Lessons from China: building technological capabilities for low carbon technology transfer and development

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Abstract
Using case study analysis across three sectors in China (cement, electric vehicles and coal fired electricity generation) and theoretical insights from the innovation studies literature, this paper analyses the development of China's technological capabilities in low carbon technologies and the ways in which public policies have contributed to developing these capabilities. It finds that China has developed significant capabilities via a strategic approach. The paper's findings have significant implications for international policies designed to support low carbon technology transfer to developing countries and broader processes of low carbon technological change and development. Such policies should go beyond the traditional focus on the transfer of technology hardware to focus on the development of low carbon technological capabilities in developing country firms.

1. Introduction

Low carbon technology (LCT) transfer[1] to developing countries remains central to international climate change policy. It facilitates access to low carbon technologies and underpins lower carbon development pathways (Ockwell et al 2010). However, achieving it at a scale or speed commensurate with the climate change problem, or in ways that meet the needs of the poor, remains contentious. For industrialised countries, LCT transfer mitigates future greenhouse gas (GHG) emissions. For developing countries, it promises access to new technologies and accompanying economic development prospects – technology ownership having long been correlated with economic productivity (Ockwell and Mallett 2012). As Ockwell et al. (2010) argue, using LCT transfer to build new technological capabilities in developing countries is more likely to hasten uptake of LCTs (and GHG mitigation), driving processes of low carbon technological change whilst boosting economic productivity. Furthermore, the innovation studies literature shows that technological capability building through processes of technology transfer relies on incremental processes of knowledge transfer, as opposed to simply transferring technology hardware – the latter often characterising standard policy framings of the issue (Byrne et al. 2012).

One country that has been particularly successful in developing new capabilities in low carbon technologies is China. Whilst the Chinese economy remains highly carbon and energy intensive (IEA 2013), its recent development pathway has seen the rapid deployment and mass manufacture of some LCTs such as wind and solar power (Lewis 2012). In this paper we therefore seek to learn lessons from China for policy interventions in other developing countries. Based on empirical analysis of three Chinese sectors with significant GHG emissions (cement, coal fired electricity generation and fuel efficient vehicles), we ask: to what extent and in what ways has China developed its technological capabilities in these sectors; and what role has Chinese domestic policy, plus engagement with international policy initiatives, played in supporting this low carbon technological capability development? The paper begins by setting out its theoretical basis. It then articulates the methodology that was applied before setting out results and drawing out insights for policy and research.

2. Conceptual framework: Building capabilities for sustained technological change and development

Whilst monolithic ideas of "development" through innovation are questionable, the majority of nations and international organisations (e.g. multilateral development banks) promote the idea that economic development is best achieved by industrialisation that exploits technology and innovation to appropriate increasing returns, rather than relying on static comparative advantages from which only diminishing returns are likely (e.g. Reinert 2007). Achieving these increasing returns via LCTs therefore becomes a

[1] LCT transfer refers to the transfer and uptake of technologies within developing countries that are lower carbon than conventional (fossil based or less energy efficient) technologies, including renewable energy technologies (e.g. wind turbines) and more efficient end use technologies (e.g. LED lighting).

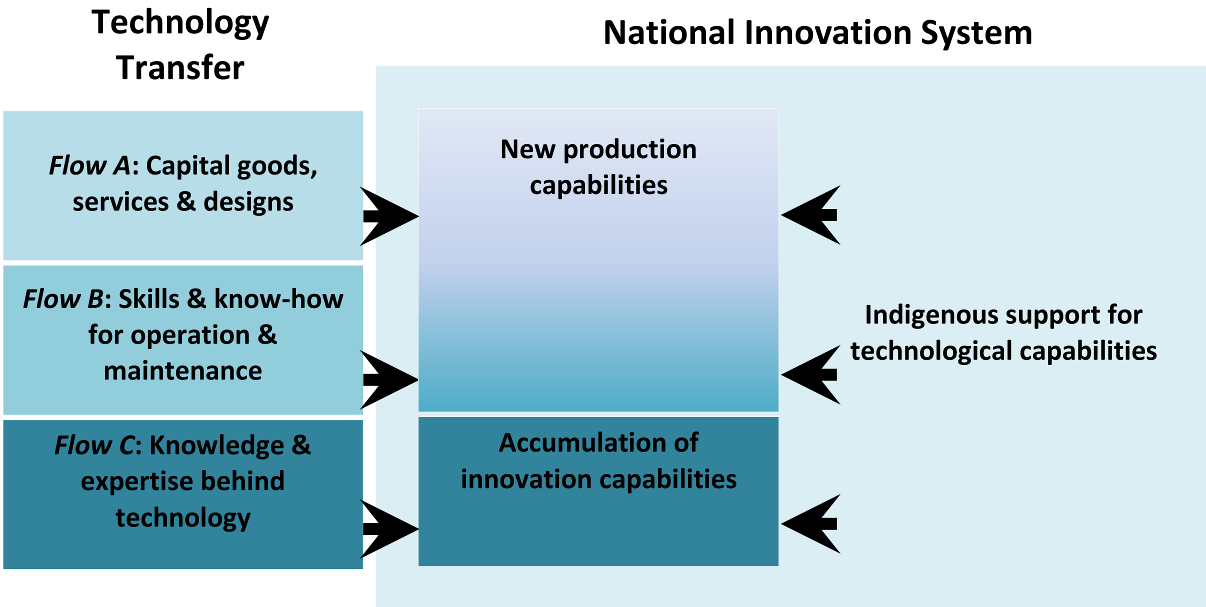
critical concern in the context of climate change. Empirically based insights from the innovation studies literature show how technological change in developing countries has been achieved by incrementally accumulating domestic technological capabilities. As well as increasing the adoption of LCTs, capability building arguably raises the potential for pursuing nationally driven (as opposed to internationally defined) development pathways.

A core insight from innovation studies is that technological change happens mainly through incremental development of "technological capabilities", understood as the capabilities of firms to manage technological change (see e.g. Kim, 1997; Figueiredo, 2001). Since concerns about climate change have driven interest in alternative development pathways characterised by widespread use of LCTs, this focus on building capabilities for broader technological change is particularly germane. Technological capabilities range in an increasingly sophisticated continuum from basic "production capabilities" through to advanced "innovation capabilities" (Bell and Pavitt 1993). Production capabilities relate to firms' abilities to operate and maintain existing products and processes, and in some cases to make basic efficiency improvements, whereas innovation capabilities allow them to make more significant changes or even develop new products and processes (Lall, 1992). Increasing levels of innovation capabilities across a whole industry or country therefore imply increasing levels of sophistication moving from changes in products and processes that might be new to a firm through to those that are new to a local or national industry or even new to the world (OECD, 2005). Note that innovation here might be incremental and adaptive rather than radical. The former incremental category is often more relevant in developing country contexts (Mani and Romijn, 2004). The more advanced the technological capabilities of a firm, industry or county, the more likely firms are to be able to absorb and further develop new products and processes that are more sophisticated and efficient.

Of fundamental importance to understanding how technology transfer can enhance technological capabilities is the emphasis this literature places on understanding technology as constituting qualitatively different types of knowledge. Hardware is simply the embodiment of this knowledge (Bell and Pavitt 1993). Bell (1990; 2012) breaks technology transfer into three different flows that contribute to different levels of technological capabilities in recipient firms (see Figure 1). Flow 'A' includes hardware – capital goods, capital services (e.g. design & engineering services) and ready-made designs and specifications. Type 'B' flows include skills, knowledge and tacit know-how for operating and maintaining such hardware. Flow C, however, consists of "...a bundle of many types of knowledge and skills for adapting, improving and further developing the technology initially acquired" (Bell 2012: 24): i.e. it is the knowledge necessary to manage technical change. Both flows 'A' and 'B' add to or improve the production capabilities of a firm or economy, but do little or nothing for developing the skills needed for generating new products or processes. Flows of type 'C', however, are those that help to develop innovation capabilities (Bell 2009). In the context of lower carbon development pathways, type C flows and their impact on developing countries' innovation capabilities are therefore of critical concern.

However, technology transfer processes take place within broader national and international innovation systems that can be technological, sectoral or national (e.g. Edquist 2005). For developing countries, national systems are particularly important, and are defined as the "... network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman 1987: 1). The role of innovation systems is implicitly recognised in many definitions of technological capabilities, e.g. by the Bell and Pavitt (1993: 163) definition of them as constituting "the resources needed to generate and manage technical change, including skills, knowledge and experience, and institutional structures and linkages". Hence, in Figure 1 Bell's three flows are conceptualised as complementing national innovation systems that provide indigenous support for technological capability development. Such innovation systems are often weak in developing countries. This emphasises a strategic role for national and international policy in helping to build these systems, and to support the networks, linkages and public institutions that are critical to their successful development and functioning. Although it takes time and resources to develop new innovation systems (Watson et al 2011), there are examples where "systems thinking" by governments have led to significant advances in national technological capabilities in different LCTs, e.g. the Chinese wind industry (Lewis 2012), the Danish wind industry, Brazilian ethanol, and renewables in Germany (Jacobsson and Bergek 2004).

Figure 1: Technology transfer and indigenous innovation



Source: Authors based on Bell (1990)

To apply these insights from the literature, it is necessary to define the analytical categories through which capability building might be assessed. A critical area for analysis is the process of importing foreign technologies, how the resulting interactions between indigenous and international firms contributes to low carbon technological capabilities in developing countries, and how policy and practice can be oriented to foster this (Hansen and Ockwell, in review). Although Bell (2012) argues that the definition of what counts as innovation capabilities is, at best, fuzzy, interactions between technology suppliers and recipients can be identified that contribute to capability building in developing country firms. The literature includes several categorisations of technological capabilities along the productive to innovative continuum (e.g. Lall 1992, Ariffin 2010, Figueiredo 2001).

This literature provides a useful basis upon which to: assess the technological capabilities within specific sectors in developing countries; attend to the emerging dynamics between indigenous and international firms; and to interrogate the processes through which indigenous firms have advanced their technological capabilities. These are articulated in the following questions guiding the analysis in this paper:

1. How advanced is the equipment being used by indigenous firms relative to leading technological companies?
2. To what extent are indigenous firms engaged in equipment manufacture? How technologically advanced is locally manufactured equipment? To what extent is the equipment based on indigenously produced components as opposed to imported components? Are there any gaps in indigenous firms' ability to manufacture technologies in-country? Is the market for indigenously produced equipment national or international?
3. To what extent were foreign firms involved in the process of enhancing indigenous capabilities?

By answering these questions we are also able to explore the contribution of national and international policies to fostering technological capability development in China and the lessons for other countries.

3. Methodology

We apply the questions derived from the conceptual framework to case study based data collected between February 2010 and April 2011 (Watson et al. 2011). Three sectors were chosen for analysis based on their significance in terms of GHG emissions and mitigation potential via adoption and development of more advanced technologies. These are:

1. Energy efficiency in the cement industry: China is the world leader in cement production, accounting for almost half world production (Hasanbeigi et al. 2012). Using the most efficient

technological hardware and optimised processes can significantly reduce primary energy consumption (Worrell and Galitsky 2008) Waste heat can also be recycled and/or recovered for power generation (Müller and Harnisch 2008).

2. Efficient coal fired power generation: 80% of China's power is from coal and coal will likely remain significant decades. Improving average efficiency of coal-fired power plants could therefore significantly reduce national emissions.

3. Electric vehicles: China is the world's number one in both production and sales of automobiles, each accounting for about 22 million units in 2013 (CAAM 2014a). The Chinese government wants to reduce transport oil demand through promotion of 'new-energy' vehicles, including hybrid and electric vehicles (HEVs) (Ouyang 2006; Wan 2008; IEA 2013). In principle, HEVs could be three times more efficient and have lower carbon emissions than internal combustion engine (ICE) vehicles (Zhang et al. 2008), although this depends on the fuel used to generate electricity. This is problematic for China since 80% of electricity comes from coal.

The choice also facilitates analysis across different stages of technological development, different markets (capital and consumer goods) and different parts of the energy system (electricity generation, industry and transport). They include near market technologies (improvements in efficiency in the cement industry and more efficient technologies for coal-fired power) but also technologies at an earlier stage of demonstration and deployment (electric vehicles).

Data was collected via semi-structured interviews and analysis of grey and published literature, including on relevant national and international policies. 29 interviews were conducted with specialists in China from industry, government and research institutions, and representatives of national and international organisations that have worked with Chinese firms and research institutes (see online Appendix A). Interviews were structured using sector-specific questions related to the conceptual framework, as well as questions relating to national and international policies (see online Appendix B). The analysis and emerging conclusions were developed further at a workshop in Beijing, attended by policy makers from several Ministries, academics and industry stakeholders.

4. Results and discussion

4.1 How advanced is the equipment being used by indigenous firms relative to leading technological companies?

The level of technology in use in China varies across the three sectors. Energy efficiency in cement production has steadily improved in China, although there remains a significant gap between international and Chinese average efficiencies. Rapid adoption of advanced New Suspension Pre-Heater kiln (NSP) technology has been an important driver of improvements, with over 1000 units now in operation. Some of the 'efficiency gap' can be explained by significant numbers of small and inefficient kilns still in operation (Müller and Harnisch 2008). By 2007, the energy-intensity of cement production in China had fallen to 158 kgce/t (kilograms coal equivalent per tonne) but was significantly higher than the international advanced level of 127 kgce/t (Ohshita and Price 2011: 53). More recently, it was announced that the energy intensity of cement production fell 16% during the 11th five year plan period (2005-2010). During the 12th five-year plan, further progress has been made. Average energy intensity in China is now comparable with the international average (IEA 2013).

Interest from China in gaining supercritical (SC) and ultra-supercritical (USC) coal-fired power plant technologies is long-standing and localising the technology was designated a Key National Programme in the 1990s (Tan 2010). In 2009, there were 132 SC and USC units in operation, with new units of increasing capacity (Li 2012: 139). In 2010, it was expected that SC and USC power plants would account for over 40% of new thermal units in China (Chen and Xu 2010). For IGCC technology, Chinese firms have a long history in coal gasification for chemicals and fertiliser production rather than power generation. The first IGCC plant in China (GreenGen) was commissioned in late 2012.

Chinese firms have developed large-scale production capacity and significant technological capabilities in ICE vehicles, but are not yet able to serve the high-end (more technologically advanced) market which is still dominated by foreign firms. Reasons include inconsistent quality of production and risk-aversion (UKTI and SMMT 2010). It appears the emphasis is on a cost-conscious mass market where quality matters less, implying less of a market for more advanced vehicles, including HEVs. This acts as a constraint on manufacturers' ability to adapt capabilities to develop and commercialise advanced technologies like HEVs. Design and manufacturing demands of HEVs appear more complex – and costly – than for traditional ICE vehicles. Nevertheless, some Chinese firms have established capabilities in HEVs through the manufacture of component parts, namely electric motors and batteries (see below).

4.2 To what extent are indigenous firms engaged in equipment manufacture?

We found Chinese firms in the cement industry were able to produce most manufacturing equipment locally. Some have built cement production facilities abroad, beginning as early as 1992. The first plant exported was rated at 700 tpd (tonnes per day of cement). This had risen to 10,000 tpd by 2005. At the time of our fieldwork, five firms were able to construct 10,000 tpd production lines and more than 300 could construct 5000 tpd facilities. However, some technologies and equipment are still imported including vertical mills, grate coolers, precision weighing machines and x-ray diffraction instruments. Some interviewees also reported difficulties training staff in new energy efficiency technologies, in integrating these technologies into production systems, and barriers to accessing Intellectual Property Rights (IPRs).

In the coal-fired power sector, there are several Chinese firms that can now build SC and USC plants. However, there is still a significant gap between their capabilities and the international frontier. Manufacturing companies like Shanghai, Harbin and Dongfang have not mastered core design software. There are also difficulties in manufacturing the high temperature components locally, and specialised steel materials need to be imported.

Advances in Chinese coal gasification technology have also been significant in recent years. The Thermal Power Research Institute in Xian developed a design which is being used in China's first full scale IGCC plant (GreenGen). The first phase of GreenGen was commissioned in late 2012, and was supported by the Chinese government's '863' R&D programme. There are plans to fit carbon capture and storage during a later project phase. The gasification technology for GreenGen has been specified for the planned Good Spring IGCC in the USA. The gasifier is, however, only one component of an IGCC plant. Another critical technology is the advanced industrial gas turbine that burns the syngas produced by the gasifier. Chinese capabilities here are considerably weaker. Very few leading suppliers of advanced industrial gas turbines exist worldwide, led by GE, Siemens and Mitsubishi. Chinese turbine companies have formed collaborations with these firms, but they are a long way from having independent capabilities (Liu et al. 2008; interviews). Within these collaborations, cutting edge technologies and knowledge embodied in high tech parts (e.g. first stage turbine blades) are not shared. This controlled approach to knowledge sharing in return for market access has been standard practice for leading gas turbine manufacturers for decades (Watson 1997).

With electric motor manufacture for HEVs, large investments have been made to increase production capacity. Capacity in 2010 was estimated to be 272,000 electric motor sets – up from 73,000 a year earlier (Ouyang 2010). With batteries, most attention is focused on Lithium-ion (Li-ion) technologies. One battery firm in Shenzhen, Build Your Own Dreams (BYD), become internationally famous by entering the automotive industry with plans for HEV models on an accelerated timescale – although these plans have not yet been fully realised. While Chinese firms can manufacture batteries, they have not mastered parts of the process, e.g. they still import a critical membrane needed to prevent overheating. Capabilities are also weak in battery management systems, with Chinese firms still dependent on foreign suppliers. Similarly, some key components for electronic control systems for HEVs have to be imported. Finally, the development of charging infrastructure in China is at an early stage in some cities (UKTI and SMMT 2010), although there are plans to increase coverage.

4.3 To what extent were foreign firms involved in the process of enhancing indigenous capabilities?

In what is a familiar pattern across our case studies, Chinese firms in the cement industry have developed their technological capabilities through a sequence of increasingly sophisticated and larger-scale activities. This aligns with Bell's (1997: 75) assertion that "… dynamic technological capabilities are cumulatively built 'upwards' from simpler to more complex design, engineering and managerial competences, not 'downwards' from R & D." The process of advancing technological capabilities in the cement industry started in the late 1970s with the installation of a 700 tpd NSP line supplied by a Japanese firm. Through a series of incremental steps following this installation, Chinese firms acquired the capabilities to design and develop NSP kilns. In the early 1990s, the first joint ventures were established, beginning with a 4000 tpd NSP line in 1992 under Dalian Huaneng-Onoda Cement Company. Others followed, including Yantai Mitsubishi, Daewoo Sishui and Qinhuangdao Asano. However, widespread diffusion of NSP cement kilns did not take place until the mid-2000s. During interviews, a number of Chinese firms said that they undertake joint R&D with local research institutes and universities. Such local collaboration is favoured because the technologies are cheaper than foreign-made equipment, after-sales service is more convenient, further improvements are easier to implement, and there is a desire to support local industry. As one interviewee put it, 'domestic techniques fit the Chinese cement development better'.

Normal practice in the SC and USC coal generation sector is for manufacturers to collaborate with regional design institutions within China on power plant designs. In addition, they often need to work with leading foreign companies like Siemens, Hitachi and Alstom to design new plants. With respect to gasifiers for IGCC plants, there has been a strategy of acquiring licenses from leading international firms such as Shell since the 1990s (Watson et al. 1998). However, as noted above, this strategy has been complemented by the development of indigenous gasifier designs. Similarly, international partnerships have been formed to partly manufacture advanced gas turbines in China.

Chinese firms are conducting significant R&D to build capabilities in HEVs, but this has not yet had commercial impacts. This includes some joint R&D with foreign firms who have been attracted by prospects of accessing China's rapidly growing private vehicles market, e.g. Shanghai Automotive Industries Corporation (SAIC) bought UK capabilities, establishing an R&D base in the UK. They have been using this for two years now to train Chinese engineers. Chang'An Automobile Company has also invested in a UK R&D base, recently establishing ties with the University of Nottingham.

Several international collaborative activities are underway on electric vehicles in China. One of the most prominent is a US-China co-operative programme aiming to develop standards, a technology roadmap and implement joint demonstration projects in a number of cities (White House 2009). Complementing this, there are partnerships being built between Chinese and US firms (Levi et al. 2010). According to interviewees, some Chinese partners argue the partnerships lack depth, whilst some international firms are wary about potential loss of technological leadership (Levi et al. 2010).

4.4 What was the role of policy (domestic and international) in fostering capability development and functioning innovation systems?

Across all the case studies, a significant driver of improving technological capabilities in Chinese firms has been the implementation of domestic policy frameworks, complemented by strategic engagement with international policy initiatives. We chart these efforts across the three case study sectors below before drawing some conclusions.

Policy frameworks for energy efficiency in the cement industry

The energy intensity targets within the 11^{th} and 12^{th} Five Year Plans have been crucial policy drivers of energy efficiency in the cement industry. According to Vice Minister of the NDRC Xie Zhenhua, the 11^{th} Five Year Plan led to a reduction in energy intensity by 16% between 2005 and 2010. The target was accompanied by the 'Top 1000 Energy Consuming Enterprises Programme' – launched by the NDRC in 2006 (Wang and Watson 2009) aiming to reduce energy intensity within firms accounting for 33% of China's final energy consumption. Projected savings were 100 mtce by 2010 (saving 260 mtCO2 vs. 'business as usual'). Cement is one of nine sectors covered by the Programme (Price et al. 2008). Targets were agreed with individual provinces then translated into firm-level agreements. Provincial officials' performance evaluations were adjusted to account for relative success in meeting targets. Firms were required to develop goals and plans, and funds were provided for energy efficiency projects specified in the plans.

Funding from Chinese central government for energy efficiency and pollution abatement was 23.5bn Yuan (over £2bn) in 2007 and 27bn Yuan (£2.5bn) in 2008 (Ohshita and Price 2011). The 2008 figure included 4bn Yuan (£400m) for phasing out small inefficient plants – a policy strengthened by surcharges on electricity tariffs. A reduction in export tax rebates for energy intensive products provided further financial incentives. Interviewees within the Chinese cement industry said that energy efficiency incentives were significant. They had accessed grants from energy saving project funds, subsidised loans and taken advantage of tax breaks. However, they also stated more could be done to accelerate adoption of more efficient technologies.

Evaluation of the Programme has been difficult due to poor data (Price et al. 2008). The Lawrence Berkeley National Laboratory found it was impossible to validate stated energy efficiency gains because of the variety of cement technologies in use. Some progress has been made closing smaller, less efficient plants. E.g. of the 250 mt of cement capacity earmarked for closure within the 11th Five Year Plan, 140 mt were closed between 2006-8 (Ohshita and Price 2011). Since then, Wang et al. (2012) note that the share of NSP kilns increased from 50% in 2006 to 81% in 2010. However, one interviewee suggested national closure programmes are often only partially successful, as local officials sometimes maintain operation of 'closed' plants for economic and employment reasons.

Despite these data inaccuracies, it is clear that the Chinese government put in place ambitious measures to incentivise more energy efficient cement production technologies. This was seen by many interviewees as a key driver of the advances China has made in developing its indigenous technological capabilities. This is reflected in China's strategic engagement with the Clean Development Mechanism (CDM) to lever funding for energy efficiency initiatives in the cement industry (e.g. Yan et al. 2009). There was a deliberate effort to build China's administrative capabilities, often with support from international donors, to enable it to use the CDM to support national policy goals, as opposed to the CDM being applied on a less coordinated project by project basis (Schroeder 2009). As of the end of January 2014, China had 3,730 registered projects out of a total of 7,426 in the CDM. Unsurprisingly, China has received more CDM project investment than any other developing country – with total investment of more than $207bn. The total emissions reductions attributed to China's projects amounted to 594 mtCO2e per year.

Almost 50% of China's energy efficiency CDM projects (104 out of 217 projects) involve cement plants, making it strategically important at a sectoral level (Stua, 2013). Whilst many projects do not claim technology transfer, a number of Project Design Documents refer to Japanese hardware being employed. Beyond the cement sector, approximately 34% of 3294 registered and proposed CDM projects in China analysed by Seres et al. (2009) claimed to involve technology transfer. Caution is required, however, as it is not possible ex ante to know whether projects will actually deliver technology transfer, or what their impacts will be on technological capabilities in recipient firms.

Policy frameworks for efficient coal-fired power

Domestic policy incentives have aimed to improve coal-fired power generation efficiency for many years. The Top 1000 Energy Consuming Enterprises Programme under the 11th Five Year Plan also covered the power sector. According to the Chinese government, 72GW of small plant capacity had been closed by the end of the Five Year Plan period (Wen Jiabao 2011). The share of coal-fired power generation capacity with unit sizes over 300MW rose from 47% to 69% from 2005-10.

Concurrent with this closure programme, the government increased emphasis on economic incentives for improved power plant efficiency. It reduced prices paid to power plants with capacities of less than 50MW, and some of 100-200MW (Andrews-Speed 2009). New rules were trialled to reinforce the incentive for the most efficient plants to operate. However, the government was slow to remove controls on final electricity prices (IEA 2006). Historically, prices to end consumers were kept artificially low, which impacted on power company finances. According to China's National Energy Administration, 43% of China's coal-fired power plants operated at a loss[2] in 2010.

Chinese government policy has played a strategic role in directing acquisition, innovation and deployment of more efficient technologies. For supercritical technology, acquisition processes started with operation of China's first supercritical units in 1992, sourced from leading international firms: ABB for boilers and GE for steam turbines (Tan 2010). The government funded an iterative process of assessment, collaborative R&D and reverse engineering so that Chinese firms developed independent capabilities in this technology. The first Chinese manufactured 600MW supercritical unit entered service in Henan province in 2004 (Chen and Xu 2010).

Acquisition of more efficient USC technology followed in 2000 with support from the 863 and 973 R&D programmes. China's first USC unit entered service in 2007 in Yuhuan, part-funded by the Shanghai government (Tan 2010; Tan et al. 2010). This included collaborations between Chinese and international firms for the main components. Boilers were co-supplied by Mitsubishi Heavy Industries and the Harbin Boiler Company. Turbines were manufactured by Shanghai Electric and Siemens (to a Siemens design).

The 863 programme also played a particularly important role by supporting coal gasification research at the Thermal Power Research Institute (TPRI) in Xian (Osnos 2009). This led to the gasification technology for GreenGen and licensed to the US (see above). According to some reports, this was chosen over competing technologies from Shell and GE due to its higher efficiency (Osnos 2009). Importantly though, as noted above, other IGCC plant components (most notably the gas turbines) are not being sourced or licensed from China.

Bi- and multilateral international policy initiatives have also played a role. One example is the Global Environment Facility (GEF). Since its creation in the early 1990s, the GEF provided modest funding to projects in China totalling less than $500m, including the "China energy efficient boiler project" which had some success in subsidising licenses to Chinese firms. It was a difficult project, and only resulted in licences from 'second tier' international suppliers (Birner and Martinot 2005). These 'second tier' firms believed they would gain more from selling licenses than by operating directly in the Chinese market – the opposite view to leading international boiler firms, demonstrating how difficult it can be to offer licensing terms that are attractive to leading players. Another example is support for SC and IGCC technology in China by the Asian Development Bank (Watson et al. 1998). The Bank financed an early supercritical plant and was involved in funding feasibility studies for an IGCC plant in Yantai during the late 1990s. Plans for this plant suffered from repeated delays, and it was not constructed. More recently, the ADB provided a loan of $135m to the GreenGen IGCC plant.

Policy frameworks for electric vehicles

The government is providing incentives for innovation in electric vehicles in China in two ways. First through financial support since 2002 for some of the R&D activities mentioned above. 860 million Yuan (£80m) was spent from 2002-2006 on electric, hybrid and fuel cell vehicles under the "863 Programme" (Tan 2010). A follow-on programme since 2006 spent a further 1.1 billion Yuan (£105m). One result of this State-sponsored R&D has been China becoming the second most successful country for HEV patents, suggesting significant advances in Chinese capabilities. In an R&D intensive industry, IPRs can be seen as particularly important. However, according to one analysis, this patent success may have become a source of paralysis in the local market (UKTI and SMMT 2010). This argues Chinese firms are reluctant to release their HEVs into the local market because they fear competitors will imitate them – a similar concern to that expressed by some international firms regarding reverse engineering by Chinese firms.

The second area of policy incentives is through demonstration and deployment support programmes. A programme was introduced to deploy 60,000 'new energy vehicles' (including HEVs and electric vehicles) in 13 cities, and a plan that these should have accounted for 5% of total car sales in 2011, i.e. more than

[2] See http://www.prlog.org/11349430-chinas-power-plants-operate-at-loss-cost-of-coal-and-energy-efficiency-blamed.html

600,000 vehicles. It is unlikely this target was met given that CAAM (2014b) claim sales of all new energy vehicles reached 17,642 units in 2013. Looking ahead, it is hoped that 0.5-1 million new energy vehicles will have been sold by 2015 (Levi et al. 2010). Within this the government intends to spend 20 billion Yuan (£1.9bn) on promotion, manufacture and sale of electric vehicles to underpin a new 'Ten Cities, One Thousand Vehicles' plan, demonstrating 1,000 new EVs each year. One report quoted a higher figure for government support for electric vehicles of 115 billion Yuan (£10.9bn) from 2011-20 (Accenture 2011), including funding for R&D, commercialisation, component manufacture and electricity infrastructure. It notes consumers could receive a subsidy of 50,000 Yuan (£4,700) to purchase plug-in HEVs, and slightly more for pure electric vehicles. It also highlights electricity charging infrastructure as a potential bottleneck, because as recently as 2009, '... there were only a handful of public charging stations located in a few cities, such as Shenzhen' (Accenture 2011: 61). However, as the analysis above demonstrates, these policy initiatives seem to have had little impact to date in terms of Chinese vehicle manufacturers' technological capabilities in either HEVs of EVs.

5. Conclusions: implications for research and policy

The empirical analysis above allows conclusions to be drawn that build on the insights from the innovation studies literature in Section 2. As Breznitz and Murphree argue in their book about the Chinese IT industry (2011), China's technological capabilities in LCTs are not as advanced as is often assumed, though Chinese firms are playing an increasingly important global role. Gaps exist relative to the technological frontier that is still dominated by companies from OECD countries. For some advanced technologies (e.g. electric vehicles and gas turbines for IGCC power plants), barriers to entry for Chinese firms remain high due to gaps in knowledge and capabilities and/or a lack of affordable access to IPRs. As might be expected, Chinese technological capabilities are stronger in more near-market technologies, such as supercritical coal fired plants. But even in firms focussing on these technologies, there is still some dependency on licenses from international firms. Whilst such licenses are affordable, their continuing presence indicates that fully independent innovation by these Chinese firms is some way off.

Despite these gaps in capabilities, however, China is making rapid advancements in developing its indigenous technological capabilities across all of the LCTs analysed. A number of observations can be made to inform policy in other developing counties. First, rather than technological capability building being driven "downwards" by efforts around more complex, R&D led interventions, it tends instead to have been driven "upwards" from technological learning at the simpler, market-oriented level. In cases where policy has focused on R&D driven interventions to build capabilities (e.g. in EVs and HEVs), there has been less success in the development of Chinese firms' technological capabilities. Second, where advances have been made by Chinese firms this has mostly been achieved via relationships with foreign firms to facilitate knowledge flows and learning. In several cases this was achieved by relationships with second-tier companies rather than those at the technological frontier. Initial advances typically developed production capabilities in Chinese firms. These led to learning and incremental change, and the development of innovation capabilities.

Third, Chinese domestic policy has played a key role in incentivising firms' engagement with LCTs. A combination of market support, regulations and R&D support has been crucial, creating a more systemic approach to LCT transfer and development of increasingly advanced technological capabilities. Fourth, the Chinese government has taken a strategic approach to leveraging opportunities for funding and capability building via international climate change policy. This has been more effective in building indigenous capabilities than the traditional international approach of hardware transfer on a project by project basis. These findings provide important lessons for climate policy in other developing countries, as well as for international policy interventions. By focussing on 'bottom up' processes of learning and technological capability development, climate policy can achieve GHG mitigation whilst promoting economic development in developing countries.