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Key Determinants of Technological Capabilities for a Green Economy in Emerging Economies

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1. Introduction

Building a global green economy will require a technology transition in both developed and developing countries. Among the developing countries the emerging economies have quickly established significant technological capabilities in fields related to the green economy. The growth of production capacity and diffusion of green technology in the emerging economies have been dramatic. China and India in particular have become one of the global leaders in some of the emergent green technology sectors such as solar photovoltaic (PV) panel, wind turbines and electric and hybrid electric vehicle sectors. What are the respective contributions to technical progress of learning by doing, indigenous R&D, and technology transfer through FDI, trade and other channels? What is the role of national innovation systems? Given limited resources, what kinds of R&D programmes and public interventions and support promote more effective technology acquisition, adaptation and development? What lessons can other developing countries learn from BIC on building innovation systems for a green economy? Where are the entry points for other countries to begin to climb the green technology ladder, particularly with regard to the technologies associated with a green economy transformation Drawing on an analysis and comparison of emergent innovation systems in emerging economies, notably China, India and Brazil, and considering how well adapted those innovation systems are to the development, diffusion, application and adaptation of green technologies, this paper addresses the key determinants of technological capabilities for a green economy in emerging economies.

The rest of the paper is organised as follows. Section 2 overviews the most recent science and technology accomplishments in China. Section 3 analyses the key determinants of the development of technological capabilities. Section 4 discusses the role of public policies and institutions as well as private actors in the innovation systems. Section 5 outlines policy implications for developing countries seeking to enhance their technological capabilities for a green economy.

2. Environmental technological capabilities in emerging economies: the case of China

Over the past three decades, China has experienced tremendous growth in its economy and a continued increase in per capita income. As GDP has grown, so has private and public expenditure in research and development (R&D). When compared to peers such as India and Brazil, China has had the largest increase in R&D expenditure at an annual rate of 19% since 1995 and draws the largest number of its youth towards research and science careers (OECD, 2008)[2]. In addition, foreign firms had established over 1200 R&D centers in China by 2008 (Zhu 2010). Although there is still a gap between China's technological capabilities when compared to OECD countries, China's S&T sector has produced many innovative accomplishments over 2006-10 period. Although these accomplishments have come to fruition near the end of the 11th Five Year Plan period (2006-2011), the path China has taken towards attaining success in S&T has been a process of continual adjustments and incremental improvement in its NIS polices. In terms of key output indicators, R&D intensity has improved from 0.6% in 1995 to 1.43% in 2006. From 1995 to 2005, there was 151% increase higher education graduates (in science, engineering, agriculture and medicine only), a 261% increase in granted patents, and a 1538% increase in high-technology exports (OECD 2008).

There have also been considerable breakthroughs in various areas of science and technology research, including substantial achievements in renewable energy and environment protection. In terms of the development of green technology, there are several notable milestones in 2009[3].

- **Pollution mitigation**: development of highly efficient water purification devices and as of July 2009 began building an Integrated Gasification Combined Cycle (IGCC) power plant.

[2] As of 2006, China is only second to the United States with 1.2 million full-time researchers OECD (2008).
[3] Adapted from MOST (2010).

- **Renewable Energy**: substantial progress on several adjustable speed wind energy power plants including two 1.5MW in early stages of production as well as a 2.5MW and 3MW in later stages of installation. Notable progress in solar energy and battery technologies including 21 cities using solar for illumination. Collaboration with Japanese to develop small generators for wind powered irrigation in arid areas.
- **Electric Cars**: 13 cities using electric vehicles for public transportation.
- **Buildings and Infrastructure**: using the world's most powerful solar power supply of 4.5MW to supply heating and cooling at Shanghai Expo pavilions and at various sports facilities.

Table 1 reports some indicative examples of these S&T breakthroughs over the 2006-10 period.

Table 1: Indicative Examples of China's S&T Accomplishments 2006-2010

General Sector(s)	Name of Project	Milestones	Innovation Accolades
Energy/ Nuclear/ Manufacturing	Sanmen 1 & 2 (Zhejiang) and Haiyang 1 & 2 (Shandong)	Rapid development and expected to start going online by 2014, 3 years earlier than original estimates	Technical advances in steel components manufacturing including pipes, safety dome, and other large components. First deployment of Third Generation Technology
Energy/ Offshore Oil and Gas Exploration	COSLPIONEER, a Deep Water Semi-submersible Drilling Platform (Shandong)	First deepwater semi-submersible drilling platform delivered by China's offshore industry	Development of advanced seismograph and a semi-submersible drilling platform with compliance to strictest world standards including compliance with zero discharge policies: solid debris are transferred onshore for disposal and various wastewater treatment systems ensure that sewage and rain are adequately treated before disposal at sea.*
Water Resources/ Environmental Protection	Water Pollution and Control	Contribution to meeting emission reduction targets for 2010	Installation of municipal wastewater treatment processes and energy-saving sludge dewatering equipment to reduce emissions from chemical and pharmaceutical industries. Progressively strict legislation and explicit pollution reduction targets since 1996 has spurred development of an innovative environmental protection industry.

Source: UKRC (2010). * (CIMC 2010).

There are also substantial ongoing resources allocations to support these efforts are significant including the following budgeted allocations for 2009-2010 such as ¥20 billion for the development of Solar Power plants; ¥200 million for the public electric cars project in 13 cities; ¥2 billion to boost related parts for electric cars; and ¥6 billion to support innovation in battery technology (MOST, 2010). As illustrated in Table 2, China's total investment in environmental pollution control grew 32.6% in 2008, accounting for 1.49% of GDP, roughly in line with previous years. The changes in the proportion of factors that sum to this expenditure, nevertheless, reveal a promising turnaround in underlying trends.

The encouraging trends are that expenditure in Industrial Pollution Control reached a zenith in 2007 and fell 1.2% in 2008, whereas investment in 'Three simultaneous policies' increased 57% over the same period. This is an encouraging trend as it suggests China's innovation policies are making headway in incorporating sustainable technologies and methods in the building of infrastructure to reduce levels of pollution emissions. Uncouples economic growth from creating any additional environmental degradation has been a real challenge that faces the Chinese government.

Table 2: Total Investment in Environmental Pollution Control (in billions of Yuan)

	2001	2002	2003	2004	2005	2006	2007	2008	Change in 2008
Industrial Pollution Control	17.5	18.8	22.2	30.8	45.8	48.4	55.2	54.3	-1.2%
Urban Environment	59.6	78.5	107.2	114.1	129.0	131.5	146.8	180.1	22.7%
'Three Simultaneous Policies'	33.6	39.0	33.4	46.1	64.0	76.7	136.7	214.7	57%
Total	110.7	136.3	162.7	191.0	238.8	256.6	338.8	449.0	32.6%
% of GDP	1.15	1.33	1.39	1.40	1.31	1.23	1.36	1.49	

Notes: 1. Industrial Pollution Control is primarily composed of expenditure in treatment initiatives for waste water effluence and noxious gas emissions from industrial facilities.
2. Urban Environment Investments focus on urban infrastructure including drainage facilities and landscaping.
3. 'Three Simultaneous Policies' prescribes that from the onset, new facilities and their required pollution control measures be designed, constructed, and placed into operation at the same time.
Source: (MEP 2010)

With regards to renewable technologies, the production capacity has grown rapdly in the past ten years. For example, in the wind power sector, China moved from 9th in the world of top wind markets in 1999 to the 2nd largest market in 2009 and having 3 of the global top 10 producers in this sector (BTM, 2009). In the solar PV industry, China's global share increased from less than 1% in 2003 to the world's largest producer in 2008 (Climate Group, 2009). Moreover, China has set an ambitious national goal for 2020 (Table 3). Put in context, these targets translate to renewable energy generation by 2020 that is three times 2006 levels, and an increase in renewable energy as a percentage of all power generation to 21% from a 2005 level of 16%. Finally, these forecasts envisage that solar powered water heaters will be installed in 1/3 of all households by 2020.

Table 3: Renewable Technology Targets for 2020

Type of Power Generation	2006 Actual	2010 Estimates	2020 Target
Total Water (GW)	130	180	300
Small Scale Water (GW)	47	60	85
Wind (GW)	2.6	5	30
Biomass (GW)	2.0	5.5	30
Feed-in Solar (GW)	0.08	0.3	2
Solar Powered Water Heaters (m^2)	100	150	300
Ethanol for Fuel (million tons)	1	2	10
Bio-diesel (million tons)	0.05	0.2	2
Biomass Pellets (million tons)	0	1	50
Gas from Biomass (million tons)	8	19	44

Source: Li, J. and E. Martinot (2007).

3. Technology transfer, indigenous R&D and technical progress

3.1 Technology transfer, indigenous R&D and technical progress in emerging economies

Innovation is costly, risky and path-dependent. This may provide a rationale for poor countries to rely on foreign technology acquisition for technological development. In fact, most innovation activities are largely concentrated in a few developed countries. International technology diffusion is therefore an important condition for economic growth. If foreign technologies are easy to diffuse and adopt, a technologically backward country can catch up rapidly through the acquisition and more rapid deployment of the most advanced technologies (Romer, 1994; Grossman and Helpman, 1994; Eaton and Kortum, 1995).

Technology can be diffused between firms and across regions and countries through various transmission mechanisms. These include: (i) licensing; (ii) movement of goods through international trade; (iii) movement of capital through inward and outward foreign direct investment (FDI and OFDI); (iv) movement of people through migration, travel, and foreign education of students and workers; (v) international research collaboration; (vi) diffusion through media and internet of disembodied knowledge; (vii) integration into global value chains to benefit from the foreign technology transferred within the supply chain (Fu, et al., 2008). Some knowledge is transferred intentionally from the knowledge owner to the recipient; but a large proportion of knowledge spillovers take place as unintended knowledge leakage. In recent years the mode of innovation is becoming more and more open and is making good use of external resources. International knowledge diffusion can therefore benefit a country or firm’s innovation at every stage of the innovation process.

Foreign direct investment and technology transfer

As a bundle of technological, managerial knowledge and financial capital inward foreign direct investment has been regarded as a major vehicle for the transfer of advanced foreign technology to developing countries for a long time (Dunning, 1994; Lall, 2003). Multinational enterprises (MNEs) are regarded as the major driver of R&D in the world. They are also found to have internal incentives to transfer technology across border to share technology between parent companies and subsidiaries (Markusen, 2002). Therefore, it is expected that in the medium- to long-run, local firms will benefit from MNEs spillovers and linkages. Technology transfer may take place within the foreign-investing joint ventures through imported machinery and equipments and through labour training. Horizontal technology spillovers may occur from foreign investing firms to other firms in the same industry and/or the same region via demonstration effects and the movement of trained labour from foreign to local firms (Caves, 1974; Fosfuri et al., 2001). There may also be vertical technology spillovers taking place between foreign and local suppliers and customers within the value chain through forward and backward linkages (Javorcik, 2004; Pietrobelli and Rabellotti, 2007). The competition effect of FDI is also expected to push inefficient firms to exit from the market and force other local firms to innovate to be competitive. However, despite the possible benefits of technology transfer and FDI spillovers, these may also have significantly negative effects on technological upgrading in the domestic firms due to a variety of reasons. First, FDI may make the competing domestic firms worse off, and even crowd them out from the market (Aitken and Harrison, 1999; Hu and Jefferson, 2002). The strong competition from foreign subsidiaries may reduce local firms' R&D efforts (OECD, 2002). Moreover, foreign subsidiaries may remain as enclaves in a developing country with a lack of effective linkages with the local economy. As a result, empirical evidence on the effect of inward FDI on the productivity and innovation capabilities of indigenous firms is mixed.

Among the BIC countries, China is the largest recipient of inward FDI. It is also the largest destination of inward FDI among all the developing countries. China has also introduced set of policies, such as local content requirement and joint venture requirement to enhance the linkages and knowledge transfer from foreign to indigenous firms. Over a certain period China has required joint venture as a condition for FDI inflows. China and Brazil both have negotiated export and local content requirements on FDI in certain industries such as the automobile industry so as to create linkages between foreign and local firms. They have also imposed training requirements on FDI in some cases. In the context of China, Buckley et al (2003, 2006) find a positive association between

FDI and productivity of domestic firms at the industry level. However, the empirical evidence is mixed. Using a large firm level panel data set from China, Fu & Gong (2008) find depressive effects of foreign R&D labs on local firms in China. This is consistent with findings of Hu and Jefferson (2002) in the electronic and apparel industries in China. This is also consistent with recent firm-level evidence from India. Using an unbalanced panel data of 1843 Indian manufacturing firms operating during the period 1994-2005, Sasidharan and Kathuria (2008) also find that the foreign equity participation acts as a disincentive for investment in R&D.

Imports and technology transfer

Imports of machinery and equipments are another important channel for foreign technology acquisition. Cross country studies on bilateral imports data suggest imports as an important channel for countries to acquire advanced technology and enhance competitiveness (Coe and Helpman, 1995; Fagerberg, 1994). Note, however, that technology transferred through imports of machinery and equipments is embedded in this machinery. Products that used these imported machines will probably be of higher quality, but this does not mean that developing countries thus necessarily master the technology of designing and producing those advanced machines. Substantial technological learning and reverse engineering are required to grasp the technologies embedded in the imported machinery. In the case of the high-technology industries of China, Li (2008) find that investing in foreign technology alone does not enhance innovation in domestic firms, unless it is coupled with an industry's own in-house R&D effort. On the contrary, domestic technology purchases alone are found to contribute to innovation, suggesting that indigenous technology is much easier to be absorbed by domestic firms.

Outward FDI and technology transfer

Firms carry out outward foreign direct investment for several reasons including market seeking, resource seeking, efficiency seeking and strategic asset seeking. For multinationals from the emerging economies, one of the major motivations in direct invest in developed economies is for knowledge sourcing through setting up R&D labs, joint ventures with foreign firms, research institutions and universities, and greenfield new production facilities with R&D function, as well as merge and acquisitions of local firms and institutions who own the needed technology know-how or even only the research manpower or potential. This type of asset exploration outward FDI has become a major type of OFDI from the emerging economies (Dunning et al., 2007). With the mode of innovation becomes increasingly open, active knowledge sourcing through such OFDI will serve as an effective mechanism enhancing firms' innovation capabilities, especially for firms who the necessary absorptive capacity.

Indigenous Innovations and Catching-up

However, the diffusion and adoption of technology is costly and requires certain pre-conditions and is sometimes difficult. Technology producers have an interest in the transfer of equipment through trade, but they may be reluctant or unwilling to share the underlying capabilities because these capabilities are core competences that are central to their own competitiveness Mallett et al (2009). So is foreign direct investment where the MNEs will try to control knowledge leakage although there may be some intended vertical knowledge transfer through the supply chain (Fu et al., 2008). Moreover, many technologies are tacit. Therefore, such technologies are difficult to transfer, let alone to transfer from abroad. For the acquisitions of tacit knowledge, in-house R&D is crucial although universities may provide some assistance to the acquisition and absorption of some tacit knowledge where the universities have an advantage to grasp. Finally, knowledge is cumulative and path-dependent. This again suggest that indigenous R&D is an important and necessary element for the effective assimilation and adaptation of transferred foreign technology and the development of indigenous technological capabilities for catch up. Effective technological capabilities building in the developing countries should make use of both the indigenous innovation efforts and foreign technology transfer, although the relative importance of each driver varies according to different stage of industrialisation and development in the concerned developing country (Fu et al., 2008; Fu and Gong, 2008). Such strategy is also suitable for the technical progress in the green sectors. The transfer of green technology and the development of a green economy is no exception.

Moreover, there is also a matter of whether foreign technologies created in the developed countries are appropriate for the developing countries. Foreign technology may be inappropriate with respect to the local socio-economic and technical conditions since technological change is a ‘localized learning by doing’ process (Atkinson and Stiglitz, 1969). All this points to the importance of indigenous innovation efforts for technology upgrading, and catching-up in particular. Moreover, because of the innovator’s incentive to maximise innovation returns, technical change will be biased to make optimal use of the conditions and factor suppliers in the country where the technology is developed (Acemoglu, 2002).

Using empirical evidence from a recent Chinese manufacturing firm-level panel dataset for 2001-2005, Fu and Gong (2008) find that FDI has served as a vehicle transferring advanced foreign technology from global reservoirs of knowledge. This improves static technological capabilities through imported machines and equipments. However, R&D activities of foreign firms appear to exert a significant negative effect on local firms’ technical change. Instead, it is collective indigenous innovation that contributes to the dynamic technological capabilities of local firms and pushes forward the technological frontier. Their study also indicates the sector specificity of the relative strength and effectiveness of indigenous and foreign innovation efforts and a ‘two-leg forward’ strategy for developing countries. A further study on the role of R&D in individual firms suggest that they serve as an effectively source of absorptive capacity in domestic firms (Fu and Gong, 2010)

Given the different roles of technology transfer and indigenous R&D, the developing countries should pursue both strategies with different emphasis but at different development stages and in different industries, as suggested by Aghion and Howitt (2005) and Fu et al (2008). International technology transfer and indigenous innovation in fact reinforce each other: localized innovation is a prerequisite for developing domestic absorptive and creative capabilities to ultimately benefit from transfer mechanisms. Unconventional technology transfer mechanisms such as international R&D collaboration and outward direct investment are only possible once local industries have developed world-class firms with international recognition and which possess the resources and clout to collaborate with, or acquire foreign firms. Such transnational firms are dubbed 'national champions' and play an active role in the acquisition of new technology and know-how by leveraging global value chains to innovate within their network (Fu, et al., 2008).

Another important role of indigenous innovation is the other side of its dual function: a major source of absorptive capacity, the ability of an organisation to identify, assimilate and exploit knowledge from its surrounding environment (Cohen and Levinthal, 1989). The level of absorptive capacity is a crucial condition affects the actual benefits from any technology transfer. Technology transfer can be partial because of the costs and variations in capacity to adopt new technology. An important component of absorptive capacity are the R&D activities carried out by local firms, that play the dual role of creating knowledge and promoting learning and absorptive capacity (Aghion and Howitt, 1998; and Griffith et al., 2004). Li (2008) and Fu (2008) both support this hypothesis based on experiences from China. Foreign technology will generate a positive effect on local firms' technological change and upgrading only insofar as sufficient indigenous R&D activities and human capital are present.

3.2 Technology transfer, indigenous R&D and technical progress for a green economy

As discussed earlier, technology transfer has been an important driver for technological capabilities building in developing countries. In the technical progress for a green economy, it remains an important driver and has been a crucial part of the global solution for reducing green house gas emission under the UNFCCC framework. However, the diffusion and adoption of technology is costly and requires certain pre-conditions and is sometimes difficult. Hence effective technological capabilities building in the developing countries should make use of both the indigenous innovation efforts and foreign technology transfer, although the relative importance of each driver varies according to different stage of industrialisation and development in the concerned developing country (Fu et al., 2008; Fu and Gong, 2008). Such strategy is also suitable for the technical progress in the green sectors. Bell (1990) argues that low carbon innovation capabilities are likely to depend on indigenous investment in training, R&D and reverse engineering. Based on the experience of the wind power, solar energy and electric and hybrid vehicles sector in India and China, Lema and Lema (2010) find that conventional technology transfer mechanisms such as patent licensing, inward FDI and imports were important for industry formation and take-off. However, Other mechanisms such us indigenous R&D, global R&D network and acquisition of firms in the West became more important when these sectors have taken off and start catching up.

Technology transfer and indigenous innovation in the wind power sector in China

In the wind power sector, China has made substantial advancement, moved from a country with about 97% of wind turbines imported in the late 1990s to nearly 100% of turbines are domestically produced in 2010 (CWEA, 2010). It moved from 9th in the world of top wind markets in 1999 to the 2nd largest market in 2009 (BTM, 2010). The market is set for a continued high-growth, aiming to reach a combined 100GW in 2020 (Schwartz, 2009). In 2006, three Chinese companies have become global top-10 players in this sector, including Sinovel, Glowind and Dongfang (BTM, 2010).

The rise of the Chinese wind power sector is a classic example of a dynamic technology development model combined indigenous innovation and foreign technology transfer. Conventional technology transfer channels such as FDI, licensing and joint ventures have been critical to the rise of China as a leading wind power industry in the early years of the formation of the industry. However, after the formation of the basic production capacity and in the catch-up stage, other indigenous R&D based knowledge creation and acquisition activities, such as in-house R&D, international R&D collaboration and cross border acquisition have become more important. The top three Chinese wind turbine producers all start from licensing arrangement from German companies, and later moved to R&D collaboration with their foreign partners (Lema and Lema, 2010). Moreover, all these major companies have undertaken substantial in-house R&D with the support of government R&D grants (Tan, 2010).

In contrast to Indian import duties, China's has required 70% local content to foreign direct investment in the green sector. This regulation provided two options for foreign manufactures: 1) establish a China-based manufacturing facility or 2) partner with a Chinese firm (Lewis, J. I., 2007).
China's local content requirements and joint venture conditions for FDI flows prescribed their formation; similarly in Brazil, local content requirements created linkages and spillovers between foreign and local firms (Fu 2008). India's trade policy strategy for competence building in wind turbine manufacturing was slightly different. A combination of a national certification program and

customs duties that favored imports of components over complete wind turbine machines supported technological transfer (Lewis 2007).

The growth of the wind power industry in India has also experienced a similar path. The India domestic wind power industry started fast growth from the mid-1990s. Similar to the case of China, the production facility also started from joint ventures with large foreign producer in the industry such as Germany's Enercon and Denmark's Vestas and some wholly foreign owned subsidiaries of other leading international producers (Mizuno, 2007). However, the major driver of the growth in the Indian wind power industry was the development of indigenous capabilities through supportive innovation system and interactive learning with international industrial and research leaders, the Danish firms and research institutions in particular (Kristinsson and Rao, 2008). However, the largest Indian company in the industry, Suzlon, has adopted a more active internationalization process through outward direct investment to outsourcing R&D and build it technological capability. It has substantial R&D in Germany, Belgium, the Netherlands, and have acquired manufacturing facilities in the US, Europe and China (Lewis, 2007). Therefore, the development experiences of the wind power industry of China and India shares some common characteristics while also differ in the relative weight they have given to various knowledge creation and acquisition mechanisms and the relative importance of indigenous and foreign innovation efforts. Both China and India start off from joint venture and foreign investment in the sector. Both of them have emphasized indigenous technological capabilities building. However, the mode of knowledge acquisition of the leading Chinese and India companies in the wind power sector is somewhat different, while the former mainly rely on inward foreign direct investment and government supported China-based strategy, the later has used more actively outward direct investment through cross border merge and acquisition, and has build up transnational innovation networks that provide a competitive advantage. Whereas Suzlon does not rely soly on its indigenous innovation, Goldwind benefits more from China's NIS policies which are attracting diverse international players to invest in China to such an extent that it is creating an international wind power innovation hub within its borders. In summary, these combined indigenous and foreign innovation efforts have significantly contributed to technology catch-up in BIC countries, and especially in green economy sectors such as wind turbine production, provided breakthroughs from mere knowledge use to knowledge creation that has begun to rival that of OECD countries (Lema 2010).

Technology transfer and indigenous innovation in the solar PV industry

In the solar PV industry, China also experienced dramatic growth. In 2003 China accounted for less than 1% of global solar PV production. In 2008, it was the world's largest producer of solar PV cells (Liu, et al, 2009). Up to 2009, there are more than 500 solar PV firms and R&D labs in China with world frontier technology (Climate Group, 2009). Suntech, Yingli and Trina Solar are ranked the global top-10 companies in the industry (Lema and Lema, 2010).

The development model of the solar PV industry in China is different from that in the wind power industry. Although there are some licensing of foreign technology, a strong emphasis has been put on indigenous R&D. All the major firms are R&D intensive. The industry has not only invested greatly in R&D, it has also invested upstream in the value chain in silicon materials. The major firms in the industry, eg. Suntech, has collaborated closely with research institutions in China and abroad, and has developed its own core technology. China has now become a global leading location in solar PV research and production, which has attracted major MNEs to set up R&D labs or joint R&D labs in China (Lema and Lema, 2010). Therefore, the model of technological capabilities building in the Chinese solar PV industry is a more advanced indigenous R&D-led model with close links between industry-university & research institutions, and with increasing international R&D collaboration in China. While that in the Indian solar PV sector is a mix of three major approaches including patent licensing, joint venture & acquisition, as well as in-house R&D (Mallett et al, 2009), which matches the current development level of the technology and production capacity in the Indian solar PV sector. One factor that both China and India has in common is that export market has been the major driver of this sector. About 98% of China's PV cells export to the international markets in late 2000s, and about 75% of India's PV cell output sought export market (Howell et al., 2010; Lema and Lema, 2010).

4. National innovation system and technology acquisition, adaptation and development

4.1 National innovation system and technological capabilities building

The framework of National Innovation Systems (NIS) is based on the perspective that a nation's propensity to acquire, adapt and develop technology can be best explained by characterizing the components of a nation's innovation system and their interactions with each other (Balzat and Hanusch 2004). This occurs within a heterogeneous and multidisciplinary domestic backdrop and includes market driven public and private firms, all levels of government agencies, research and training institutions and financial intermediaries, to name a few actors.

- The role of R&D programs and complementary innovation policies

As a clear departure from two earlier S&T plans, the 'National Medium- and Long-Term Strategic Plan for Development of Science and Technology' adopted in 2006 emphasizes the objectives of promoting indigenous innovation and striving for an 'innovation –orientated' society by the year 2020. Objectives for 2020- include: 1) Increase R&D intensity to 2.5%; 2) Innovation to contribute to 60% of economic growth; 3) Reliance of foreign technology to be reduced to 30%; and 4) Attain top 5 international ranking for all key innovation output indicators (Hutschenreiter and Zhang 2007).

The Chinese government has also introduced a set of complementary policy instruments to ensure that these objectives will be reached. Table 3 summarised a selection of policies issued by the Chinese government.

Table 3: Summary of National Medium- and Long-Term Strategic Plan for S&T

	Policy Heading	Details and Examples
1)	Increasing science and technology investments	Explicitly, to exceed that of the ordinary fiscal revenue during 10th 5 year plan
2)	Targeted tax incentives	Including a 100% offset in taxable income for innovation investments by private firms. Tax reductions and holidays for incubators, science parks, and green economy related enterprises.
3)	Increasing R&D financial support through banks, insurance companies and other intermediaries	Including tax relief for high-tech venture capital. Creation of non-commercial 'policy banks' in addition to state-owned and private banks to invest in promising R&D
4)	Government technology procurement	Such as requiring over 60% of domestic content
5)	Increasing public funding to support the adoption or imported technology	Such as improving technology transfer links between foreign procurement and local industries
6)	Strengthening intellectual property rights	Such as shortening patent review and improving information services
7)	Human resources development	Including encouraging talent to return from overseas
8)	Investing in education and science	Including promoting careers in science and providing grants and tax incentives to intermediaries that promote awareness and dissemination of scientific knowledge
9)	Investing in public research institutions and improving national standards	Including a new evaluation system to ensure efficient public resource use allocations and aligning Chinese technology standards with international standards
10)	Strengthening coordination	In particular between civil and military research and procurement

Source: Sumarised from publications in various government website including the National Long-Term Science and Technoology Development Plan 2006-2020 (MOST), the National Taxation Bureau and People's Bank of China.

Many of these initiatives reinforce elements of previous strategic plans and government policies. However, with regards to the tax regime and government fiscal expenditure, there are some new polices worth noting: 1) policy to encourage accelerated depreciation of capital expenditure for R&D; 2) policy to import duty exemptions for R&D related materials; and 3) specific government technology procurement policy to support innovation. This last policy was inspired by the success of similar government procurement policies and objectives that were successfully implemented in OECD countries, notably Korea and the United States. (Hutschenreiter and Zhang 2007).

- <u>University-industry linkages: the special role of universities</u>

As an important player in national and regional innovation systems, universities have received increasing attention with respect to their role in innovation, competitiveness and wider social and economic development. Universities are widely regarded as a major contributor to advances in basic scientific research and the creation of innovation of great novelty. Transiting from a centrally-planned to a market economy, universities in China have historically played an important role in its national innovation system, similar to the case of the science and technology system in the former Soviet Union (Liu and White, 2001). In terms of R&D expenditure and patents of inventions, universities and research institutes played a leading role in China (Li, 2009). Reforms started in 1985 to render the science and innovation system more relevant to the market and signalled a departure from the Soviet model where scientific research at public research institutions and production at state-owned enterprises were completely separated (Xue, 1997).

The mid-1980s witnessed several reforms in science policy in China. The most significant change was the cutting of government research funding in order to push research organisations into the market (Hong, 2008). The Chinese government has been advocating a use-driven science policy since its establishment, encouraging universities to serve the national economy by solving practical problems for industry (Hong, 2006). On the one hand, university-industry linkages in China are built through licensing, consulting, joint or contract R&D and technology services, closely resembling how universities in the West interact with industry. On the other hand, a second form of use-driven innovation occurs as a result of university-affiliated or university-run enterprises (Ma, 2004; Zhang, 2003). Chinese universities since the market-oriented reforms have had strong incentives to pursue economic gains and strong internal (R&D and other) resources to launch start-ups, and thus established their own firms, given the low absorptive capacity of industrial firms and underdeveloped intermediary institutions (Eun et al., 2006). Government-driven spin-off formation has proved an appropriate solution for technology transfer at Chinese universities (Kroll and Liefner, 2008). Based on a recent firm-level national innovation survey, Fu and Li (2010) find that domestic universities have played a significant role in the promotion of the diffusion of frontier technology and the creation of new country- or firm-level innovation outcomes in China. In contrast to the traditional view that collaboration with universities will lead to greater novel innovation (an outcome which is supported by our evidence from the UK), the contribution of domestic universities to the creation of ground-breaking innovations is limited in China.

4.2 Environmental innovation system in emerging economies: the case of China

Analysis using the NIS framework is also sector and context specific; the effects of individual actors depend on the system's conditions such as the regulatory framework, which ultimately influences market demand and underlying technological push and pull dynamics (Walz 2009). As such, government policy regulations can guide the evolution of a country's NIS and help determine competencies and international competitiveness of domestic industries. In particular, as this paper will argue, environmental regulation is a key driver of domestic demand for sustainable technologies in water, energy, and transportation. When coupled with funding and favourable policies aimed at creating and strengthening indigenous capabilities and technological expertise, there are real possibilities for developing countries to take alternative paths towards development and "leapfrogging" into an internationally competitive low-carbon economy.

Environmental preservation and innovation in energy conservation are intertwined with regards to government policy and the private domestic enterprises that policy will impact. Achieving success in terms of moving closer to an energy efficient and low carbon society will require the combined approach of polices for high level direction and funds at the grass roots level to motivate and nourish growth of indigenous SMEs. Policy instruments that support this goal will harness incentives through the tax system, unleash public and private sources of financial support and improve government services. Such policies are aimed towards targeted to enterprises that address either or both goals of environmental protection and reduction of energy consumption. In particular, the government policies have given priority to the promotion of 'Resource Saving and Environmentally Friendly Society" using government procurement to elevate green economy industries; and supporting enterprises that reduce emissions through favorable tax policies.

In terms of policy implementation, the evolution of environmental protection from a policy and funding perspective is revealing: despite initiating environmental protection regulations in the 1970s, effective government policies on pollution control began during the 9th Five Year Plan period (1996-2001) and continue through the 10th and 11th periods where the state frequently formulated new laws and revised old ones (Xinhua 2006). During this time, the central government established explicit goals and a framework of environmental protection standards that has evolved into a system where governments at all levels are now responsible for environmental protection within their jurisdiction. Reinforcing these policies are measures to strengthen enforcement of legislation by government agencies, promote indigenous R&D using public funds, and galvanize market forces to innovate solutions to mitigate pollution (Xinhua 2006). The result however is still far from ideal. By

2006, China's energy consumption had doubled within 10 years and stood second highest in the world (Li and Martinot 2007), yet China's NIS approach to developing environmental technologies has made it strong in cleaning up pollutant emissions and relatively weak in creating and deploying clean technology to impact the root cause of pollutant emissions (Strangway, et al., 2009).

The state has been a major player in the national innovation system. It can lead the direction of and promote innovation research through various government policies and state-funded R&D program. In China, government R&D program has played an important role in nurturing major technological breakthroughs through government R&D programs, including the key basic research program (973), special program focused on the high-technology field (863). In these programs, research for applied environmental technologies in renewable energy, ecology of rural areas and wastewater treatment have all been covered. According to MEP (2010), of the total of 1327 projects of '863 program', 9% are research on new energy and 6.4% focus on resource and environment research, accounting for 5% and 9.4% of total R&D expenditure in this program. In the 'Xin Huo' program, research on environmental protection and resources exploitation account for 12.5% of the total of 454 projects. In the 'Huo Ju' (torch) program, new material, new energy and environmental protection technologies account for 9.4%, 3.1% and 9.4% of total projects, respectively. Green technology has also been a major focus of China's international science and technology collaboration program. In terms of both number of projects and R&D expenditure, energy and environmental science both ranked the 2nd and 3rd largest recipient discipline of all the subject areas, account for 19.9% of total number of projects and 18.1% of total R&D expenditure in the international S&T collaboration program. These programs have nurtured a number of breakthroughs in the S&T research in the green technology area. Some of the programs, such as 'golden sun' program and the 'ten cities thousand cars' program, have provided incentives and financial support to the diffusion and adoption of the environmental technology.

An important feature of the Chinese innovation system, including the environmental innovation system, is the collaboration and coordination between the relevant government departments and the introduction of set of complementary innovation policies that can effectively guide and incentivise firms to innovate. In addition to the Ministry of Environmental Protection, there are many other government bodies responsible for the environmental innovation in China. These include the National Development of Reform and Committee (NDRC), Ministry of Science and Technology (MOST) and others. These governmental bodies often issue joint policies and regulations or issue separate but coherent policies which give the firms regulative and financial incentives and technology information and assistance. Although the coordination of the policies issued by different departments can be improved, they have in the main coherent as they all serve a common objective.

In the national innovation system in China, universities and government research institutions are the major knowledge creator in the environmental science and technology system. Government funding is the major source in the national environmental innovation system. On average, however, there is still a problem that most of the research carried out in the universities and research institutions does not met the needs of the industry well. The industry-academic joint research is not strong despite the substantial government push for greater research-industry linkage. The marketisation of the S&T sector has led many applied research institutes being transformed into private companies, and leaving a gap in transforming outputs from basic scientific research into applied technologies that are badly needed in the industries (Strangeway, Liu and Feng, 2009). On the other hand, however, looking at the several successful large national champions in the green energy sector, many of them have research collaboration with domestic and international universities and research institutions. Global industry-academic linkage has also played a role in assisting Chinese firms move to the global technology frontier. For example, the latest knowledge on photovoltaic was learned from an

Australian university. Leading companies such as Suntech has also international collaboration with foreign universities.

In the green technology sector in China, firms, especially private firms, are the major force in the innovation system by undertaking R&D and transforming scientific inventions into production technologies and commercialising them in the market. Most of the national champions in this sector are large private firms. However, in terms of the diffusion of green technology, especially for pollution mitigation technologies, in sectors outside the green technology sector, due to the lack of strong enforced environmental regulations, firms have not had a strong incentive to innovate.

Foreign firms as an active player in the national innovation system through knowledge transfer, knowledge creation (sometimes) and competition effect. Many MNEs from developed countries have good environmental consciousness driven by tough environmental standards at home. On average, MNEs use relatively cleaner technology than domestic firms in developing countries even in ‘dirty’ heavy polluting industry. Therefore, there is a possibility of clean technology transfer from foreign to domestic firms. This is especially the case in joint ventures in the green energy sectors such as wind power and clean electric vehicles industries. On the other hand, however, some MNEs are looking for institutional voids and are likely to locate in the so-called pollution heaven. Zhang and Fu (2008) find that due to the lower pollution standards and lack of enforcement, China has selectively attracted more heavily polluting industries, and FDI in such industries prefer to locate in regions with relatively weak environmental regulations. Therefore, the role of FDI in the national environmental innovation system is two-fold. Realising this problem, the Chinese government has recently modified the FDI policy by curbing energy-consuming and environmental-polluting industries.

4.3 IPR protection and transfer of green technology

Compared to the developed world, developing countries are less able to adjust to the effects of climate change due to the lack of resources and technological means of mitigating the possible outcomes. The UNFCCC[4] is a multilateral framework that facilitates the negotiation and transfer of information and technology to mitigate the effects of climate change through incentive mechanisms such as the Clean Development Mechanism (CDM) and Global Environmental Facility (GDF). This forum encourages conventional technology transfer across borders in order deal with the climate change issue (Lema 2010). Under auspices of the post-Kyoto framework on climate change, developing countries proposed regulations that include the relatively mild—patent pooling and royalty free compulsory licensing of sustainable technologies, as well as the more controversial—complete exclusion of sustainable technologies from patenting and revoking existing patent rights (Hall 2010).

Empirical evidence on the relationship between IPR protection and innovation suggest a positive association between the two, for example in the phamarceutical industry (eg., Hall and Helmers, 2010). However, experience with pharmaceutical patents are not translatable to green technologies since the market for green technologies has a large range of competing technologies unlike the pharmaceutical market that generates the infrequent blockbuster drugs. In addition, unlike drug development, improvements of green technologies is usually incremental due to non-rivalry characteristics and capability to be tweaked in new applications without significant loss of functionality (Hall 2010). Therefore, the effectiveness of strong IPR protection and environmental innovation still needs exploration.

[4] The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty signed by most of the world's nations about 10 years ago. The Kyoto Protocol is an extension of this treaty and includes legally binding measures.

4.4 *Cross country studies of national environmental innovation systems*

An earlier study by Walz (2010) compares the relative strength each of the BRIC country's sustainability orientated innovation system (SoIS). Although his data does not reflect recent developments (2000-2004) it provides useful information of BIC countries' NIS over that period. Table 5 summarises his arguments and findings. He finds that during the 2000-2004 period, none of the countries specifically aimed at decoupling environment and resource consumption from economic development. As far as specific policy and program for sustainability research, Brazil is the only country. It has earmarked R&D funds in the energy, water and transport sector. Finally, in India and Brazil, there is an increasing shortage of young scientists representing a large barrier for the capacity development in sustainability research and public research in general.

Table 5: BIC Countries Sustainability Oriented Innovation Systems Compared, 2000-04[5]

	China	Brazil	India
Technological Specialization	Solar (PV) and other energy efficiencies	Agriculture and transportation	Wind turbines, biopolymers, and desalination
Framework conditions	Focus on general manufacturing and trade	Specific SoIS framework for water and transport sector	Best overall framework conditions for general innovation
FDI Attractiveness (Trade Policy)	Most attractive and far ahead in magnitude	Inflows behind China, yet far ahead of India	Lowest inflows
Sustainable R&D	No specific policy on developing sustainable technologies	Biomass, bio-fuels (ethanol)	Material efficiency and water technologies
Sustainable IP	Largest number of transnational patents in absolute numbers	Low amount of patents relative to exports	Low number of patents. High capabilities and IP in other sectors.
Exports of sustainability technology products	Highest exports: Solar (PV), transportation, and building technology	Behind China, yet well ahead of India	As a proportion of population, exports play minor international importance
Implications and intra-	Average role of sustainable technologies.	Sustainable technologies play	Sustainable technologies play a below average role

[5] Entries summarized from Walz, R. (2009). Technological Competencies in Stainablity Technologies in BRICS countries.

country comparison of sustainable technologies	Weak in terms of future supply of energy and material resources. FDI strength implies China possesses most absorptive capacity for technology.	an important role. Energy supplied through hydro and other 27enewable. Strong technical capabilities in sustainable technologies	despite best overall framework conditions. Legacy of week environmental protection.

Source: summarized from Walz (2010)

Looking at the BIC countries now, there has been dramatic growth in green technology and the development of a green economy. India's wind turbine exports and IP for instance, have increased dramatically. As mentioned above, since 2006 China has made sustainable technologies a primary component of national policy and has made strides in many fields including catching up in wind turbine technologies. Such analysis will be key to extending understanding the role of NIS despite the short timeframe as both China and India have gone from having local companies with no wind turbine manufacturing capabilities to companies capable of manufacturing complete turbine systems, with almost all components produced locally in under 10 years (Lewis 2007).

As a noteworthy comparison, Brazil's rapid catch-up in the biophotonics industry and their application to medical devices is explained as mostly due to the general newness and fragmented nature of related medical equipment industry (Pereira 2010). Likewise, the newness and fragmented nature of sustainable technologies and their applications towards developing products for an emerging green economy present opportunities. Recent evidence shows that technological advances in the sustainable technologies are more widely dispersed worldwide than in other technology areas, perhaps reflecting the fact that it is a relatively recent area of innovation in which some developing countries benefit from geographical advantages (Hall 2010).

5. Conclusions and lessons for other developing countries

This paper analyses the determinants of technological capabilities in emerging economies with a special focus on green technologies development in China and India, and discusses the policy implications for other developing countries with respect to their technological capabilities building for a green economy.

Both China and India have grown dramatically in wind power, solar PV panel and electric cars industries in a very short time. The successful leapfrogging in the environment-related green industries in the emerging economies suggests that there are opportunities for the developing countries to catch-up in the emergent green industries.

Both development of the green industries in China and India has both made good use of indigenous innovation-based international technology transfer although the importance of difference mechanisms vary with the different levels of technology and production capabilities that the concerned industry have at a certain development stage. Most of the green industries in these countries started from international technology transfer through licensing and joint venture with MNEs. All of them have put substantial effort into in-house R&D for the assimilation, adaptation of the transferred technology and the development of indigenous technological capabilities. However, once the basic production and technological capabilities are built up, they start more active knowledge acquisition and creation through indigenous innovation, international R&D collaboration and cross border merge and acquisition. The experiences of the emerging economies suggest that to accomplish such catch-up process requires a combination of international technology transfer and indigenous innovation. Technology transfer will be a feasible and evidenced proved entry point for the developing countries.

Some of the green industries are resource- or labour-intensive once the basic production technology has been acquired, for example, the solar PV panel manufacturing industry. Many of the developing countries are abundant of semi-skilled labour and relevant resources, such as sunshine and wind in Africa. Therefore, once these countries have acquired the production technology through international technology transfer, they will have the comparative advantage in producing low cost outputs such as solar PV panel. Moreover, the export-market orientation of the solar PV industry in China and India also suggest that international market can be a major driver of the growth that the developing countries can rely on. Of course, both China and India have cheap semi-skilled labour available for the production. For African countries to effectively build up their capabilities in the green industries, education and training of semi-skilled labour is a crucial necessity.

The experience of the emerging economies, China in particular suggests that there is a crucial role of the state in initiating the transition process and in maintaining the momentum of the catch-up process. Given the public product of technology as well as environment, government funding support through focused R&D program has been crucial in promoting the technological breakthroughs and hence the indigenous technological capabilities. Government program focused on encouragement of diffusion, such as the 'Golden sun' and 'ten cities thousand cars' programs in China has also greatly facilitated the diffusion and application process.

The experience from China also demonstrates that the development of a green economy is not the task only for the Ministry of Environmental Protection. Instead, a set of complementary and coherent policies from various relevant government bodies covering regulatory, finance, technology and industry policies are important to promote and ensure a substantial change. China has harnessed transfer mechanisms and localized innovation to deal with issues of environmental sustainability through regulation, tax incentives, and public awareness campaigns. To borrow from Lema and

Lema, the approach is ‘sustainability-oriented innovations systems’ SoIS which includes particular attention to policies that decouple economic growth with resource consumption and greenhouse gas (Lema 2010).

In developing, especially low income countries, sunk cost is low in respect to the transition from existing production system to a green economy. Combining this advantage with appropriate technology and financial resources, the developing countries will be able to carry out the transition at a relative low cost and fast pace.

The emergence of the green industries in the emerging economies also suggests that the other developing countries have more alternative sources of technology for their choice. Such Southern green technologies may make better use of the factors that the developing counties are aboundant of and hence are more appropriate to the economic-, social- and technical conditions in the developing countries. Therefore, South-South innovation collaboration and environmental technology transfer should be seriously taken into consideration for the developing countries seeking to build a green economy.

In sum, technological development and innovation are complex, path-dependent, and embedded within the socio-economic fabric of each country (Saviotti 2005). With this perspective, technology transfer can be interpreted as a means of providing building blocks for local experimentation. In the context of developing countries, indigenous innovation is less the development of ideas that are ‘new to the world’ but rather the application and adaption of old knowledge to new environments (Fisher 2010). This approach is sympathetic to the idea that despite the ostensible benefits of technology transfer ‘foreign technology may not fit the specific socio-economic and technical context prevailing in the technology recipient’ and help explain the divergence of developed and developing country incomes (Fu et al., 2008). More specifically, with regards to indigenous technology creation in BIC countries, the differences in factor endowments, such as the abundance of labor and low-to-medium technological capabilities, will tend to drive innovation to suit labor intensive low-to-mid level technology applications (Fu, et al., 2008). Experiences from emerging economies imply that most benefits are yielded from a two pronged strategy in which technological transfers are complemented by localized innovation to help with adaptation and diffusion. Therefore, the legacy concept of technology as being static and embodied in equipment, which literally was transported across borders during early stages FDI, is inappropriate in a forward thinking NIS framework. Rather, technological development is a process of acquiring, learning and local capabilities building in which developing countries can feasibly contribute to the development process through adaptation by local firms.

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