities and industrial structure of developing countries and thereby attenuate the adding-up problem

3.3 Potential of STI in catching-up development

While developing countries confront many challenges, such as poor endowments of skilled labour, weak infrastructure, or financial capital, they do have certain advantages— namely, they can draw on the accumulated knowledge of the developed world, and do so without the inherited constraints and inertia of the industrial leaders. This provides a clear focus and strategic goal for the latecomers. The great Russian economic historian, Gerschenkron, introduced the notion of the “latecomer effect” (Gerschenkron, 1962), which includes the fact that these countries may start to use the technology only after it matured enough to have standardized capital goods suitable for mass production.

However, this discussion is confined to catching-up in the mature technologies. It is Freeman and Soete (1985) and Perez and Soete (1988) that suggested the idea of leapfrogging with focus on the role of a new technological paradigm that brings forth a cluster of new industries. Emerging technological paradigms serve as a window of opportunity for the catching-up country, which is not locked into the old technological system and is thus ready to grab new opportunities in the emerging or new industries. Perez and Soete emphasize the advantages of early entry into the new industries, such as low entry barriers in terms of IPRs, given that knowledge tends to reside in public domain initially, as well as that there is no firmly established market leaders. During the initial stages of a new technological paradigm, the performance of technology is not stable and is not dominated by a single firm. Therefore, if human resources that could access the sources of knowledge and create new additional knowledge are available, entry into emerging technology can be easier at initial stages than at the later stages of technological evolution. Furthermore, catching-up countries are in a rather advantageous position as they are not locked into the existing technologies. The advanced countries tend to be locked into the current existing technologies while unsure about the profitability of emerging technologies¹⁰.

The above discussion identifies two different types of advantages for the latecomers: one advantage is associated with mature industries and the other with emerging industries. The former is about the possibility of low cost-based entry at mature stages or into mature industries by the latecomers as they do not have to bear the burden of R&D costs. The latter is about leapfrogging and entering into new emerging industries at an earlier stage, with entry costs but without the cost of being locked into existing technologies. Leapfrogging in new sectors such as clean technology has particular advantages (such as avoidance of carbon lock-in) but also particular barriers, as discussed by Perkins (2003), for example. Forerunners’ trap may apply to the latter case because the forerunners want to stay with the existing technologies until they fully recover their investment costs and benefits and thus might be late in entering new fields. In this kind of trap, the

10 An example is Motorola, which invented analogue-based cell phones and kept investing in this technology despite the emergence of cell phones based on digital technologies, as led by Nokia. Recently, Nokia repeated Motorola’s mistake by ignoring the emergence of new generations of cell phones (smart phones), giving market leadership to Samsung. This phenomenon may be called “the incumbent trap”.

technological leaders would in fact allow some space for the latecomers to become the first movers into these new industries.

The above discussion is consistent with the idea that there can be several different paths for the latecomers to catch up with the forerunners. Lee and Lim (2001) have identified the three different patterns of catch-up (see figure 1): (i) a path-following catch-up, where the latecomer firms follow the same path taken by the forerunners; (ii) a stage-skipping catch-up, where the latecomers follow the path of the leaders but skip some stages and thus save time; and (iii) a path-creating catch-up, where latecomer firms explore their own path of technological development.

Table 1: Three patterns of technological catch-up

Path of the Forerunner: stage A --> stage B --> stage C --> stage D
1) Path-Following Catch-up: stage A --> stage B --> stage C --> stage D ^a
2) Stage-skipping Catch-up (leapfrogging I): stage A -----> stage C --> stage D ^b
3) Path-Creating Catch-up (leapfrogging II): stage A --> stage B --> stage C' --> stage D' ^{c, d}

Source: Authors.

Notes:

^a For example, consumer electronics in Korea during analogue era, PC, and machine tools

^b For example, engine development by Hyundai Motors; DRAM development by Samsung (Lee and Lim, 2001, and digital telephone switch development by China (Mu and Lee, 2005)

^c For example, CDMA mobile phone, and digital TV (Lee, Lim & Song, 2005)

^d In stage C, the two technologies, C and C', represent alternative technologies.

As an illustration, Samsung's achievement in memory chips (Dynamic Random Access memories, or DRAMs) can be considered as a case of stage-skipping catching-up. Seeing the potential in the memory chip business, Samsung decided to enter this new industry as a latecomer, with the United States and Japanese firms as leaders. Samsung was considering entering memory chip production during the transition period from 16 kilobit (16 K) chips to 64 K chips in the world DRAM industry. The Government's advice was that Korean firms had to start from 1 K DRAM, but it was private firms' decision to skip the 1 to 16 K DRAM and enter directly into the production of 64 K DRAM chips. Samsung entered the market with the 64 K memory chip as it purchased the 64 K DRAM design technology from Microelectronic Technology and the production technology from the Japan-based Sharp. Owing to this strategy of stage-skipping, Samsung was able to save time in catching up with the incumbent and became the market leader in the 2000s.

A typical example of a path-creating catching-up or leapfrogging is the case of digital TV development in Korea. The Japanese companies were the first to create and develop the analogue-based high definition (HD) TV in the late 1980s, and suggested that Korean companies learn the new technology and products from them. The Korean firms initially considered taking that direction as they had done in the past (1970s and 1980s). Soon, however, they changed their plan and undertook a leapfrogging strategy of

developing an alternative and emerging technology: digital technology-based HD TV. A public-private R&D consortium was formed which began the period of Korea's dominance over Japan, as seen in today's global display markets. Without such risk-taking and leapfrogging, Korea's catch-up with Japan would have taken much longer, or perhaps never happened at all.

Leapfrogging is more likely to happen with sectors or products where there are frequent changes in technologies or product-generation changes. Lee (2013a) and Park and Lee (2006) show that such features are closely linked with the length of the technology cycle time, for example, how quickly technologies change or become obsolete over time and with how frequently new technologies emerge. Then, we can reason that it is advantageous for qualified latecomers to target and specialize in such sectors experiencing rapid technological change. While risky as a strategy, it makes sense because the latecomers do not have to rely much on the existing technologies dominated by the incumbents and because there is always more growth opportunity associated with ever-emerging new technologies. Thus, Lee (2013a) suggests that MICs should consider short technology cycles as a criterion for sectoral specialization, because a short technological cycle time indicates a sector with less reliance on existing technologies and greater opportunities for the emergence of new technologies. This possibility of new technologies points to greater growth opportunities, while it may allow for faster "internalization" of knowledge creation. It also indicates lower entry barriers and the possibility of higher profitability associated with less competition with the advanced countries' technology, fewer royalty payments, and even first/fast mover advantages or product differentiation.

The strategy of leapfrogging makes more sense during a technological paradigm shift. At that point, every country or firm is a beginner in terms of the newly emerging techno-economic paradigm, and entry barriers tend to be low because the incumbent is likely to ignore new technologies and stay with existing dominant technologies¹¹. In this regard, industrial latecomers can capture latecomer advantages by adopting green technologies, leapfrogging the carbon lock-in stage that holds back the developed world (Mathews, 2013). While almost all the technologies involved in renewable power generation, energy efficiency, heat and power cogeneration, development of alternative fuels, and transport systems emanate from the advanced world, greater opportunities for applying them are found in the developing world, where "carbon lock-in" does not act as a constraint. There is historic opportunity for developing countries to build new industrial systems based on renewable energies and resource efficiency that will generate advantages for the countries concerned (and serve as export platforms for their future development), as well as provide a pathway of sustainable development for the planet as a whole.

One might say that advanced countries also try to enter new emerging or renewable industries during these periods of shift, and there will also be fierce competition between the advanced and emerging countries. However, what is typical of new industries in these early stages is that the entrants from the advanced countries often tend to be new or small firms rather than established big companies. Thus, during the period of paradigm change or emergence of new industries, early entrants tend to be small or unestablished, and everybody is starting from the same start line. Thus, there will be a period of experimentation, turbulence, and many ups and downs. This creates a period of opportunity for the firms from the developing countries, especially when they can count on the support of their Governments for R&D and finance. Short-cycle technology sectors do not necessarily imply the absence of entry barriers, but rather the presence

11 Examples of paradigm change include these shifts: from canals to railways; from steam engines to electric power; from horse-drawn to internal combustion engine; from Bessemer to open hearth. Now the shift is from fossil-fuelled to renewable energy driven. The idea of leapfrogging is consistent with the idea of technological discontinuity proposed by Anderson and Tushman (1990; 1986) that competence-destroying discontinuity may lead to the rise of new entrants.

of lower barriers, and that there are fewer disadvantages for developing countries. A case in point is the wind turbine industry which used to be dominated by European firms but has now seen significant and successful entry by firms from China and India (Lema et al., 2012).

IPRs constitute a potential obstacle to leapfrogging. However, it should be noted that, at least in theory, IPRs in the new and emerging areas tend to remain initially in the public domain such as universities and public research labs, and thus less subject to infringement issues. This has been pointed out as one advantage of adopting a leapfrogging strategy when there is an emergence of new technologies. However, a troubling emerging sign is that new knowledge has been registered as patents in an increasingly fast manner. If this is the trend, this implies serious damage to our goal of achieving sustainable development with the support of STI. This issue will be further examined in section 6.

Moreover, for leapfrogging to work certain conditions need to hold, not only availability and access to new technologies but also concerning the management of risks related to the choice among alternative technologies and the creation of initial markets (see Lee et al., 2005). To handle these risks and also to create certain locational production advantages, government policies are called for. To build a bridge across the gap between developed and developing countries, there needs to be a certain level of capability to understand the risks and potentials of leapfrogging. We turn to these issues in the next section and try to learn lessons from the existing or on-going cases and experiments.

4. Necessity and feasibility of new growth models

Industrialized countries share a common pattern of energy consumption and production, which has involved access to new energy sources of unprecedented power (steam power, then electric power based on fossil fuels) to resources at unprecedented levels of exploitation (largely through exploitation of extra-territorial colonial possessions), and the targeting of finance to facilitate the construction of a vast industrial infrastructure (through new industrial banks such as the Deutsche Bank). Latecomers such as the East Asian countries of the past half-century (Japan, then Korea and Singapore and Taiwan) faced a situation where they could deploy the same industrial model but exploit latecomer advantages, thereby developing novel strategies for the building of their own industrial corporations and accessing export markets through cost-driven mass production capacities. Now in the twenty-first century, large developing countries such as Brazil, China and India are looking to advance through the industrialization of their economies and to increase the welfare of their populations using the same conventional industrial model previously used by the industrial countries.

The problem—or inconvenient truth—is that the conventional industrial model will not satisfy the aspirations of these twenty-first century industrial giants, let alone the aspirations of the many countries in Africa, Central and South America, and Central and South Asia that are looking to increase their wealth and income through industrialization. The Earth's resources are already overstretched by the actions of the “first” industrializers, which have allowed around 1 billion people to enjoy a comfortable and prosperous lifestyle. To bring as many as 6 billion people to a middle-class lifestyle by mid-century (as foreseen by economists such as Michael Spence (2011)) would call for a sixfold expansion of economic outputs, with intensity multiplied by the accelerated pace of change. China and India are both courting disaster, from rising oil prices, increasing vulnerability to a handful of oil suppliers and exacerbating tensions with existing industrialized countries and their carbon lock-in.

The answer to this conundrum is not for China and India to turn their back on growth and industrial development, but to build a new kind of industrial paradigm. This is what is known as the “green” industrial system, and the current interest of the United Nations and all development-oriented agencies is to ascertain to what extent a green industrial system is in fact being fashioned and implemented in these countries, and to what extent it may represent a fresh option for the many developing countries coming after them. Such a green development strategy is the inevitable choice for China because, while the country is lagging in R & D in conventional fossil-fuelled technology, it can leapfrog to the lead with green technology, and because it has such a huge population for which the traditional model would not scale¹².

Recently, China has been taking important initiatives in new green growth strategies by building its Renewable Energy (RE) industries in earnest, for example, and so far with notable success. In wind power, China rose from a marginal position in 2005, doubled its wind power capacity on an annual basis, and by the end of 2010 became the world leader in both the production of wind power generators and in the size of the domestic wind power market (Lewis 2012). By then, China was adding more power generating capacity in hydro, nuclear and new renewables than in conventional thermal power stations—an extremely important milestone for both China and the world. Its Twelfth Five-Year Plan has notable goals of raising these levels. In terms of electric power, China’s leadership, in the form of the planning body (the National Development and Reform Commission (NDRC)) anticipates that electric power capacity will be rated at 1.6 TW by 2020, and of this, 500 GW (0.5 TW) will be generated from the renewable sources of hydro, wind and solar. In other words, renewables will account for 30 per cent of electric power capacity by 2020 (Mathews 2011; Mathews and Tan 2013).

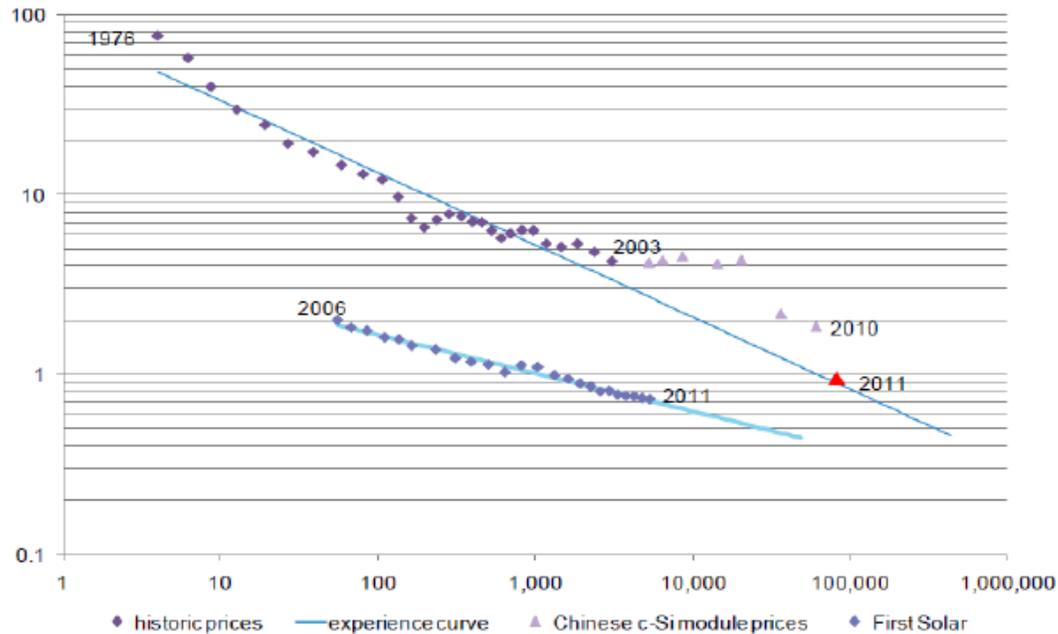
These unprecedented investments by China in the development of green power sources are driving costs down, not just for China but for all other developing countries. The issue is this: Can the costs of shifting to a renewable energy pathway, called for in the Sustainable Energy for All program of the United Nations Secretary-General,¹³ be moderated so that developing countries can enjoy the advantages of shifting to such sources, while not paying a penalty in terms of higher costs and reduced competitiveness? In this regard, it is important to note that in fact the cost of renewables are consistently coming down (owing to the learning curves) while the costs for fossil fuels can only be expected to rise (driven by rising demand from the newly emerging developing countries). Thus, latecomers who build their industrial strategies on green development will certainly have a decisive advantage.

Consider the situation for solar photovoltaic (PV) power. Figure 1 indicates that the costs for solar PV are falling at a rate of 45 per cent per year, and that grid parity will be achieved (if not already being achieved) by 2015. Thus, the data that now need to be considered in framing any development strategy are those relating to the falling costs of power produced from renewable sources. The Bloomberg/New Energy Finance team in London have recently produced a White Paper titled “Re-considering the economics of photovoltaic power” (Bazilian et al., 2012) where they make some very important points.

12 See Hu Angang, “Green development: the inevitable choice for China (parts I and II)”, China Dialogue, 26 June 2006, available from <http://www.chinadialogue.net/article/show/single/en/134-Green-development-the-inevitable-choice-for-China-part-one-> and <http://www.chinadialogue.net/article/show/single/en/135-Green-development-the-inevitable-choice-for-China-part-two->; and Hu (2011).

13 See <http://www.sustainableenergyforall.org/>

Figure 1. Photovoltaic module experience curve, 1976-2011



Source: Bazilian, M. et al 2012. Reconsidering the economics of photovoltaic power, White Paper, Bloomberg New Energy Finance, London, available at: <http://about.bnef.com/white-papers/re-considering-the-economics-of-photovoltaic-power-a-co-authored-white-paper-on-pv-economics/>

In this chart, based on and updating the chart on experience curves relating average costs and the volume of production contained in the recent Intergovernmental Panel on Climate Change (IPCC) report on Renewable Energies (IPCC, 2012), the overall experience curve is shown in the upper blue line, indicating that costs had fallen to the long anticipated point of \$1 per watt by the end of 2011, bringing solar PV power within the range of almost all emerging and developing countries. The period immediately preceding this decline show that costs hovered for several years (from 2004 to 2008) at about four times this level (\$4/W)—a phenomenon now understood to be caused by the ability of suppliers to command feed-in tariff rates locked at these levels, while a reduced number of silicon supplies meant that there was little price competition in the sector. This was a major factor behind the belief that renewable energies would always be costlier than conventionally fuelled power. But as silicon supplies became more flexible, some manufacturers reduced their prices, which in turn reduced input costs for solar cell producers, and their prices fell as well. The bottom blue line represents the cost curve for thin-film solar cell producers, dominated by First Solar, an American manufacturer of PV modules. Because thin-film PV cells utilize much lower quantities of silicon, their costs have always been lower, but they are not yet enjoying the economies of scale of amorphous silicon cells (the dominant technology, where China has excelled).

The message for developing countries is clear: the costs of solar PV cells are falling rapidly. In many low-income developing countries with above-average isolation (countries right across the tropical belt), this means that producing electric power from solar PVs is now cheaper than producing power from, for example, stand-alone diesel generators. Thus, implementation of the *Renewable Energy for All* programme of the United Nations Secretary-General can become a reality.

We now turn to selected case studies to illustrate how developing countries can overcome their latecomer disadvantages and capture potential latecomer advantages. We will focus on STI issues and, more specifically, strategies that break with carbon lock-in. We shall draw on examples of telephone switches in Brazil, China, India and Korea; biofuels in Brazil; solar thermal heating in China and solar power in Nigeria; and green vs. black development strategies in Mozambique. In each case, our aim is to demonstrate how attention to STI issues enables countries to restructure their economies and maximize the potential for catch-up.

5. Learning from cases of stage-skipping and leapfrogging

5.1 *Telephone switches in China and Korea vs. Brazil and India*¹⁴

Most developing countries tended to have serious telephone service bottlenecks in the 1970s and 1980s. However, most of them had neither their own telecommunications manufacturing equipment industry or R&D program. As a result, they used to import most of the equipment and related technologies at high prices, and local technicians merely installed foreign switching systems into the nation's domestic telephone networks. With industrial and commercial bases developing rapidly and population growing, many countries wanted to build their own manufacturing capabilities.

Starting in Brazil in the 1970s, followed by India and Korea in the mid-1980s and, finally, by China towards the late 1980s, all four countries crafted a state-led system of innovation in telecommunication equipment industry, with a public research institute at the core of the system that developed digital telephone switches more or less "indigenously" that were then licensed to public and private domestic enterprises. In these four countries, a common pattern in the indigenous development of digital switches was the tripartite R&D consortium among the government research institutes (GRIs) in charge of R&D function, the SOEs or the Ministry itself in charge of financing and coordination, and private companies in charge of manufacturing the equipment.

One of the reasons why all four latecomers were able to develop their own digital switches owes to the fact that the knowledge system of digital switches was mature and with stable trajectories, and arranging access to knowledge was not difficult whether it was in the form of licensing/joint ventures or study of the literature in the public domain. This story first indicates that technology targeting makes more sense when the latecomers are below the technological frontier and thus face less uncertainty in terms of selecting the right or wrong R&D target. With concentration of human, physical and financial resources, the latecomers would be able to develop products that are similar to the existing products of the incumbent companies.

However, the subsequent wave of privatization and liberalization of the industry in two countries (Brazil and India), when compared with consistent infant industry protection in the other two (China and Korea), has implied different subsequent trajectories in these four countries. At one extreme, we have China and Korea where indigenous manufacturers took over the foreign supplier, while enhanced capabilities in wired telecommunication that accumulated over the preceding decades have led to the growth of indigenous capabilities in wireless telecommunication, too. At the other extreme, we have Brazil and India which have increasingly become net importers of telecom equipment, and their industries are now dominated by affiliates of the multinational corporations (MNCs).

¹⁴ This case is explained in detail in Lee, Mani and Mu (2012).

Let's consider the role of public policies in these countries. In China, government policy basically provided market protection and gave incentives for local telecommunication authorities to adopt domestic products. The Chinese Government began to impose tariffs on imported communication equipment and to promote the purchase of locally made equipment. Similarly, in Korea, public policies supporting (especially through public procurement in the 1980s) and protecting the sector were important factors for emergence of indigenously developed telephone switches. In the mid-1980's, the Korean Government limited imports of foreign switches, whereas it regulated the domestic market by establishing a quota system for the four leading producers.

In Brazil, from 1976 through the 1990s, the state attempted to foster the emergence and consolidation of a domestic local equipment manufacturing industry through a variety of public support measures, such as public procurement. However, since the mid-1990s these policies were abandoned owing to economic liberalization (for example, elimination of market guarantee for local products and local content requirement in the 1990s). In India, policy orientation changed in the 1990s and actually undermined a wider diffusion of the indigenously designed C-DOT switches as it allowed imports of the foreign telephone switches. Furthermore, with the provision of telecom services having been effectively privatized, the manufacturing of telecom equipment has been open to imports and indeed foreign direct investment (FDI).

5.2 *Biofuels in Brazil*

The case of Brazil and its very successful biofuel programs is an illustration of how developing countries can capture latecomer advantages in renewables by restructuring their economies and building new value chains. Brazil is a developing country that has not faced the problem of fossil fuel dependence. It has been able to build an electric power system based largely on hydropower (which is still being extended, not without controversies); an urban private transport system based largely on homegrown and processed ethanol and (now) biodiesel; and, thanks to oil discoveries, an export platform for oil and gas that earns export revenues to finance development across the economy. The Brazilian experience can thus be a model for all tropical developing countries – particularly those in Africa like Angola and Mozambique that also have oil, gas and coal deposits and abundant solar and water resources.

The Brazilian biofuel programme is well-known. The growing of sugar cane crops in areas far from the Amazon, and with agricultural yields superior to those attained in temperate countries, means that Brazil has a comparative advantage in cane-derived bioethanol and oilseed-derived biodiesel. Improved yields have meant that more sugar (and hence ethanol) is produced without infringing on food production. (And carbon-intensity of both growing and harvesting cane is being reduced – such as by regulating the burning off prior to harvesting – and sugar mills and ethanol plants are becoming energy-neutral by utilizing bagasse as fuel.)

Yet its potential to earn export sums for Brazil is curtailed by tariffs imposed by others, such as the United States (up to 2012) and the European Union, while oil is often imported by these countries at zero or very low tariff. There are still substantial barriers to imports of bioethanol and biodiesel on the part of the European Union countries (in terms of import tariffs and technical standards), while the United States dismantled its tariff barriers and subsidies to ethanol producers in 2012, creating a hemispheric biofuel free market¹⁵. An important step towards the elimination of trade barriers across a range of “environmental goods” was also implemented by the APEC countries at the Leaders’ Summit staged at Vladivostok in

15 See Mathews (2012a).

September 2012, where it was agreed that duties and tariffs on a long list of environmental goods (including electric vehicles, renewable energy systems and components, smart grid elements and energy efficiency products) would be reduced to no more than 5 per cent within 5 years. This established an important precedent and could lead to free trade in green goods—a step that would be of huge benefit to developing countries looking to import advanced green technology¹⁶.

Brazil developed its bioethanol programme in the 1980s through utilizing its own domestic resources (sugar cane plantations fed by rainfall without the need for irrigation) and technology. Through the National Alcohol Program, dating back to the military dictatorship in the 1970s, a market for ethanol was mandated as a means of saving on oil imports. Domestic producers were encouraged as well as local suppliers of equipment (such as Dedini) thus creating an entire value chain on the supply side. On the demand side there was initial resistance because cars had to be either ethanol-adapted or conventional. Consumers that switched to ethanol-only vehicles in the 1980s were placed at a disadvantage when global oil prices fell and ethanol became non-competitive. But in the 2000s, Brazil's ethanol programme was revived with the strong support of the Government, of the national oil company Petrobras, and with the demand-side innovation, developed in Brazil, of flex-fuel vehicles, which could run on ethanol, gasoline or any combination of the two.

The success of the Brazilian bioethanol programme (now being replicated in the case of biodiesel) is not a conventional story of import of product, followed by import of equipment and insertion in global value chains in order to access technology. Rather, Brazil was already a sugar producer at the world frontier in terms of technology and prices and was able to carry these initial advantages across to the production of ethanol. Technology for ethanol production was initially imported and rapidly endogenized (leading to formation of domestic equipment suppliers such as Dedini) and then diffused rapidly through the R&D efforts of the national R&D institution EMBRAPA. Equivalent to is the Industrial Technology Research Institute (ITRI) in Taiwan Province of China, this was the body, that maintained a technological watch on global developments and utilized advanced technological methods for researching Brazil's sources of comparative advantage (soils suitable for sugar cane cultivation as revealed by satellite surveillance, for example). But these natural advantages would have mean little had it not been for strong government support in mandating a steadily increasing market share for domestically produced ethanol, and for the role of the national oil company, Petrobras, in acting as primary distributor of ethanol through pipelines, terminals and fuel outlets across the country. Now Brazil is building an entire value chain for the production of first-generation ethanol as well as creating companies to usher in the second generation (in competition as well as collaboration with United States and European firms).

5.3 Solar thermal heating in rural China and solar power in Nigeria

Thermal heating in China: Solar thermal technology is one of the alternative sources of energy in the search for low-carbon energy solutions. However, diffusion has been slow worldwide. In contrast, China is having notable success, especially in rural areas (Zhou et al. 2012).

Solar thermal technology in China was developed in the 1980s, a result of the R&D project executed by Tsinghua University as part of China's national R&D initiatives. After the University disclosed the

16 International Institute for Sustainable Development, "APEC economic leaders agree on trade in environmental goods", 9 September 2012, available from <http://uncsd.iisd.org/news/apec-economic-leaders-agree-on-trade-in-environmental-goods/>

vacuum tube patent in order to allow easy transfer of technology to the manufacturing sector, China now enjoys large-scale solar thermal production.

Lack of success in urban areas results from the mismatch with the existing urban architecture. Specifically, the existing city planning and construction design did not take into account the possible installation of water outlets required for the solar thermal system; changing the existing pipeline-based hot-water system in the existing buildings was too costly. In other words, compared to gas and electric thermal systems which are already installed in cities, solar thermal systems which function for only six months are not attractive to urban dweller (Rogers, 1995).

In contrast, solar thermal systems in the rural market can be adopted successfully; rural buildings tend to have simpler structures and can be more easily rebuilt by individual owners who care more about the practical utility and than appearance. Most important, the scarcity of gas, electricity and other energy infrastructure means there is no competitive barrier to installing a new energy facility. Compared to no hot water at all, a six-month supply of hot water is a big attraction for rural users.

The case of solar thermal energy in China shows that rural areas bypassed the stage of gas or electricity-based heating and leapfrogged into the stage of solar thermal-based heating. It also indicates that both supply side (technology) and relative match or mismatch with the demand side can be an impetus for leapfrogging. Solar water heaters meant a huge disruption for the existing lifestyle and residential norms of high-end or urban dwellers, whereas under-developed areas had no such lock-in, allowing them greater receptivity to alternative energy systems.

Solar Power in Nigeria¹⁷: The Jigawa State in Northern Nigeria now boasts a successful solar-generated electricity project implemented in the desert grasslands rural area. The project has attracted a great deal of attention from international media and has seen households leap from no modern energy use to the use of solar power. The project also aims at improving water supply, health, education, agriculture, commerce, security and women's opportunities and has been implemented in three villages since the mid-2000s, benefitting over 7,500 people. In home lighting, solar energy creates better light without the inherent fumes and fire danger of the old kerosene lamps. Jigawa Alternative Energy Fund (JAEF), a non-governmental organization formed specifically to promote the use of renewable energy, will be able to continue electrifying houses using a microcredit scheme where the payments for each system will accumulate to purchase additional systems for more homes¹⁸.

Having a reliable water supply in the semi-desert of Jigawa State is a big challenge. Typical methods of getting water range from open wells with rope and bucket, to hand pumps, to government-supplied diesel-powered pumps that work only until they break down or until villagers run out of money to buy the expensive diesel fuel. Now, powerful solar-powered pumps designed to run maintenance free for eight to ten years or more are currently supplying the villages with clean, fresh water from deep wells.

17 This case is a summary of a case introduced in Assefa (2011).

18 The only source of income for most village women is the production and sale of peanut oil. However, small amounts of oil are made in the traditional method. A solar-powered oil expeller has now been incorporated that will save time and labour while earning more income for women (Assefa, 2011).

5.4 *From black to green development in Mozambique*

After decades of war, involving a 10-year struggle for independence followed by a 15-year civil war, Mozambique achieved peace and a democratic constitution 20 years ago. Its economy has been growing at around 9 per cent per year for the past decade. Nevertheless, the country is still one of the poorest in Africa, with a per capita GDP of just over \$1000 on a Purchasing Power Parity basis. All fuel oil is imported, with the import bill amounting to just under 15 per cent of GDP—a crushing burden (Cuvilas et al., 2010). The country has a low level of electrification, mostly coal-powered and deriving from the Cabora Bassa dam on the Zambezi River. Green development strategies can provide the country with new industries to build export platforms and to power domestic development.

But it is black development that provides the most immediate prospects for Mozambique in terms of earning hard currencies. Coal reserves are extensive, but production was also greatly diminished by the wars. The Moatize coalfield is now being developed anew by the Brazilian coal company Companhia Vale do Rio Doce with a huge \$1.7 billion investment that will allow production to double. Mozambique could thus become a major coal exporter (like Australia and Brazil). All this is unboundedly carbon-based development, but no one can deny that Mozambique needs this 2 GW power supplier to support its industrial development and enable the country to put its war-torn past behind it. An interesting aspect of Mozambique's situation is that it has used the cash flow from carbon-based development projects to finance its entry into green development projects, following the Brazilian model. This could be a workable model for other low-income countries endowed with resources.

In a country with so much land, good sunshine and rainfall, the prospects for renewable energy are enormous, provided that the right levels of investment and policies can be put in place. Biofuels (both bioethanol from sugar cane and sweet sorghum and biodiesel from jatropha), cotton seed and native coconut plantations are an obvious choice for such a country, and have been promoted actively by the Frelimo Government. Although progress has been slow in general, bioethanol projects launched in Mozambique have had some success. A high-profile project involved the UK company Bioenergy, which was to develop an area of 30,000 hectares for sugar cane cultivation with a view to producing ethanol. (Note that the concern over food security in these African biofuel ventures has been minimized by the fact that biofuel production raised agricultural yield generally, not just for the biofuel crops.) There are other projects under way, both for biodiesel and for bioethanol, on the Brazilian model¹⁹.

Mozambique thus has good prospects to become a biofuels powerhouse, which could reduce the country's dependence on fossil fuel as well as build a substantial export industry and, if properly managed, an entire industry value chain feeding into the production and export of biofuels. This exemplifies the industrial restructuring potential of green growth projects in developing countries.

Solar power, particularly photovoltaic-generating capacity, is also being developed in a way that involves STI as an important factor. The Korean Government is assisting in the provision of three PV power stations to be built in the northern province of Niassa. The Governments of Korea and Mozambique signed a \$35 million loan agreement in October 2011 for the cost of construction, with the funds being made

19 The two countries, formerly Portuguese colonies and sharing the Portuguese language, seek common developmental pathways. The state oil company, Petromoc (modelled on Petrobras in Brazil) has partnered with the Portuguese oil company Galp, and local company Ecomoz in a \$19 million investment to develop jatropha-based biodiesel on up to 50,000 hectares of land. See Nhantumbo and Salomão (2010) for a searching analysis of these issues.

available by the Export-Import Bank of South Korea on concessional terms over a 40-year period, including a 15-year grace period, and at a nominal interest rate of 0.01 per cent. Meanwhile, Mozambique's first factory for producing solar panels has been built with Indian assistance in the capital city of Maputo. Costs for solar power are high in Mozambique because most of the equipment is imported. This joint Indian-Mozambican factory will lower such costs, and there is commitment from the Indian partners to utilize local suppliers within the plant's first year of operation.

Complementing such initiatives, in Mozambique the Government is placing stress on developing domestic scientific and technological capacity and, to that end, announced in 2012 the creation of a state-owned entity that will manage all the country's science and innovation parks, acting to concentrate, aggregate and focus the facilities already engaged. What is lacking, however, is financing on the scale that is needed. Its absence has already led to the cancellation of some biofuels projects. This is where development banks such as the African Development Bank and Development Bank of Southern Africa need to step into the breach, along with the World Bank and its MIGA (Mathews and Kidney, 2012).

6. Specific strategies and policies for sustainable development

6.1 Building technological capability in three stages and the role of public laboratories

There are several stages of learning and capacity-building which can eventually involve the final stage of leapfrogging.

In the first or initial stage, the latecomer countries tend to specialize in mature, long-cycle technology-based industries or in the low-end segment of short-cycle technology-based industries. An example of the long-cycle technology-based sector is the textile industry. Latecomers produce textiles for the export market via an original-equipment-manufacturer (OEM) arrangement with firms from advanced countries. OEM arrangement is a specific form of subcontracting under which a complete, finished product is made to the exact specification of the buyer. Examples of low-end or low value-added segment of the shorter-cycle technology based sectors are the OEM- or FDI-based assembly products in consumer electronics, automobile, or telecommunication equipment industries. These arrangements are typical in low-income and/or middle-income countries. During the 1970s, 1980s, and even 1990s, OEM accounted for a significant share of electronic exports, and served as one of the institutional mechanisms to enter into new markets and facilitate technological learning in Korea and Taiwan Province of China (Hobday, 2000).

In the initial stage, the developing countries are learning by doing or exporting, with positive side effects for the economy as a whole, such as job creation and foreign-exchange generation. Policy tools often include tariffs and undervaluation of the currency, which tends to be more horizontal, less sector-specific as tariffs. In this regard, it is suggested that tariff policies should be asymmetric, that is, higher tariffs should be applied on products that are to be promoted domestically and lower tariffs applied on capital goods needed in the sectors that are being supported. This type of policy was successfully pursued in Korea and contributed to increasing the country's share in international markets. Besides foreign-exchange policies, other forms of horizontal intervention are needed. The promotion of physical infrastructure, such as transportation, energy and communication, is a case in point. While the OEM can be an effective way of catching up at the early stages of economic development, its success as a long-term strategy is less certain because the foreign vendor firms may move their production orders to other lower-wage countries (Lee, 2005) as is currently the case of flower producers in East Africa. The foreign vendor firms are placing orders not only in Kenya—the first

country in the region to develop the flower export industry—but also in other countries which emerged later than Kenya.

From the above, firms producing under OEM arrangements need to prepare a longer-term plan to make the transition to original design manufacturing (ODM) and eventually to original brand manufacturing (OBM). The ODM firms carry out most of the detailed product design, and the customer firms which buy products from these ODM companies perform the marketing functions. Meanwhile the OBM firms carry out manufacturing, design of new products, R&D for materials, processing of products, and conduct sales and distribution for their own brand. Thus, moving from OEM to ODM to OBM has become the standard upgrading process for the latecomer firms. An example of such upgrading in the case of the African firms in the flower sector would be to enhance quality and differentiate their product by producing flowers that can last longer, or that have specific scents, are insect resistant—all of which require inputs of STI. Transition to OBM in the flower sector would imply that African firms enter into marketing operations and set up their own outlets with their own brands in Europe, which is typically the main destination of African flower exports. Such transition to ODM or OBM is not easy, but has been the path followed by some Asian countries which moved from low-income towards middle or even high-income status. Another possible development trajectory available for low-income countries endowed with natural resources is a combination of carbon and green development. Mozambique is a case in point, where revenues from exports of coal can be used to finance entry into green or low-carbon industries.

In general, once countries reach middle-income status, additional sector-specific or vertical intervention policies are needed because the country must now identify its niche between low-income countries with cost advantages in low-end goods and high-income countries with quality advantages in high-end goods. For middle-income countries, public policies should focus on the two kinds of upgrading: (i) one is an inter-industry upgrading by entering into new or higher-value-added industries; and/or (ii) an intra-industry upgrading by moving into a higher value segment in the existing industry (Lee and Mathews, 2012).

We can suggest short-cycle technology-based sectors as a niche for latecomers. The issue is how to break into medium short-cycle technology-based products or into the higher-valued segment of the existing sectors. Good targets for such an entry are those products that the latecomers had to import at higher prices due to oligopolistic market structure. A very fitting example is the case of the telephone switch development in the 1980s-1990s, discussed in the preceding section (section 4).

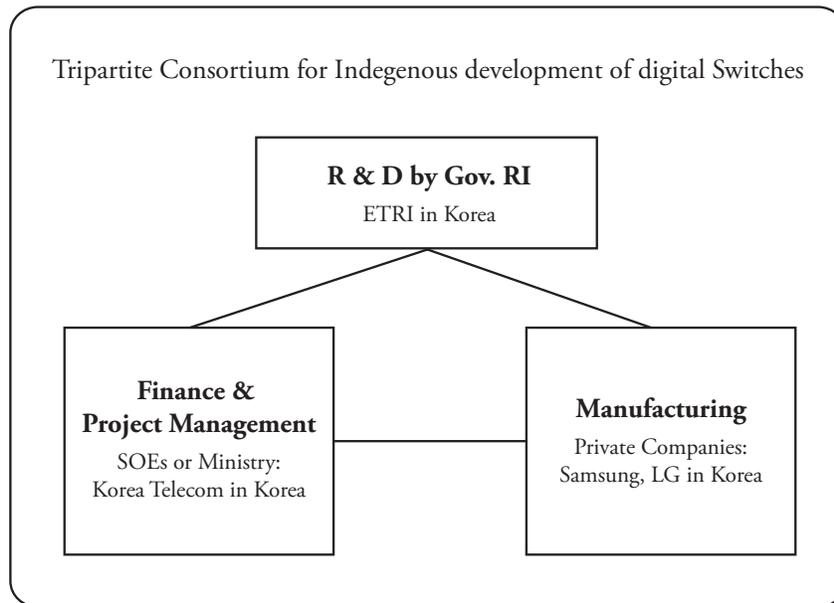
The final stage of leapfrogging involves public-private R&D efforts that target emerging rather than existing technologies. In this case, the role of the Government and public labs is to share the risk involved in the choice of technologies and to promote the initial markets. Specifically, coordinated initiatives on promoting locally developed technological standards and incentives for early adopters would be essential in reducing the risk faced by the nascent and still fragile initial market. In reality, larger, latecomer economies, such as Brazil, China and India, have already been seeking a new development path powered not by traditional fossil fuels but by alternative energy sources, like biofuel and other sources of renewable energy. These countries are trying to move into a low-carbon path by developing a range of alternative energy sources such as wind, solar and thermal energy, as well as photovoltaic and biogas digesters.

The three stages in the above scheme can be further elaborated with focus on the changing roles of the GRIs or public research organizations (PROs). The essence of this latecomer model of technological development is the three party cooperation model, or the G-P-G model, which involves cooperation among

government research institutes, private firms and government ministries, each one fulfilling different roles according to the country's level of technological development. As any type of technological development involves R&D, production, and marketing, the GPG model specifies which actor is responsible for which component or stage of the development of a particular technology. For instance, government or public research labs can be in charge of R&D, private firms are in charge of production, while government ministries are in charge of supporting marketing efforts through direct procurement or by extending protection through imposing tariffs on similar imports and setting exclusive standards. There are several approaches to the G-P-G model.

One option, that is among the most typical representations of the GPG model (let us call this GPG-1), is to have R&D mainly done by the GRIs or public research organs (see figure 2). In GPG-1, private firms are in charge of manufacturing and the Government helps marketing by procuring the domestically made products. An example of this model is the case of the telephone switches discussed above. Other alternatives are also possible depending upon the level of capabilities of private firms and public agents involved. For instance, under a GPG-2 framework, costs and risks of R&D are shared between government research institutes and private firms, while the GRIs monitor technology trends in global markets as well as coordinate diverse actors participating in the consortium. This GPG2 model can be considered as a more advanced form of the GPG in that it is possible only when the capabilities of private firms are advanced enough to carry R&D activities. The development of digital TV and the CDMA mobile phone in Korea (Lee et al., 2005) is an example of a GPG-2.

Figure 2: the G-P-G Model of Technological Development
GPG-1 in the case of telephone switch development



Source: Authors.

Another variation of the GPG model is the case of government agents doing both R&D and production, which may take place when the capabilities of private firms are nil or the nature of the targeted industry tends to involve heavy start-up costs. This variation can be called GPG-0 although it could be more accurately called a GGG model, without involvement of private firms. The case of POSCO or steel development in Korea by the government-owned enterprise is an example of the GPG-0 approach.

The opposite case to the GPG-0 mode is that of GPG-3 or PPG, when there is no participation by public research institutes. An example is the case of development of automobile industry spearheaded by Hyundai Motors. As discussed in Lee and Lim (2001), in this case, the Government or a government research institute was not involved in R&D while the government role was limited to the provision of protection through tariffs. As R&D was done by private firms or Hyundai Motors, it is the PPG model, not GGP model, with private firms doing both R&D and production.

In sum, based on the cases in the Korean experience, we have identified the four modes of state intervention for technological development. Ordered according to the level of participation of the private sector, these are: i) the GPG-0 (or GGG) mode with the Government doing market provision and government-owned enterprise doing both R&D and production; ii) GPG-1 mode with R&D by GRIs, production by private firms, and market support/protection by the Government; iii) the GPG-2 with increased R&D responsibilities shifted to the private firms cooperating with the GRIs; and, finally, iv) GPG-3 (or PPG) mode, where private firms do both R&D and production. In all of these variations, the role of the Government (or ministries involved) tends to be guaranteeing the initial markets in the form of procurement policies, and/or local market protection by tariffs or exclusive standard setting.

It is important to note that one common element across the four modes of technological development is access to foreign knowledge through diverse channels. As discussed in the literature (Lee, 2005), the role of foreign knowledge is very critical, without which the latecomers' catching-up effort is often at risk, in addition to taking longer and being costlier. In general, the diverse channels of access to knowledge and learning include training in foreign firms and institutes, OEM, licensing, joint ventures, co-development with foreign specialized R&D firms, transfers of individual scientists or engineers, reverse brain drain, overseas R&D centers, strategic alliances, and international mergers and acquisitions (Lee, 2005). Then we can say that successful technological development by the latecomers tends to involve government support, access to foreign knowledge, and private firms' own efforts, and that the weight and specific role of these three factors would differ according to the production sector and levels (or stages) of economic development of the country concerned.

The GPG model can be modified to include the participation of official development assistance or a foreign partner for technology development in low-income countries. It could be then renamed as the FLG model ("F" to designate the foreign partner, "L" for the local firm, and "G" for the Government). The idea behind this proposal is to have a relevant foreign player (for example, a foreign research organization invited by the donor Government or by the United Nations) to replace the GRI/PRO in the GPG model, so that the foreign entity (cooperation partner) conducts R&D to develop original processes or products relevant for the domestic conditions of the recipient country and/or to address the technical problems of the local firms (private or state-owned) in developing countries (stage FLG-0). In the next stage, or FL-L-G, foreign partners conduct joint R&D with local R&D organizations or with the local firms. Then, in stage 3, the aid-receiving developing countries become able to conduct R&D locally as private-public partnerships, which is equivalent to GPG2. The final stage is, of course, where all functions are performed by the private sector.

Table 2. From GPG model to FLG (Foreign actor-Local firm-Government) model

<i>1st Stage</i>	<i>GPG-0</i>	<i>F-L-G0</i>
Tech Transfer/R&D	PRO/Foreign Actor	Foreign Cooperation Partner
Production	SOEs/Private firms	Local Firm (private, SOEs)
Market Promotion/Protection	Government	Government
<i>2nd Stage</i>	<i>GPG1</i>	<i>FL-P-G (FLG1)</i>
R&D	PROs	Joint R&D by foreign & Local PROs/Firms
Production	Private Firms	Local Private Firms
Market Promotion/Protection	Government	Government
<i>3rd Stage</i>	<i>GPG2</i>	<i>G-P-G2 (FLG2)</i>
R&D	Public & Private Joint R&D	Local public & Private Joint R&D
Production	Private Firms	Local Private Firms
Market Promotion/Protection	Government	Government
<i>4th Stage</i>	<i>GPG3 (PG)</i>	<i>G-P-G3 (FLG3)</i>
R&D	Private Firms	Local Private Firms
Production	Private Firms	Local Private Firms
Market Promotion/Protection	None	None

Source: Authors.

6.2 *Using incentives to kick-start environment-friendly technological trajectories*²⁰

Market-based approaches may not be adequate to bring in necessary new technologies and replace unsustainable old ones at the necessary speed, that is to say, before irreversible environmental damage occurs (Altenburg and Engelmeier, 2012; Stern, 2007). Thus, policy intervention may be justified to correct market failures and make green technologies more competitive. One way to make green technologies profitable is to create artificial rents to attract capital into socially desirable green investments, e.g., through subsidies. In other words, temporary rents can have the impact of inducing deployment of green technologies, thereby spurring technological learning and allowing producers to reap economies of scale, as foreseen by Schumpeter²¹.

However, the use of rents as incentives also involves risks of misallocation and political capture. Subsidies need to be managed with care; the total monetary value of rents provided should not be excessive and a clear timetable of the phasing out and withdrawal of the subsidies should be spelled out in advance. This was the case with many subsidy schemes engineered by the Governments in East Asian countries²². The Indian experience is another case in point. It indicates that green rents can be managed in a fairly effective way and Governments can find ways to trigger new industries at a pre-commercial stage while also keeping subsidies at an affordable level. In 2009, the Government of India launched the Jawaharlal Nehru National Solar Mission (NSM) as one of the first coherent federal government attempts to increase solar power

20 This subsection is a summary of the main argument of Altenburg and Engelmeier (2012).

21 According to Staffhorst (2006) in the case of PV solar panel technology, the cost of electricity generation decreased by roughly 20% without any doubling of the cumulative globally installed generation capacity. Re-cited from Altenburg and Engelmeier (2012).

22 Altenburg and Engelmeier (2012) elaborate how rent has been managed in the case of India's National Solar Mission.

generation and develop domestic capabilities in solar technology. The initiative has been successful so far and the key mechanism for this was a process of competitive reverse bidding for tariffs²³. The first rounds of competitive reverse bidding succeeded in both mobilizing investors and in eliciting information on the required level of rents; there were bids for more than 5,000 MW in the first batch that had only tendered 150 MW of PV projects.

Although it is still premature to pass judgment on the Indian solar mission, one cannot deny it has been remarkably effective in triggering solar investments and keeping the necessary subsidies at a manageable level. The process of reverse binding has allowed finding the lowest tariff rate at which investors would pursue solar projects, thus bringing tariffs and public subsidies to producers down. As a result, retail grid parity is expected to be achieved around 2017, five years earlier than the NSM had envisaged. Solar investments are clearly on the rise, with 507 MW of solar capacity installed at the end of March of 2012, compared to just 18 MW two years before (Altenburg and Engelmeier 2012).

6.3 *IP strategies for latecomer firms*

As discussed in the preceding section, proper handling of IPRs has emerged as a vital concern for the latecomer firms as it affects their opportunities for learning and catching-up. It is our view that each country should be allowed certain room to tailor its own IP system to its specific needs. This is especially true for middle-income countries as they face more complicated and dynamic situations. In general, the developing countries at earlier stages of development may be encouraged to adopt a petit patent (utility models) system, in addition to regular invention patents. This secondary IP system has turned out to be successful in the past and for countries currently successful in catching-up, such as China, Japan and Korea, and most recently in Thailand after 1999.

The experience of Taiwan Province of China also offers important policy lessons. An important player in the country's technological development is ITRI. ITRI's main role has been to conduct R&D services for Taiwanese industries. ITRI has also played a vital role in promoting strategic industries and overcoming entry barriers in selected markets. For instance, when the country entered the semiconductor industry as a follower to Japan and South Korea, ITRI had already initiated related R&D and generated many patents which were transferred to the firms. In this role, the strategic use of IPRs has been quite important.

A strategy used by the Taiwanese is "patent combinations" (Shih 2005, p. 293). The two main examples of this strategy are biochip R&D alliances and TFT-LCD patent alliance. In the latter case, ITRI has formed an alliance with the Taiwan TFT-LCD Association (and its seven key companies) to share a portfolio of 232 key patents for large-size flat panels. With this patent pool, the Taiwanese companies were able to stage a late entry into an industry dominated by Japan and South Korea because some of these patents were used to strike a cross-licensing deal with the incumbent firms (Shih 2005).

Another type of support in the area of IPR comes from Korea and its measures to help the SMEs in IPR disputes. One early initiative included the direct sharing of costs of legal IPR disputes by the SMEs. This initiative has now evolved into the provision of commercial insurance against possible IPR lawsuits, where the Government pays at least 70 per cent of the insurance premium with the maximum amount set for a company. Other ex ante measures include a service to conduct pre-marketing/export investigation of

23 It is called "reverse bidding" or "auction" because a supplier bidding with lowest prices (costs) becomes the winner, compared to the conventional auction where a buyer bidding with highest prices becomes the winner.

the possibility of legal disputes when the SMEs plan to export to some countries. Ex-post measures include offering consulting service for SMEs who face IPR lawsuits with foreign entities. Most recently, a public-private consortium fund, the so-called patent angel, was created to purchase, manage, license, and sell various types of IPRs, and help the SMEs that joined the fund either as a fee-based membership or as an equity holder. The fund is supposed to act as a patent umbrella for SMEs exposed to possible claims by patent trolls.

7. Concluding remarks and suggestions for the international community

In this paper we have argued that STI can play a critical role in expediting transition to a sustainable mode of development, through industrial restructuring and fostering of green growth. A critical concept in this transition is leapfrogging, including stage-skipping, whereby the developing country can jump into a new eco-friendly techno-economic paradigm. In the case of inclusive green growth, this concept has intuitive appeal because it is the developed countries that have the most infrastructural inertia in terms of business models based on fossil fuels (carbon lock-in) while developing countries have the opportunity to leap to new green energy and resource systems unconstrained by such lock-in. They also have powerful competitive advantages based on their abundance of resources (sun, land, water) which can be utilized as renewable sources of energy, not only to power the industrial development of the latecomer itself but also for exports. Korea's initiatives in green growth are exemplary in this regard (Mathews, 2012b).

However, if developing countries are to realize this potential they need to build up technological capabilities and have enhanced access to knowledge available in the developed world. In this paper we have reviewed the experience of some countries in capacity-building and related policy options, such as the case of China's development of renewables, India's promotion of solar PV through the NSM, and Brazil's development of biofuels.

We have emphasized the role played by diffusion and FDI in technology upgrading and capacity-building, as well as the efforts made by the countries concerned to promote their own indigenous innovation, utilizing public research institutions such as KAIST and ETRI in Korea, ITRI in Taiwan Province of China and EMBRAPA in Brazil. The next step is to promote the diffusion of the new clean and green technologies; in this context we discussed the need to create incentives to stimulate the adoption of new technologies and their uptake by new sectors in the developing countries. A final issue is IPRs, which may interfere with the process of diffusion of new environment-friendly technologies and calls for systemic reforms to ensure that IPRs work to advance diffusion rather than constrain it.

To sustain economic growth, a re-balancing of development focus should emphasize not only infrastructure development or business climate improvement but also support and nurturing of the private sector (firms) and its innovation capabilities. While there are many binding constraints in developing countries—and constraints can vary from country to country—lack of access to foreign currency is a challenge confronting many developing countries. This is because growth depends in a robust manner on investment, and hard currencies are needed to pay for the investment goods which are likely to be imported from abroad. Accordingly, we can reason that developing countries should promote export industries to earn the foreign currencies, while ODA and concessional loans can ease such constraint to some extent.

Pursuing this line of thought, we can argue that developing countries are advised to choose and specialize in selected sectors or industries for export. Initially, such sectors might include tourism, labour-intensive manufacturing, or production for export of primary products, while the industrial structure needs to be diversified and upgraded throughout the stages of development and with the help of STI. Focusing on a few growth poles is important because many resources are scarce and must be mobilized into just a few strategic or priority areas. The business climate can be improved first in these growth poles or strategic areas.

There can be several roles for international organizations like the United Nations in helping cultivate firm-level technological capabilities in developing countries. First of all, discussion can be renewed on how to reform international trade architecture in order to help the latecomer build innovation capabilities that can be started by United Nations initiatives. In domestic settings, developing countries should be allowed certain policy space to nurture their local firms—without such policy space, local firms are exposed to competition with foreign goods from the beginning and may not survive. Having elementary school players competing with the professional players in the same soccer tournament is not a fair game. In the international setting, new emphasis is needed in the area of providing access to developed country markets; at the same time, aid policies should be reformed so as to encourage capacity-building of the private sector in developing countries.

Second, to further facilitate nurturing of firm-level technological capabilities in developing countries, the United Nations may consider starting a new initiative to promote local-foreign partnerships (LFPs) which can be regarded as a modification of private-public R&D consortium/partnerships (PPPs). While the latter has involved private firms and public research units and was quite effective in solving innovation bottlenecks in several successful countries in East Asia, the LFP involves private firms in less developed countries and public R&D units from developed countries to solve the existing technical production problems. LFPs also execute new business projects which may be import-substituting or export-generating items in mature or emerging technology sectors. With possible United Nations initiation, an international assistance programme that might be called “STI doctors” can be mobilized to help firms in the developing world. STI doctors would comprise a team of foreign experts from public R&D units, retired engineers from private sector, and policy practitioners from donor countries. Such teams could help solve technical bottlenecks of the developing country firms in the areas of innovation, management consulting and know-how. The Korean Government has promoted such programmes to help the SMEs, and UNIDO already has a similar programme that can be extended further²⁴.

We have demonstrated in this paper that technological leapfrogging has been emerged around the world, including by countries in Africa, many of which are often considered to have insufficient capacities in STI, and has had tangible positive impacts. However, greater policy intervention is called for to expedite the diffusion of new technologies needed to maintain the upgrading momentum. Various forms of incentive or subsidy provision are needed to correct market and coordination failures and to generate economies of scale. The international community, including the United Nations, may consider setting up a global fund to support R&D activities into new environment-friendly technologies and to promote their diffusion.

24 The United Nations Industrial Development Organization (UNIDO) operates extensive technical field services by running diverse technical offices throughout the world, including: Investment and Technology Promotion Offices which promote investment and technology flows to developing countries; International Technology Centres which act as catalysts for technology upgrading and assist in managing technology change. Also, in collaboration with the United Nations Environment Programme (UNEP), UNIDO has set up a global network of National Cleaner Production Centres, aimed at building national capacities in clean production technologies.

Finally, this paper has considered the role of intellectual property rights (IPRs) and argued that IPRs (particularly patents) can be a serious deterrent factor in countries' efforts to make a transition to a sustainable mode of development with the help of STI. We argue that IP systems need to evolve further from an institution that protects IP to one that fosters dissemination of technology. Each country should be allowed certain room to tailor its own IP system to its specific needs. There is a pressing need for a global dialogue on the reform of the patent system. Developing countries as a group are well positioned to undertake a leadership role in adapting traditional IP laws to new technological challenges that current advanced countries have failed to address, thus undermining markets for technology in these economies (Reichman, 2009).

The rise of innovation models utilizing multi-field and outside knowledge, and the associated rise of patent licensing have indicated a need to consider a whole new set of policies. The international community, including WIPO, should discuss several policy issues, such as a broad research exemption for experimental users and judicial power to require non-exclusive licensing in the spirit of anti-blocking or public interests. Regarding the patenting of publicly funded research results, there is a need to install a minimum safeguard of public interests by ensuring transparency in licensing and allowing wider use of non-exclusive licensing. Also, the increasing mobility of knowledge works indicates a need for a reform in the IP regime to guarantee inventors' continuing research (especially non-commercial) and activities regardless of affiliation changes. Various schemes, such as the Inter-Institutional Agreement and the Material Transfer Agreement, could be further improved and diffused, together with appropriate rules for benefit-sharing.

Finally, our paper argues that inclusive green growth is a feasible development goal that can deliver sustainable energy for all, to use the terms of the United Nations Secretary-General. Growth is essential to enable the balance of the world's population to aspire to and achieve the living standards enjoyed by the one billion living in the advanced world. Latecomers have potential advantages that, if utilized adroitly—as in East Asia over the past half-century—can enable developing countries to accelerate their catch-up with the West. But they cannot do so by utilizing the traditional model of development powered by fossil fuels, since this would lead them to gross energy insecurity and probable resource wars. The way around this supremely “inconvenient truth” is to fashion an alternative green development model, as, arguably, China is doing, and to some extent Brazil and India. Green growth is thus a feasible goal for developing countries, enabling them to leapfrog over the advanced world with its carbon lock-in and move to the exploitation of abundant resources in tropical developing countries. Tropical countries such as Mozambique are demonstrating that they can utilize revenues from fossil fuel resources to build a black development platform that finances entry into green sectors, which promise long-term economic and energy sustainability. And green growth offers good prospects for social inclusion, given that almost all the renewable sources of energy will have to be developed in rural areas and can generate employment and social infrastructure development for rural communities. This would appear to be a promising way forward for developing countries.

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