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

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Introduction

Building a global green economy will require a technology transition in both developed and developing countries. Technology transfer in developing and the least-developing countries is an important component of the global efforts to move toward the green development path. Among the developing countries, the emerging economies have quickly established significant technological capabilities in fields related to green development. The growth of production capacity and diffusion of green technology in emerging economies have been dramatic. For example, China and India in particular have become global leaders in some of the emergent green technology sectors such as solar photovoltaic (PV) panels, wind turbines, and electric and hybrid electric vehicle sectors.

This chapter analyzes the determinants of technological capabilities in emerging economies with a special focus on the development of green technologies in China and India and discusses the policy implications for other developing countries with respect to their technological capabilities for a green economy transformation. By using the examples of wind power, solar PV, and environmental innovation system of China, the discussion intends to: (1) uncover the respective contributions of indigenous research and development (R&D) and technology transfer to technical progress in the green sectors; (2) highlight the important role of government policy and regulation; (3) understand what kinds

of R&D programs and public interventions promote more effective technology acquisition and adaptation under the circumstances of having limited resources. In addition, the comparison of emergent innovation systems in Brazil, India, and China (BIC) offers valuable lessons for other developing countries on how to build innovation systems and climb the green technology ladder for a green economy transformation.

The rest of the chapter is organized as follows. A short overview presents the most recent science and technology accomplishments in China. This is followed by an analysis of the key determinants of the development of technological capabilities. The role of public policies and institutions as well as private actors in the innovation systems are discussed. The chapter concludes with an outline of some policy implications for developing countries.

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 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 percent since 1995 and draws the largest number of youth toward research and science careers.³ Meanwhile, foreign firms had established over 1,200 R&D centers in China by 2008 (Zhu, 2010). Although there is still a gap between China's technological capabilities when compared to Organisation for Economic Co-operation and Development (OECD) countries, China's science and technology (S&T) sector has produced many innovative accomplishments over 2006–11 period. In terms of key output indicators, R&D intensity has improved from 0.6 percent in 1995 to 1.84 percent in 2011.⁴ From 1995 to 2011, there was 250 percent increase in the total number of personnel involved in R&D activities, a 213 percent increase in granted patents, and a 544 percent increase in high-technology exports.⁵ There have also been considerable breakthroughs in various areas of science and technology research, including substantial achievements in renewable energy and environmental protection (Table 6.1). In terms of the development of green technology, there are several notable milestones during 2009–11.⁶

Table 6.1 Indicative example of China's S&T accomplishments, 2006–10

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, three 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 deep water semisubmersible 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.

Note: *(CIMC 2010).

Source: RCUK (2010).

- *Pollution mitigation*: development of highly efficient water purification devices and, as of July 2009, began building an Integrated Gasification Combined Cycle (IGCC) power plant including set up 250 MW IGCC plant in Tianjin in 2009 and 400 MW power plant in 2015–20.⁷
- *Renewable Energy*: substantial progress on several adjustable speed wind energy power plants including two 1.5 MW in early stages of production as well as a 2.5 MW and 3 MW in later stages of installation; notable progress in solar energy and battery technologies including twenty-one cities using solar for illumination; collaboration with Japan to develop small generators for wind powered irrigation in arid areas.
- *Electric Cars*: the establishment of a policy framework to accelerate electric-vehicle technology development including the Auto Industry Restructuring and Revitalization Plan (US\$1.50 billion); e-vehicle technology development investment from the State Council (US\$ 3 billion); and a series subsidy program for e-vehicle customers; thirteen cities using electric vehicles for public transportation in 2009. In 2010, the government plans to expand the use of energy-efficient vehicles in public transportation to twenty cities.
- *Buildings and Infrastructure*: using the world's most powerful solar power supplier (4.5 MW) to supply heating and cooling at Shanghai Expo pavilions and at various sports facilities in 2009. In May 2011, the National People's Congress (NPC) set 5 GW as an official minimum PV target for 2015, with a longer-term target of 20–30 GW by 2020.

There are also substantial ongoing resources to support these efforts including budgeted allocations for 2009–10, such as RMB 20 billion for the development of solar power plants; RMB 200 million for the public electric cars project in thirteen cities; RMB 2 billion to boost related parts for electric cars; and RMB 6 billion to support innovation in battery technology (MOST, 2010). As illustrated in Table 6.2, China's total investment in environmental pollution control grew 37 percent in 2012, accounting for 1.59 percent of GDP, slightly above the average of previous years. Concerning the industrial pollution control, the total expenditure reached a zenith RMB 55.2 billion in 2007⁸ and fell to RMB 39.7 billion in 2010, then grew back to RMB 50.1 billion in 2012. From 2005 to 2012, the direct investment in "Urban Environment" increased 284.7 percent whereas investment in "Three simultaneous policies" increased 320.3 percent over the same period. This encouraging trend suggests that China's innovation policies are making headway in incorporating sustainable

Table 6.2 Total investment in environmental pollution control (in billions of RMB)

	2005	2006	2007	2008	2009	2010	2011	2012	Changes in 2012 (%)
Industrial Pollution Control	45.8	48.4	55.2	54.3	44.3	39.7	44.4	50.1	12.6
Urban Environment	129.0	131.5	146.8	180.1	251.2	422.4	346.9	506.2	45.9
“Three Simultaneous Policies”	64.0	76.7	136.7	214.7	157.0	203.3	211.2	269.0	27.4
Total	238.8	256.6	338.8	449.0	452.5	665.4	602.6	825.4	37
Percent of GDP	1.31	1.23	1.36	1.49	1.33	1.66	1.27	1.59	

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: China Statistic Yearbook 2012 (National Bureau of Statistics 2012, <http://www.stats.gov.cn/>).

technologies and methods in the building of infrastructure to reduce levels of pollution emissions.

With regards to renewable technologies, the production capacity has grown rapidly in the last ten years. For example, in the wind power sector, China moved from ninth in the world of top wind markets in 1999 to the second largest market in 2009, having three of the global top ten producers in this sector (BTM, 2011). In 2010, China became the largest wind energy provider worldwide, with the installed wind power capacity reaching 41.8 GW at the end of 2010. In the solar PV industry, China's global share increased from less than 1 percent in 2003 to the world's largest producer in 2008 (Climate Group, 2009). As Table 6.3 shows, the capacities for Solar PV and wind power have increased dramatically in the past years. Moreover, China has set an ambitious national goal for 2020 (Table 6.4). Put in context, these targets translate to renewable energy generation by 2020 that is three times its 2006 level and an increase in renewable energy as a percentage of all power generation to 21 percent from a 2005 level of 16 percent. Finally, these forecasts envisage that solar powered water heaters will be installed in one-third of all households by 2020.

Table 6.3 Capacities of PV power and wind power in China, 2005–12 (Units in MW)

Year	2005	2006	2007	2008	2009	2010	2011	2012
PV power in China*	70	80	100	140	300	800	3,300	8,300
Wind power in the PRC**	1,260	2,599	5,912	12,200	16,000	31,100	62,700	75,000

*Source: Xu et al. (2011).

**Source: US Energy Information Administration: <http://www.eia.gov>.

Table 6.4 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	5.5	30
Feed-in Solar (GW)	0.08	0.3	2
Solar Powered Water Heaters (m2)	100	150	300
Ethanol for Fuel (million tons)	1	2	10
Biodiesel (million tons)	0.05	0.2	2
Biomass Pellets (million tons)	0	1	50
Gas from Biomass (million tons)	8	19	44

Source: Martinot and Li (2007).

Technology transfer, indigenous R&D, and technical progress

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. Expenditures for R&D are US\$453.5 billion in the United States, US\$151.7 billion in Japan, and US\$102.3 billion in Germany⁹. Although the total R&D expenditure in China reached US\$293.5 billion in 2012, the R&D expenditure as percentage of GDP (1.98) is still far below that of developed countries (2.13% of GDP for fifteen OECD countries).¹⁰ International technology diffusion is therefore an important driver of global economic growth. If foreign technologies are easy to diffuse and adopt, a technologically backward country

can catch up rapidly through learning and acquisition (Grossman and Helpman, 1994; Romer, 1994; Eaton and Kortum, 1995).

Technology can be diffused between firms and across regions and countries through various transmission mechanisms. While some knowledge transfer occurs intentionally, 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 countries and firms at every stage of the innovation process (Fu et al., 2011).

Foreign direct investment (FDI) and technology transfer

As a bundle of technological, managerial knowledge and financial capital, inward FDI has been regarded as a major vehicle for the transfer of advanced foreign technology to developing countries (Dunning, 1994; Lall, 2003). Multinational enterprises (MNEs) are regarded as the major driver of R&D in the world (Markusen, 2002). It is expected that in the medium to long run, domestic firms in the recipient country will benefit from MNEs spillovers and linkages. Spillovers can be horizontal technology spillovers (Caves, 1974; Fosfuri et al., 2001), vertical technology spillovers (Javorcik, 2004; Pietrobelli and Rabellotti, 2007),¹¹ and the induced competition effect is also expected to force local firms to become innovative. However, despite the potential benefits of FDI spillovers, these may also have significantly negative effects on technological upgrading in the domestic firms. FDI may not only crowd domestic firms out from the market (Aitken and Harrison, 1999; Hu and Jefferson, 2002), the induced competition effect may also discourage 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, the net impact 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 developing countries and received nearly US\$111.7 billion in 2012.¹² China has also introduced a set of policies, such as local content and joint venture requirements to enhance the linkages and knowledge transfer from foreign to indigenous firms. Over certain time periods, FDI in China had to meet specific joint venture conditions; until 2010 in the automobile industry, for example, foreign investors could not have more than 50 percent of the total share of capital. 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. Empirically, Buckley et al. (2002; 2006) find a positive association between FDI and productivity of domestic firms at the industry level. However, using a large firm level panel data set from China, Fu and Gong (2011) find depressive effects of foreign R&D labs on local firms in China. This is consistent with the 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 (Sasidharan and Kathuria, 2008).

Imports and technology transfer

Imports of machinery and equipment 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 (Fagerberg, 1994; Coe and Helpman, 1995). Note, however, that technology transferred through imports of machinery and equipment is embedded in this machinery. Products that are produced by using 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 embedded technologies. Acharya and Keller (2007) empirically showed that the global patterns of technology transfer are highly asymmetric. The cause of the divergence attributes to the differences in absorptive capacity, such as domestic R&D investments or levels of education. In the case of the high-technology industries of China, Li (2009) found 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.

Outward FDI and technology transfer

Although the leading role of outward FDI is still taken by the developed countries, developing countries, especially the emerging economies, have become an important player in the last two decades. Between 1980 and 2011, the share of outward FDI from developing countries rose from 6.2 percent to 26.9 percent and peaked in 2010 at 31.8 percent (UNCTAD, 2012). Firms carry out outward FDI for several reasons including seeking market, finding resource, improving efficiency, and securing of strategic assets. For MNEs from the emerging economies, one of the major motivations to invest in developed economies is

for knowledge sourcing through the setting up of R&D labs, establishing joint ventures with foreign firms, research institutions and universities, and green fielding new production facilities with R&D function. There is also a motivation for merging and acquisitions of local firms and institutions who own the needed technology know-how or the research manpower. This type of asset-exploration FDI has become a major type of cross-border investment from emerging economies (Dunning et al., 2007). To the extent that this mode of innovation becomes increasingly open, active knowledge sourcing through outward FDI will serve as an effective mechanism to enhance the innovation capabilities of firms in emerging economies.

Indigenous innovations and catching-up

However, the diffusion and adoption of technology is costly and is not automatic. It requires certain pre-conditions and is sometimes difficult. Technology producers have an interest in transferring equipment through trade, but they may be reluctant or unwilling to share the underlying capabilities because these capabilities are the core competences that are central to their own competitiveness (Mallett et al., 2009). Moreover, technology diffusion is difficult to complete due to the tacit nature of many technologies. Therefore, indigenous innovation is a necessary element for the effective adaptation of transferred foreign technology during the catching-up phase of development.¹³

Another important role of indigenous innovation capacities is the other side of its dual function: a major source of absorptive capacity, the ability of an organization to identify, assimilate and exploit knowledge from its surrounding environment (Cohen and Levinthal, 1989). The level of absorptive capacity in a firm is a crucial condition that affects the actual benefits from any technology transfer. Technology transfer can take place at different degrees depending on the costs and variations in local firms' capacities to adopt new technology. An important component of absorptive capacity is the R&D activity carried out by local firms, which play the dual role of creating knowledge and promoting learning and absorptive capacity (Aghion and Howitt, 1998; Griffith et al., 2004). Li (2009) and Fu (2008) both support this hypothesis based on experiences from China. Foreign technology will generate a positive effect on local firms' technological upgrading only insofar as sufficient indigenous R&D activities and human capital are present.

International technology transfer and indigenous innovation in fact reinforce each other. Effective technological capabilities building in 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 the different stages of industrialization and development in the concerned developing country (Fu et al., 2011; Fu and Gong, 2011). Such a strategy is also suitable to support technical progress in the green sectors. An outstanding question in this discussion is whether foreign technologies created in the developed countries are appropriate for the developing countries' context. Foreign technology may be inappropriate to the local socio-economic and technical conditions of countries since technological change is a "localized learning-by-doing" process (Atkinson and Stiglitz, 1969). All this points to the importance of indigenous innovation efforts to support technology upgrading, and catching-up in particular. Because of the innovator's incentive to maximize innovation returns, technical change will be biased to make optimal use of the conditions and factor for suppliers in the country where the technology is developed (Acemoglu, 2002). Using empirical evidence from a recent Chinese manufacturing firm-level panel dataset for 2001–5, Fu and Gong (2011) find that FDI has indeed served as a vehicle to disseminate advanced foreign technology from global reservoirs of knowledge. However, R&D activities of foreign firms appear to exert a significantly 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.

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

There is general consensus that development of the green economy in emerging countries requires strengthening of sustainability innovation capacities in order to accelerate the catching-up phase. Apart from reducing the domestic environmental pressures brought by fast economic growth, one incentive driving emerging economies toward a green development path is the fact that environmental technology advancement helps to improve their infrastructure and economic modernization (Walz, 2009). Another important incentive driving emerging economies into the development of green technology is the gain from first mover advantage; emerging countries are competing with developed countries for leading roles in supplying the international market for green technologies. While technology transfer remains a key driver in the technical progress for a green economy and has been a crucial part of the global solution for reducing greenhouse gas emission under the United Nations Framework

Convention on Climate Change (UNFCCC) framework, the diffusion and adoption of technology is costly and requires certain preconditions; enhancing indigenous innovation capability is very central to accelerate the catching-up phase among emerging countries (Bell, 1990; Lema and Lema, 2010).

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 percent of wind turbines imported in the late 1990s to nearly 100 percent of turbines domestically produced in 2010 (CWEA, 2010). In 2011, China became the largest wind power provider worldwide, with the installed wind power capacity reaching 62.4 GW as shown in Figure 6.1. The market is set for continued high-growth, aiming to reach a combined 100 GW in 2020 (Schwartz, 2009). By the end of 2008, more than fifteen Chinese companies were commercially producing wind power turbines and components. Three Chinese companies have become global top-ten leading players in this sector, including Sinovel, Glowind, and Dongfang (BTM, 2011).

The rise of the Chinese wind power sector demonstrated a classic example of a dynamic technology development model that combined indigenous innovation and foreign technology transfer. Conventional technology transfer channels, including FDI, licensing, and joint ventures, were critical to the rise of China as a leader in the wind power industry in the early years of the industry's formation. Once basic production capacity was gained, indigenous R&D based knowledge creation and acquisition activities have become more important in the catching-up phase, including in-house R&D, international R&D collaboration, and cross border acquisitions of technology and plants. The top three Chinese wind turbine producers all started from licensing arrangement from German companies and

Figure 6.1 Top ten countries by total installed wind capacity (2011)

Source: BTM Consult, 2011.

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).

Particularly noteworthy is to note that China required 70 percent local content to FDI 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, 2007). China's local content requirements and joint venture conditions for FDI flows were critical to accelerate the formation of this sector. Similarly in Brazil, local content requirements created linkages and spillovers between foreign and local firms (Fu, 2008). In contrast to Chinese regulation, India's trade policy strategy for competence building in wind turbine manufacturing was slightly different. Technological transfer was supported by a combination of a national certification program and customs duties that favored imports of components over complete wind turbine machines (Lewis, 2007).

The India domestic wind power industry started its fast growth from the mid-1990s and has significantly increased in the last few years; by early 2011, the installed capacity of wind power in India reached 16.3 GW (see Table 6.5). Similar to the Chinese technological development model, production capacities 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). The major driver of growth in the Indian wind power industry was the development of indigenous capabilities through a supportive innovation system and interactive learning with international industrial and research leaders, the Danish firms and research institutions in particular (Kristinsson and Rao, 2008). The largest Indian company in the industry, Suzlon, has adopted a more active internationalization process; by investing directly in other countries this firm has built its technological

Table 6.5 Major Chinese solar PV enterprises and their industry chain products

Enterprises	Silicon	Ingots	Wafers	Photovoltaic	Cells	Solar
Yingli Solar	PL	PL	PL	PL	MP	
Suntech Power				OP	MP	OP
Trina Solar		PL	PL	PL	MP	
LDK Solar	PL	PL	MP	PL		
Jingko Solar	PL	PL	OP	OP		
GLC Poly	MP	PL		PL		

Notes: MP: Main product; OP: Other products; PL: Product Line.

Source: Li and Wang (2011); UNEP (2013).

capability through outsourcing substantial R&D in Germany, Belgium, and the Netherlands, and through the acquisition of manufacturing facilities in the United States, Europe, and China (Lewis, 2007).

The development experiences of the wind power industry in China and India shares some common characteristics, but they also differ in the relative weight they have given to various knowledge creation mechanisms, the relative importance of indigenous and foreign innovation efforts. Both China and India started off from joint ventures with foreign investors, but they also emphasized indigenous technological capabilities building. Yet the mode of knowledge acquisition of the leading Chinese and India companies in the wind power sector is somewhat different. The former mainly relied on a government supported China-based strategy, including inward FDI. For example, Goldwind has benefited from China's National Innovation System (NIS) policies of attracting international players to invest in China to such an extent that it is creating an international wind power innovation hub in the country. India has used more actively outward FDI through cross-border mergers and acquisitions and has built up transnational innovation networks to boost its competitive advantage. An example of this is Suzlon, a company that not only relied on indigenous technology development but also imported foreign technologies. In summary, efforts to use different combinations of indigenous and foreign innovation efforts have significantly contributed to technology catching-up in India and China, especially successful in green economy sectors such as solar panels and wind turbine production. These two countries have made interesting breakthroughs from mere use of knowledge to knowledge creation in a way that they have begun to rival OECD countries (Lema and Lema, 2010).

Technology transfer and indigenous innovation in the solar photovoltaics (PV) industry

Since 2006, China has witnessed remarkable investment in solar PV manufacturing. In 2003, China accounted for less than 1 percent of global solar PV production. In 2011, production of solar PV in China accounted for 48.5 percent of the total world production, and it has been the world's largest manufacturer for four consecutive years from 2008 to 2011 (UNEP, 2013). By 2009, there were already more than 500 solar PV firms and R&D labs in China with world frontier technology (Climate Group, 2009), and the total exports from these Chinese firms reached US\$35.8 billion in 2011 (Scotney et al., 2012). Suntech, Yingli, and Trina Solar are ranked among the global top-ten companies in the industry (Lema and Lema, 2010).

The development model of the solar PV industry in China is different from that of the wind power industry. Although there is some licensing of foreign technology in the solar industry, a strong emphasis has been put on indigenous R&D. Given the large potential profits in the exports market and with strong supports from the government, the major solar firms are R&D intensive. The government “Golden Sun” demonstration program¹⁴ offered the initial support for the development of domestic solar capacity. The Chinese authorities further offered incentives such as tax breaks and better intellectual property regulation to encourage an increase in R&D investment (UNEP 2013). As a result, the industry has not only invested greatly in R&D but it has also invested in the development of production lines along the value chain (See Table 6.5). The major firms in the industry, such as Suntech, have collaborated closely with research institutions in China and abroad and have developed their own core technology. China has now become a global leading location in solar PV research and production; it has attracted major MNEs to set up R&D labs or joint R&D labs in China (Lema and Lema, 2010). 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 and research institutions and with increasing international R&D collaboration in China.

In the case of India the development of the solar PV sector is a mix of three major approaches that shaped the current level of the technology and production capacity of the Indian solar PV sector; these include patent licensing, joint venture and acquisition, and in-house R&D (Mallett et al., 2009). One factor that both China and India have in common is the fact that the export market has been the major driver of this sector. About 98 percent of China’s PV cells export to the international markets in late 2000s, and about 75 percent of India’s PV cell output sought the export market (Howell et al., 2010; Lema and Lema, 2010).

National innovation system and technology acquisition, adaptation, and development

Technology-push and demand-pull effects play critical roles in driving technological innovation.¹⁵ The technologies for environmental sustainability differ from conventional ones in view of the failure of market demand-pull incentives. The formation of demand thence depends strongly on two factors: (i) policy coordination between different government bodies in charge of environmental, economic, and industrial policies and (ii) an incentive-driven

innovation system. The framework of NIS is based on the perspective that a nation's propensity to acquire, adapt, and develop new technologies can be best explained by the different components of its innovation system and the interactive linkages among those components (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.

The role of R&D programs and complementary innovation policies in China

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 emphasized the objective of promoting indigenous innovation for the creation of an "innovation-orientated" society by the year 2020. Objectives for 2020 include: (1) increase R&D intensity to 2.5 percent from 1.42 percent in 2006;¹⁶ (2) innovate to contribute 60 percent of economic growth; (3) rely of foreign technology to be reduced to 30 percent; and (4) attain top five international ranking for all key innovation output indicators (Hutschenreiter and Zhang, 2007).¹⁷ The Chinese government has also introduced various policy instruments to ensure that these objectives will be reached. Table 6.6 summarized a selection of them.

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 policies 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).

University-industry linkages: The special role of universities in China

As an important player in national and regional innovation systems, universities have received increasing attention with respect to their role in strengthening the innovation, competitiveness, and wider social and economic development. In terms of R&D expenditure and patents for inventions, universities and research

Table 6.6 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 Tenth Five 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 noncommercial “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 of imported technology	Such as improving technology transfer links between foreign procurement and local industries
(6)	Strengthening intellectual property rights	Such as shortening patent review periods 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 (public research institutions) and aligning Chinese technology standards with international standards
(10)	Strengthening coordination	In particular between civil and military research and procurement

Source: Summarized from publications in various government website, including the National Long-Term Science and Technology Development Plan 2006–20 (MOST), the National Taxation Bureau, and People’s Bank of China.

institutes are playing a leading role in China (Li, 2009). Reforms started in 1985 with the objective of rendering the science and innovation system more relevant to the market, in an important departure from the Soviet model where scientific research at public research institutions is completely separated from the production process in state-owned enterprises (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 organizations into the market (Hong, 2008). The Chinese government has been advocating a use-driven science policy 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 (Zhang, 2003; Ma, 2004; Eun et al., 2006). Government-driven spin-off formation has proved an appropriate solution for technology transfer at Chinese universities (Kroll and Liefner, 2008).¹⁸ Based on a recent firm-level national innovation survey, Fu and Li (2010) found that domestic universities have played a significant role in the diffusion of frontier technology and the creation of new country- or firm-level innovation outcomes in China. Still the creation of ground-breaking innovations is limited.

Environmental innovation system in emerging economies: The case of China

Analysis using the NIS framework is 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 policies can guide the evolution of a country's NIS in a direction that helps to build competencies among 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 favorable regulatory regimes, there are real possibilities for developing countries to develop indigenous technological expertise and take alternative paths toward "leapfrogging" into an internationally competitive green economy.

It has been generally acknowledged that environmental preservation and innovation in energy conservation are intertwined with regards to government policy and in relation to the impact that government policy will have on private domestic enterprises. Successfully moving closer to an energy-efficient and low-carbon society will require high-level policy decisions to direct investments to the grassroots level and to motivate and nourish the growth of indigenous small- and medium-sized enterprises (SMEs). Policy instruments that support this goal

will have to harness incentives through the tax system, as well as public and private financial support with the overall objective of improving environmental protection and reducing energy consumption. In particular, government policies should give priority to the promotion of a “Resource Saving and Environmentally Friendly Society,” using government procurement to strengthen green economy industries and supporting enterprises that reduce emissions through favorable tax policies.

While environmental protection regulations in China were introduced in the 1970s, effective government policies on pollution control actually began during the Ninth Five Year Plan (1996–2001) and continue through the Tenth and Eleventh Five Year Plans when the state formulated new laws and revised old ones (Xinhua, 2006b). 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 responsible for environmental protection within their jurisdiction (Xinhua, 2006a). As China’s energy consumption had doubled within the last ten years and stood second highest in the world in 2006 (Martinot and Li, 2007), the Eleventh Five Year Plan heightened concern with the environmental costs of China’s development model. The Eleventh Plan aimed to stimulate a balanced economic growth model with several targets related to the reduction in energy consumption (by 20% during 2006–10) and water consumption per unit of industrial added value. Achieving green development requires long-term policy continuity. On March 14, 2011, China officially adopted its Twelfth Five Year Plan, which includes a robust ambition to make the transition toward a more sustainable development model. The Twelfth Plan is the first plan formulated around the theme of green development. This five-year blueprint set up the development path from 2011 to 2015, and its green targets are shaping the country’s environment innovation system with respect to energy and pollution reductions and the conservation of water and forestry. Yet China’s NIS approach to the development of environmental technologies is strong in cleaning up the emission of pollutants but relatively weak in creating and deploying clean technology to reduce the root cause of emissions (Strangway, et al., 2009).

An important feature of the Chinese innovation system, including environmental innovation, is the collaboration and level of coordination that exists between the relevant regulatory regimes and the innovation policies that guide innovation for environmental sustainability. In addition to the Ministry of Environmental Protection, there are many other government bodies responsible for environmental innovation in China. These include, among others, the

National Development of Reform and Committee (NDRC) and the Ministry of Science and Technology (MOST). These governmental bodies often issue joint policies and regulations (or separate but cohesive policies), which provide regulations and financial incentives to firms, as well as technology information and assistance. Although the coordination of the policies issued by different departments can be improved, they have mainly been coherent as they all served a common objective. Table 6.7 gives some selective government programs that involved different regulatory regimes.

In the national innovation system of China, the universities and government research institutions are the major creators of knowledge in the environmental science and technology system. Universities are widely regarded in their role in advancing basic scientific research and innovation of great novelty. Transiting from a centrally planned to a market economy, universities in China have historically played an important role in the national innovation system, similar to the case of the science and technology system in the former Soviet Union (Liu and White, 2001). However, the industry-academic joint research is not strong as yet, despite the substantial push from the government to foster greater research-industry linkages. On the one hand, the marketization of the S&T sector has led to the transformation of many applied research institutes into private companies, leaving a gap in the transformation from basic scientific research outputs into applied technologies—a transition badly needed for the development of industries (Strangway, Liu, and Feng, 2009). On the other hand, 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 in China also have international collaboration with foreign universities.

Turning to its green technology sector, Chinese private firms are the major force in the innovation system; they are undertaking R&D and transforming scientific inventions into production technologies, including their commercialization in the market. Most of the national champions in this sector are large private firms. Foreign firms have also been active players in the national innovation system through knowledge transfer, knowledge creation in China and through induced competition effects. Many MNEs from developed countries have good environmental consciousness driven by strict environmental standards at home. They tend to use relatively cleaner technology than domestic firms in developing countries even in

Table 6.7 Selective government S&T programs for green innovation and authorities involved

Policies	Launched Year	Environmental-related contents	Authorities
“Golden Sun” program	2009	Promote renewable energy generation and create a domestic market for its solar cell and panel manufacturers	Ministry of Finance, MOST, and NDRC
“Ten Cities Thousand Cars” program	2009	Stimulate electric vehicle development through large-scale pilots in ten cities that would identify and address technology and safety issues associated with electric vehicles.	MOST, Ministry of Finance, NDRC, Ministry of Industry and Information Technology
Basic Research Program (also known as “973 Program”)	1997	Includes environmental technologies in renewable energy, ecology of rural areas, and wastewater treatment	Central Government and MOST,
“Huo Ju” (torch) program	1988	New material, new energy and environmental protection technologies account for 9.4%, 3.1%, and 9.4% of total projects, respectively	Central Government and MOST
“Xing Huo” program	1985	Research on environmental protection and resources exploitation account for 12.5% of the total of 454 projects	Central Government and MOST
State High-Tech Development Plan (863)	1986	9% for research on new energy and 6.4% focus on resource and environment research, accounting for 5% and 9.4% of total R&D expenditure	Central Government and MOST

Source: Various reports from Ministry of Finance (<http://www.mof.gov.cn/>), MOST (<http://www.most.gov.cn/>), NDRC (<http://www.sdpc.gov.cn/>), and Ministry of Industry and Information Technology (<http://www.miit.gov.cn/>).

heavy polluting industries. Accordingly, the possibility of clean technology being transferred from foreign to domestic firms emerges. This is especially the case in joint ventures in wind power and clean electric vehicles industries. Nonetheless, other MNEs are looking for institutional voids and are likely to locate in the so-called pollution heaven. Zhang and Fu (2008) found that due to the lower pollution standards and lack of enforcement, China has selectively attracted heavily polluting industries as foreign firms operating 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 mixed. Realizing this problem, the Chinese government has recently modified its FDI policy by placing new restrictions on energy-consuming and environmental-polluting industries.

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 for mitigation. The UNFCCC¹⁹ 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 (GEF). This forum encourages conventional technology transfer across borders in order to deal with climate change (Lema and Lema, 2010).

With respect to formal technology transfer (e.g. licensing), the strength of the IP regime in technology recipient countries is a positive determinant of exports of high-technology goods from developed economies. More recently there is empirical evidence to argue that there is a positive association between high-technology FDI flows and the level of national legal protection of patent rights (Branstetter et al., 2006; Hall and Helmers, 2010). However, Maskus and Okediji (2010) argued that these findings seem to hold only for large- and middle-income emerging economies, where there is substantial capacity to adapt technologies; high-technology flows however, do not respond much to variations in patent rights among low-income countries. Moreover, empirical experience in the high-tech pharmaceutical industry, where there is solid evidence about a positive correlation between strengthened IP regulation and technology transfer, may not easily translated to green technologies. In contrast to the pharmaceutical industry, the market for green technologies has a large range of competing technologies and improvements in green technologies are usually incremental due to their nonrivalry characteristics and capability to be tweaked in new

applications without significant loss of functionality (Hall and Helmers, 2010). Therefore, the efficiency gains from formal sustainability technology markets may limit developing countries access to external technological advances through informal channels such as reverse engineering and skilled labor mobility. Under these circumstances, the impact of strong IPR protection on environmental innovation is ambiguous and still needs further exploration.

Cross country studies of national environmental innovation systems: Brazil, India, and China (BIC)

An earlier study by Walz (2009; 2010) compares the relative strength of each one of the BRIC countries in relation to their sustainability-orientated innovation systems (SoIS). Although his data (2000–4) does not reflect recent developments, it provides useful information about the NIS of Brazil, India, and China over that period. Table 6.8 summarizes his arguments and findings. Among the three countries, India possessed the best NIS framework in terms of a well-established legal framework and formal mechanisms for coordination. The focus of China's NIS is oriented to support general manufacturing and trade whereas the innovation system in Brazil was established with a focus on water and transportation; in that sense, Brazil is moving faster toward the creation of a SoIS. During 2000–4, none of these 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 that has earmarked R&D funds, for the energy, water, and transport sectors.²⁰ With respect to FDI attractiveness, the development of IP rights and the volume of exports of sustainability technology products, China had achieved remarkable progress due to its high level of technological absorptive capacity, while Brazil and India were relatively moving slowly. Finally, in India and Brazil, there is an increasing shortage of young scientists representing a large barrier for the development of public research in general and sustainable R&D in particular.

Looking at the BIC countries now, there has been a dramatic growth of green technology and improved conditions for the development of a green economy. India's wind turbine exports for example have increased tremendously. 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. Careful evaluation of the SoIS in BIC countries will be key to improve understanding of the role of NIS for the development of environmentally sustainable technology. In the last ten years, local companies in China and India

Table 6.8 BIC countries sustainability-oriented innovation systems compared, 2000–4*

	China	Brazil	India
Technological Specialization	Solar (PV) and other energy efficiencies	Raw materials, agriculture, and transportation	Wind turbines, biopolymers, and desalination
NIS 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 in 2000–2004	Biomass, biofuels (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	Exports play minor international importance
The role of sustainable technologies	Medium-important role of sustainable technologies. Weak in terms of future supply of energy and material resources. Large presence of FDI implies China possesses most absorptive capacity for technology.	Sustainable technologies play an important role. Energy supplied through hydro and other 27 renewable energies. Relatively strong technical capabilities in sustainable technologies. However, still lack of engineers to accelerate progress and for leapfrogging.	Sustainable technologies play a less important role despite best overall framework conditions. Legacy of weak environmental protection.

Note: *Entries summarized from Walz (2009). Technological Competencies in Sustainability Technologies in BRICS countries.

Source: Summarized from Walz (2009).

have successfully manufactured complete turbine systems in spite of the fact that they had no wind turbine production capacity in the past (Lewis, 2007).

Conclusion

The technological capacities in China and India have grown very fast in wind power, solar PV panels, and electric cars in a very short time. Such successful leapfrogging in environment-related green industries in emerging economies has provided encouraging examples on how developing countries can effectively catch up in the emergent green industries. Meanwhile, the development of green industries in emerging economies provides developing countries more alternative sources of technology. Green technologies in the South may make better use of the factors that the developing countries are abundant of and hence are more appropriate to their economic, social, and technical conditions. South-South collaboration for innovation and environmental technology transfer should be seriously taken into consideration and encouraged.

Along the development models of green technologies, there are some similarities between China and India. Development of green industries in China and India has made good use of international technology transfers based on indigenous innovation systems, although the importance of these mechanisms varies with the different levels of technology capabilities and development stage. Specifically, most of the green industries in both countries started from international technology transfers through licensing and joint venture with MNEs, while substantial effort have been put into the development of indigenous technological capabilities for the assimilation and adaptation of the transfer of technology. 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 merges and acquisitions based on their comparative advantages. The experiences of the emerging economies suggest that to accomplish such a catch-up process requires a combination of international technology transfer and indigenous innovation. Technology transfer is feasible, and its evidence has proven to be an entry point for developing countries, but indigenous innovation systems are also important.

Once the basic production technology has been acquired, developing countries should continue to catch up in the technological frontier based upon their own comparative advantages. Many of the developing countries are abundant in semi-skilled labor and relevant resources, such as sunshine and wind in Africa.

Once countries have acquired the basic production techniques through cross-border transfers, they will have a comparative advantage in producing low-cost outputs (as was the case in the solar PV panel manufacturing industry). Moreover, the export-market orientation of the solar PV industry in China and India also suggest that the international market can be a major driver of growth. Both China and India have cheap semi-skilled labor available for production; for African countries to effectively build up their capabilities in the green industries, education and training of semi-skilled labor will be crucial.

Due to the market failure (demand side) in driving the green technology development, government policy and incentives become essential. The experience of the emerging economies, China in particular, suggests that there is a crucial role of the State in initiating the transition toward the development of green technology development and in maintaining the momentum in the catch-up process. Given the public good nature of technology and the public bad nature of environment degradation, government-funded support through focused R&D programs has been crucial in promoting technological breakthroughs and hence the development of indigenous technological capabilities. Government programs focused on the diffusion of technology, such as the “Golden Sun” and “Ten Cities Thousand Cars” programs in China, has greatly facilitated technological diffusion and the development of other applications. Furthermore, the experience from China also demonstrates that the incorporation of environmentally sustainable technology is not the task of a single actor; it requires a set of complementary and coherent policies from various government bodies covering regulatory, financial, technological, and industrial policies, as well as being effective for the private sector. The synergy of multiple actors is important to promote and ensure a substantial change.

In sum, technological development and innovation are complex, path-dependent, and embedded within the socioeconomic fabric of each country (Saviotti, 2005). 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). Despite the ostensible benefits of technology transfer, “foreign technology may not fit the specific socioeconomic and technical context prevailing in the technology recipient” especially where there is large divergence of income between developed and developing countries (Fu et al., 2011). Our evidence 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 through FDI is inappropriate in a forward-thinking NIS framework. Rather, technological development is a process of acquiring, learning, and building local capabilities in which developing countries can feasibly contribute to the development process through adaptation by local firms.

Notes

- 1 Oxford Department of International Development, University of Oxford; Email: Xiaolan.fu@qeh.ox.ac.uk.
- 2 TMCD, Oxford Department of International Development, University of Oxford; Email: Jun.hou@qeh.ox.ac.uk. The author would like to thank the United Nations Department of Economic and Social Affairs for financial support and Tom Muchiri Kabuga for excellent research assistance.
- 3 As of 2011, China is only second to the European Union (fifteen countries) with 1.3 million full-time researchers. Data source: OECD statistics on science, technology and patent: <http://stats.oecd.org/>.
- 4 R&D intensity is defined as the ratio of total expenditures on R&D to GDP (in the country or region in question) in a given year. Data source: OECD statistics on science, technology and patent: <http://stats.oecd.org/>.
- 5 Data source: China Statistic Yearbook 2012. National Bureau of Statistics of the People's Republic of China: <http://data.stats.gov.cn>.
- 6 Adapted from MOST (2010).
- 7 The US\$1 billion project is planned to have three stages of development. It started building a 250 megawatt (MV) IGCC plant in Tianjin in 2009 and the plant was scheduled to begin operation by 2012. The second stage involves a smaller pilot plant, which uses both fuel cell and turbine to generate electricity while converting CO₂ for industrial use at the same time. The third stage, 400 megawatt power plant with carbon capture and storage (CCS) technology is scheduled for 2015–20.
- 8 In December 2007, 1 US\$ is equivalent to about 7.355 RMB. 1 US\$ = 6.616 RMB (December 2010); 1 US\$ = 6.312 RMB (December 2012).
- 9 R&D expenditures are the gross domestic expenditure on R&D (with PPP adjustment) from OECD statistics 2012. Data source: <http://stats.oecd.org/>
- 10 Data source: OECD Science, Technology and Patents statistics 2013: <http://stats.oecd.org/>
- 11 In value chain, horizontal linkages are longer-term cooperative arrangements among firms at the same level that involve interdependence, trust, and resource

- pooling in order to jointly accomplish common goal. Vertical linkages are the cooperative activities between firms at different levels of the value chain such as suppliers, customers, and clients.
- 12 Data source: China Statistic Yearbook 2012. National Bureau of Statistics of the People's Republic of China: <http://data.stats.gov.cn>.
 - 13 The idea of catching up (also sometimes known as “convergence”) is the hypothesis that fast economic growth in poor developing countries will eventually lead to converge to the level of per capita income of richer countries.
 - 14 The “Golden Sun” demonstration project was established in July 2009 and provided upfront subsidies for qualified demonstrative PV projects in the years 2009–11. The aim of the program was to promote renewable energy generation and create a domestic market for its solar cell and panel manufacturers.
 - 15 Technology push implies that a new invention is pushed through R&D, production, and sales functions onto the market without proper consideration of whether or not it satisfies a user need; Demand pull innovation implies a new invention has been developed by the R&D function in response to an identified market need (Martin, 1994).
 - 16 R&D intensity is calculated as the share of GDP in China, the value in 2006 is obtained from Science and Technology Statistic Yearbook 2007.
 - 17 Output indicators here are those proposed by the OECD (2008) as follows: high-technology employment, high-technology exports, sales shares of new-to-market/ firm products, and number of patents, trademarks, and designs.
 - 18 Research-based spin-offs are generally understood to be small, new technology-based firms whose intellectual capital originated in universities or other public research organizations.
 - 19 The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty signed by most of the world's nations about ten years ago. The Kyoto Protocol is an extension of this treaty and includes legally binding measures.
 - 20 The conclusion was drawn based on the study of Walz (2009). It meant to highlight and compare the earmarked R&D policy and programs in China, India, and Brazil during 2000–4. There are many other policies in these three countries to promote investment in R&D, which are not included in the comparison made in the text.

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