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Technological Learning, Energy Efficiency, and CO_2 Emissions in China's Energy Intensive Industries

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Abstract

Since the onset of economic reforms in 1978, China has been remarkably successful in reducing the carbon dioxide intensities of gross domestic product and industrial production. Most analysts correctly attribute the rapid decline in the carbon dioxide intensity of industrial production to rising energy prices, increased openness to trade and investment, increased competition, and technological change. China's industrial and technology policies also have contributed to lower carbon dioxide intensities, by transforming industrial structure and improving enterprise level technological capabilities. Case studies of four energy intensive industries—aluminum, cement, iron and steel, and paper—show how the changes have put these industries on substantially lower carbon dioxide emissions trajectories. Although the changes have not led to absolute declines in carbon dioxide emissions, they have substantially weakened the link between industry growth and carbon dioxide emissions.

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Technological Learning, Energy Efficiency, and CO_2 Emissions in China's Energy Intensive Industries[1]

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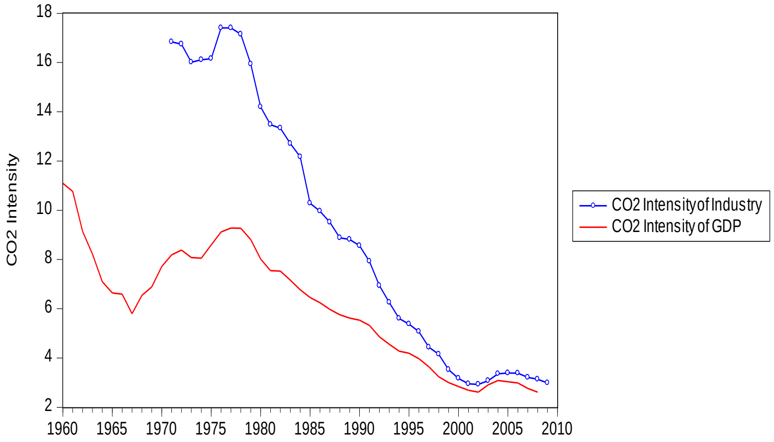
I. Introduction

A. Background

Since the onset of economic reforms in 1978, China has been remarkably successful in reducing the CO_2 intensity of GDP and industrial production (figure 1) despite a rising share of energy intensive industries in industrial value added (Fisher-Vanden et. al 2004) and a rising CO_2 intensity of fuel use (figure 2). Most analysts attribute the rapid decline in the CO_2 intensity of industry to rising energy prices, increased openness to trade and investment, and increased competition.[1] Given the large inefficiencies in energy use in China's industrial enterprises at the beginning of China's reform program, there is little doubt that these policies presented enterprises with the possibilities of reaping large scale energy savings. But, as we argue, actually realizing those savings has been highly dependent on policies and institutions that encouraged enterprises to build their technological capabilities.[2] Hu et al. (2005) demonstrate that success in technology transfer, and hence in building more robust technological capabilities, in a large sample of Chinese enterprises is conditional on own enterprise investments in technological upgrading. We study how China's industrial and technology policies affecting four energy intensive industries—aluminum, cement, iron and steel, and paper—have transformed the industrial structure within these industries and technological capabilities within enterprises in these industries, and how both types of changes have contributed to lower CO_2 intensities,

Figure 1
China
CO2 Intensity of GDP and Industry
(Kg per Real $ of GDP and Industry)



Source: WDI Online, 2012 and IEA Data Services Online, 2012

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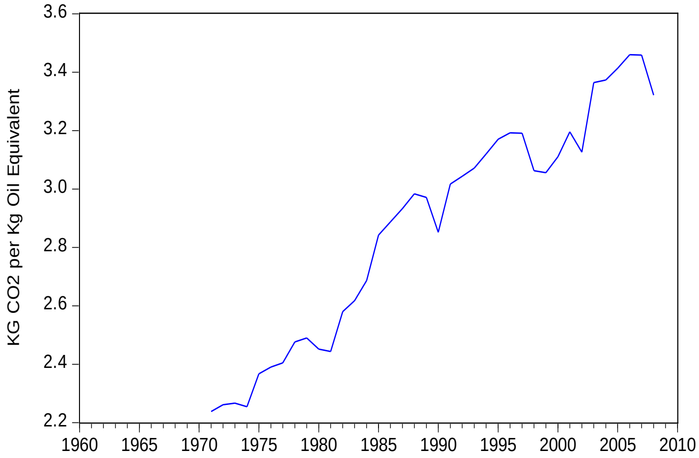
[1] Most analysts also attribute some of the decline in the CO_2 intensity of GDP to shifts in the composition of GDP away from energy intensive industries.

[2] For an example of firms in a country (Indonesia) adopting state of the art technology in an energy intensive industry (cement), yet failing to capture win-win environmental (or energy) technique effects because the country lacks a viable technology policy see Rock (2012).

putting each of these industries on substantially lower CO_2 emissions trajectories. While these changes have not led to absolute declines in CO_2 emissions, they have substantially weakened the link between industry growth and those emissions.

Figure 2
China
CO2 Intensity of Energy Consumption
(Kg of CO2 per Kg of Oil Equivalent)



Source: WDI Online, 2012

We focus on China because it is a major contributor to global CO_2 emissions and because changes over time in its industrial and technology policies offer many opportunities to observe impacts on energy intensity and CO_2 emissions. [3] We focus on the abovementioned four industries in China because they are the building blocks of China's rapid urban[4] and industrial[5] transformation; because they currently account for nearly 60% of CO_2 emissions from industry (figure 3); and because this trend is likely to continue as China works its way through further urban and industrial transformations.[6] The win-win improvements in CO_2 intensity in these industries, illustrating the environmental technique effects of China's high speed technological catch-up industrial development strategy, highlights opportunities to reduce emissions growth even in the absence of more explicit policies to reduce CO_2 emissions. [7]

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[3] China's share in global CO_2 emissions from fossil fuels has risen from 8% in 1978 to 24% in 2009. Its incremental emissions accounted 65.7% of incremental global emissions between 1971 and 2000 and 71.8% between 2001 and 2009 (IEA Online Data Services, 2012).

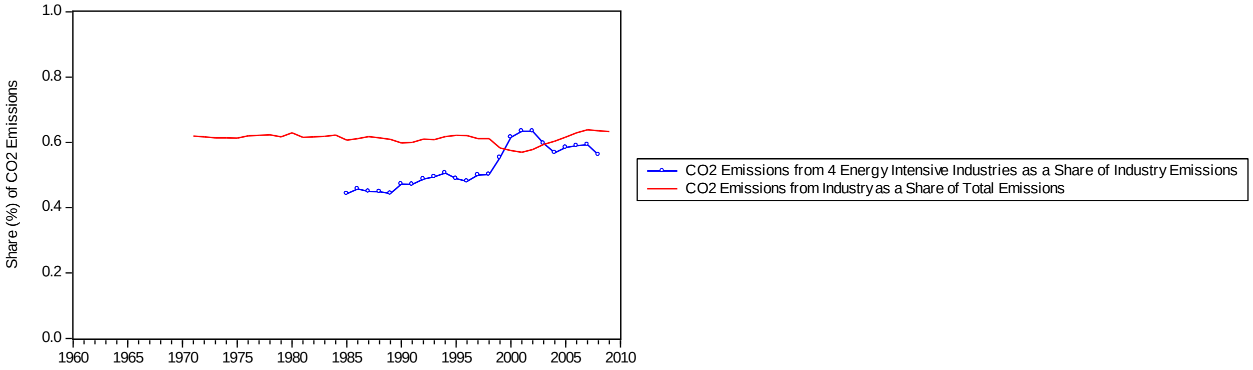
[4] China's urban population increased 3.2 times between 1978 and 2009 as it grew from 178.9 million in 1978 to 585.8 million in 2009 (WDI 2012). At the same time the number of people living in cities with populations greater than 1 million increased from 71.3 million in 1978 to 233.9 million in 2009 (WDI 2012)

[5] Industrial output grew by 9.8% per year between 1979 and 2009 such that real value added in industry in 2009 was 17 times larger than in 1979 (1.36 trillion RMB versus 79.9 billion RMB, WDI 2012).

[6] China's incremental emissions accounted 65.7% of incremental global emissions between 1971 and 2000 and 71.8% between 2001 and 2009 (IEA Online Data Services, 2012).

[7] However, we are not suggesting that industrial and technology policies can be an alternative to more explicit emission limitation measures for reducing longer-term GHG emissions.

Figure 3
China
Industry Share of CO2 Emissions
and Four Energy Intensive Industries Share
of Industry CO2 Emissions



Source: IEA Online Data Services, 2012

Along the way, we argue that China's success in reducing the CO_2 intensity of industrial production has not been easy or without cost. Following adoption of a new industrial policy to "grasp the large, let go the small" (Sutherland 2003: 2 and 10), attempts to create a small number of technologically sophisticated national champion enterprises that can save energy and dominate in each of these industries have not been entirely successful.[8] Even where successful, some (World Bank 2012) have worried about the economic costs associated with the anti-competitive effects of this strategy. Others (Allen et al 2008) argue that bank loans to China's state-owned enterprises, including those to national champions, undermine an efficient allocation of capital thereby imposing additional significant economic losses on the Chinese economy. Finally, given China's highly fragmented industrial structure (Oh 2012: 5) and its highly decentralized industrial governance system, it should not be surprising that the central government has not been entirely successful in "letting go the small" by closing nearly all of the small scale, energy inefficient, and polluting facilities in these industries. Yet despite these problems, as we show, China has been quite successful in reducing the CO_2 intensity of production in the industries we study.

Our argument proceeds in four steps. Because improving energy efficiency in particular enterprises and industries depends on the ability of enterprises in particular industries to successfully adopt the minor process changes and the major technological changes that enable them to reap environmental technique effects, the analytical frame of technological learning/upgrading is at the center of our analysis. After delineating the major elements of such an analytical framework, we provide a historical overview of the evolution of industrial structure and technological capabilities in these four energy intensive industries in China. The focus here is on the evolution of policies and institutions affecting these industries that ultimately culminated in high speed technological catch-up in enterprises in these industries and by their domestic capital goods and services suppliers.

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[8] See discussion in the appendix.

We then turn to several enterprise-level case studies in these industries to document the link between enterprise level investments in technological learning and CO_2 intensity. We also present some industry wide estimates of actual declines in CO_2 intensities and we relate these to aggregate industry wide CO_2 emissions reduction against a business as usual scenario.[9] We close by considering what broader lessons can be learned from China's experience.

B. The Importance of Technological Upgrading

Because improving energy efficiency in particular enterprises and industries depends on the ability of enterprises within particular industries to successfully adopt the minor process changes[10] and major technological changes[11] that enable them to reap environmental technique effects (Copeland and Taylor 2003), the analytical framework of technological learning/upgrading (Nelson 2005, Kim 1997, Hobday 1995, Bell and Pavitt 1992, Lall 1992, Dahlman et al 1987, and Westphal 1981) is at the center of our analysis. The literature on innovation and technological learning within enterprises shows that the introduction, diffusion, and consolidation of new processes and technologies in any industry are costly, difficult, and risky. Success depends on the existence of institutions and incentives that encourage firms to make costly and risky investments in learning. Because technological learning requires effort, trial and error, and gaining tacit experience with particular technologies, it is ultimately a task that only firms can undertake (Lall 1992: 166).[12]

The task of building technological capabilities in developing economies tends to be largely an imitative, rather than an innovative, process that requires enterprises to import and adapt already existing technologies, rather than engage in basic research or new product innovation. Innovative efforts often tend to focus as much or more on business processes than on technological processes (like supply chain management), and the focus in both is on innovations that are new to that country or particular market, more than new to the world (Dutz et al. 2011). Developing country enterprises often start the process of importing and adapting technologies and processes with very limited technological capabilities, including limited capabilities to gain and learn from their neighbors and others. Because of this, they face a particularly daunting set of problems and choices. They must match their choice of acquired technology to local needs, conditions, and constraints (Dahlman et al. 1987: 762).

Once enterprises narrow their search to particular technologies, they must decide how to acquire all the elements—information, means, and understanding—associated with their technology choices (Dahlman et al. 1987: 767). Options include relying on foreign direct investment, licensing agreements, turnkey projects, purchases of individual pieces of capital equipment, and/or acquiring technological capabilities through technical assistance (Dahlman et

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[9] The focus of comparison between declining CO_2 intensities in these industries and business as usual covers the period between 1985 and 2010.

[10] Such as recovering heat for co-generation of electricity.

[11] Such as shifting from vertical shaft kilns to manufacture cement to rotary kilns, or shifting from basic oxygen furnaces to electric arc furnaces to make steel, or from the Sinter process for producing primary aluminum to the more energy efficient Bayer process.

[12] What follows in this and the next four paragraphs is taken nearly verbatim from Rock and Angel (2005: 129-130).

al. 1987: 767-769). Having settled on technology choices and options for acquiring all the elements associated with particular technologies, enterprises must invest in the sometimes arduous tasks of acquiring the investment, production and linkage capabilities offered by the technologies they have chosen. Once the technology is installed, emphasis shifts to acquiring production capabilities—or the capability to improve the operation of the factory, to learn how to optimize operations, including raw material control, production scheduling, quality control, trouble shooting, and adaptation of processes and products to changing circumstances, and to repair and maintain equipment (Lall 1992: 171). Enterprises must also develop linkage capabilities that enable them to transmit information, skills and technology and receive information, skills and technology and other inputs from raw material suppliers, subcontractors, and technology institutes (Lall 1992: 171).

Because all enterprises are embedded in a larger socio-political and economic environment, government policies and institutions have enormous impact on how much enterprises in developing economies invest in building their technological capabilities, and how successful those efforts are.[13] How countries do this varies. For example, Korea promoted the development of large conglomerates that were linked to government via subsidized promotional privileges for manufactured exports (Kim 1997, Amsden 1989 and Rhee et. al. 1984). Singapore built a first world oasis in Southeast Asia and offered promotional privileges to first world manufacturing multinationals (Lee 2000 and Huff 1994). Taiwan, China's approach to technological upgrading relied on small and medium sized firms linked to government subsidized research and development institutes (Wade 1990). As will be noted below, China's path to technological upgrading relied on fundamental reform of its public sector research and development institutes, and promotion of national champions in a wide range of industries as part of a larger effort to enhance industrial productivity (Rock 2013).

II. China's Industrial and Technology Policies

China's industrial and technological development policies affected the ability of enterprises and industries in our four energy intensive industries to engage in long-run technological learning and upgrading through a more or less constantly evolving, experimental, incremental, and pragmatic search for a successful industrial and technological development strategy. Between independence in 1949 and the end of China's First Five Year Plan (1953-1957), the government pursued a classic Soviet style heavy industry strategy relying on the import of industrial blueprints and turnkey plants based on Soviet technologies. This strategy led to the creation of a small number of large state owned enterprises in the commanding heights of

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[13] For a review of the policies and institutions used by the East Asian newly industrializing economies see Rock and Angel (2005: chapter 2). For a more general review see UNIDO (2002).

the economy that dominated our four energy intensive industries.[14] There is at least some evidence that this strategy did not lead to much technological learning.[15]

When that strategy began to break down, the government's search for a viable alternative led first to the disastrous Great Leap Forward (1958-61) before settling on a decentralized industrial development strategy (1961-1978).[16] That strategy emphasized agriculture and small-scale capacity growth in five industries serving agriculture—cement, iron and steel, agricultural implements, chemical fertilizer, and power. Given the closed nature of the Chinese economy during this period and the fear of western military intervention, industrial policy focused on the creation of a large number of small scale plants ubiquitously distributed throughout the Chinese countryside, using readily available, although antiquated technologies. At the same time, technology policy focused on minor process improvements in small scale industrial plants (Sigurdson 1997, Rawski 1980 and Perkins et. al. 1977). As a result, the share of small scale plants in total production of iron and steel rose from 8% in 1958 to 21% in 1978 (Rock and Jiang 2013). In cement, the small scale share rose from virtually nothing to 70% in 1978 (Rock and Cui 2013). Similar developments are visible in aluminum (Rock and Song 2013) and pulp and paper (Rock and Song 2013).

When returns to the decentralized strategy slowed, China began experimenting with gradual and incremental quasi-market reforms in agriculture that spawned rapid growth in grain production.[17] Then reforms spread to small-scale town and village enterprises (TVEs), including in cement, iron and steel and pulp and paper (Wong 2003 and 1979). These reforms were accompanied by special economic zones (SEZs) that incrementally opened the economy to trade and foreign investment (Naughton 2007).[18] The success of this set of reforms facilitated very

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[14] In iron and steel, large plants accounted for 92% of production during the FFYP (Rock and Jiang 2013). Since China did not start making small scale cement plants until 1958, virtually all of the increase in production during the FFYP was with large scale rotary cement kilns (Rock and Cui 2013).

[15] For example, in 1958 Yueyang Paper, LTD began as a state owned enterprise with the first Kraft pulp production line in China using a long-web paper machine imported as a turnkey project from Finland. Because Yueyang did not invest in technological learning it was unable to repair its Finnish long-web paper machine when it was damaged by a natural disaster in the early 1960s (Rock and Song 2013).

[16] Because central planning tilted political-economic institutions and regulations toward heavy industry it seriously neglected agriculture. The major consequences of this industrial development strategy were over-representation of heavy industry in the economy, a slowdown in growth in agriculture, inadequate grain supplies for urban areas, insufficient agricultural raw materials for light industry, and a dearth of rural small scale industries. In addition to ignoring agriculture, this over-centralized model was criticized for stifling local initiative, promoting unproductive duplication at the local level, and inconsistent with the limited capabilities of the central agencies charged with meeting the information demands of a vast and heterogeneous production structure. To make matters worse, the emphasis on complex, capital intensive, heavy industry turnkey projects with long gestations periods slowed growth while failing to absorb labor. Critics argued, what was needed was a new industrial development model—one with the institutional capability and regulatory capacity to promote a rapid rate of growth in agriculture, foster small scale industrial projects with short gestation periods, absorb labor, and take advantage of local initiative and local conditions (Rock 2012:5-6).

[17] Cereals production rose from 243 MMT in 1977 to 407 MMT in 1993 (WDI 2011).

[18] In 1978 China also began reform of its centrally planned foreign trade and investment apparatus. Policy and institutional changes in China's trade and investment regime followed what had become a common practice—reforming a sector gradually and with dual track provisions that created new pockets of opportunity while protecting the rest of the economy from too much competition. The device used to implement duel track trade and investment

rapid growth in agriculture[19], industry[20], and GDP[21], as well as increasing the overall openness of the economy,[22] ultimately permitting the rise of a quasi-private sector that outgrew the plan. As China's quasi-private sector grew, both the national government and local governments established a large number and variety of SEZs that eventually led to the opening of the entire economy to trade and investment.[23]

Until the mid-1990s, these gradual reforms privileged small scale enterprises. Not surprisingly, small scale enterprises using antiquated technologies continued to dominate production in the industries in question. In cement, small scale vertical shaft kiln cement plants accounted for 85% of production in 1992 (Rock and Cui 2013). In iron and steel, small scale open hearth furnaces nearly doubled their share of production (from 21% to 40%) between 1978 and 2000 (Rock and Jiang 2013). In primary aluminum, the average scale of production was 37,169 metric tons in 1995 and production tended to be dominated by the antiquated Soderberg cell technology (Rock and Wang 2013). In addition, as late as 2003, 25 of China's 34 provinces had at least one primary aluminum production facility (Rock and Wang 2013). In pulp and paper, small mills[24] using small scale Chinese digestors to make pulp from straw and reeds, and equally small paper machines[25] accounted for 76% of production in 1994 (Rock and Song 2013).

Past reform successes subsequently paved the way for large scale privatization of TVEs and closing of unprofitable industrial enterprises, including those in the four energy intensive industries we studied. It also paved the way for corporatization of state owned enterprises

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reforms was special economic (SEZs) or export processing zones (EPZs). This began in 1978-79 when the government permitted a Hong Kong SAR, China businessman to sign export processing contracts with TVEs in the Pearl River Delta. Under these contracts, the businessman provided raw materials (fabrics) and designs for shirts while the TVEs earned a processing fee for turning the materials and designs into finished products (Naughton 2007: 383). This initial experiment led to the development of four Special Economic Zones (SEZs) in Guangdong and Fujian provinces in which firms located in these zones were allowed duty free imported inputs used to produce exports. These SEZs proved so successful that the government expanded duty free access to imported inputs used for exports to 5,000 local government Foreign Trade Companies and over 10,000 enterprises effectively breaking the government's monopoly over imports and exports (Naughton 2007: 384). Subsequently, China devalued the currency to make exports more profitable and replaced its centralized trade monopoly with tariff and non-tariff barriers to protect domestic firms from competition from exporters and foreign investors. By the mid-1980s both the national and local governments had created numerous other SEZs and EPZs. Ultimately, the central government shifted to a Coastal Development Strategy that turned much of coastal China into one large export processing zone while continuing to use tariff and non-tariff barriers to protect some industries, particularly in the state-owned sector (Naughton, 2007: 386 and Rock 2012: 14-15).

[19] This is particularly true for cereal yields which rose from 2536 kg/ha in 1978 to 4567 kg/ha in 1993 (WDI 2011).

[20] The growth rate of industry rose from 7.69% per year between 1960 and 1977 to 11.76% per year between 1978 and 1993 (WDI 2001).

[21] The growth rate of real GDP rose from 4.83% per year between 1960 and 1977 to 9.87% per year between 1978 and 1993 (WDI 2011).

[22] China's foreign trade ratio [(X+M)/GDP] rose from 9.01% in 1977 to 41.97% in 1993 while foreign direct investment as a share of GDP rose from virtually nothing to 6.23% of GDP in 1993 (WDI 2011).

[23] The trade ratio rose to 70% in 2006 before leveling off making China one of the most open large country in the world. While the share of FDI in GDP fell after 1993, it averaged 3.68% per year between 1994 and 2008 making China the largest recipient of FDI in the world (WDI 2011).

[24] The average scale of production was quite small prior to 1994 (2,200 metric tons of paper per year) while the average scale of foreign mills was 170,000 metric tons of paper per year (Rock and Song 2013).

[25] Most paper machines were round-web models with low efficiencies—normally lower than 200 m/min (Rock and Song 2013).

(SOEs) that led to the closing of numerous facilities, the shedding of significant amounts of labor[26], and the unhitching of SOEs from their social obligations. Corporatization of state owned enterprises was a tangible manifestation of a new industrial policy, "grasping the large, letting go of the small" (Naughton 2007). The policy of "grasping the large" signaled the **national** government's intent to create a small number of very large enterprises in key industries managed by a new government agency, the State Owned Asset Supervision and Administration Commission (Naughton 2007: 302). The policy of "letting go of the small" gave **local** governments the authority to restructure and close unprofitable TVEs along with other failing local enterprises – though not all governments embraced the use of that authority.

The intent in this new policy was to reduce production costs and increase competitiveness in industries subject to economies of scale, such as cement, iron and steel, aluminum, and pulp and paper, by systematically closing small enterprises using antiquated technologies while supporting the development of enterprises that were large enough to reap economies of scale and scope. The effect of this shift in policies led to massive closing of unprofitable TVEs, some closing of equally unprofitable state owned enterprises, and a rising share of large scale and modern production facilities using state of the art technologies. For example between 1985 and 2010, the share of cement produced in large scale modern rotary kilns rose from 10% to 81% (Rock and Cui 2013). In iron and steel, large modern plants increased their share of production from 72% in 1985 to 84% in 2010 (Rock and Jiang 2013). Similar developments are visible in aluminum[27] (Rock and Song 2013) and pulp and paper[28] (Rock and Song 2013).

As corporatization proceeded, the government built on its new industrial development strategy of 'grasping the large, letting go of the small' (Sutherland 2003:10). The more expansive application of the strategy was rooted in an assumption that the government could use large state-owned industries to create East Asian style conglomerates that could compete with OECD multinationals in a wide range of industries. State actors believed that making this transition required both enterprise-level institutional reforms, and promotional policies that would entice reformed enterprises to become more competitive and technologically sophisticated. Following the targeting for promotion of 57 state-owned enterprise groups, or conglomerates, with at least one such group in each of our energy intensive industries,[29] (Sutherland 2003: 46), the core enterprise in each group was (1) granted greater control over state assets in the group; (2) encouraged to develop an internal finance company to mobilize capital; and (3) enticed to annex

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[26] State-owned enterprise workers declined from roughly 75 million in 1994 to under 20 million by 2004 (Naughton 2007:106).

[27] While primary aluminum production averaged 37,169 metric tons in 1995, the scale of production grew quite dramatically thereafter reaching an average of 331,506 metric tons in 2009 (Wang 2011: 8).

[28] Average mill size rose from 2,200 metric tons per year in 1994 to nearly 25,000 metric tons per year in 2008 (calculated from annex tables in Rock and Song (2011). At the same time a number of very large modern mills using state of the art technologies emerged. For example, Shandong Chenming owns the largest printing paper line in the world (400,000 tpy capacity); APP Gold East possesses the world's largest 'fine' paper machine (700,000 tpy capacity); UPM Kymmene has the world's largest uncoated wood free machine (450,000 tpy capacity); and Pan Asia's Hebei mill has the fastest newsprint machine in the world (2000 m/minute) (Rock and Song 2013).

[29] Eleven of the 57 promoted groups were in our four industries. Other promoted groups include electricity generation, automobiles, electronics, chemicals, aerospace, and pharmaceuticals (Sutherland 2003: 50).

state research institutes to enhance their R&D capabilities. These institutional reforms were supported by incentive policies that gave promoted groups preferential access to state bank finance and capital markets.[30]

At the same time the government was promoting its more expansive policy of "grasp the large, let go the small," the government adopted the goal of becoming an "innovation economy" (Gu et al 2009). To meet this goal, the government began reforming its national innovation system by radically increasing R&D expenditures as a share of GDP[31], funding a number of new S&T programs[32], while also converting a large number of government research institutes (GRIs) that were a legacy of central planning into non-government S&T enterprises that had to fend for themselves.[33] As Naughton (2003) and Zweig (2001) argue, the restructuring of GRIs was aimed at forcing them to become market-oriented, "demand-driven" technology support institutes that serve the technology upgrading and learning needs of firms.

Chinese policy makers also experimented with ways to increase technology transfers and spillover effects associated with foreign investment (Gu, et al 2009: 373). Initially, the government adopted a self-reliant ("we will make it on our own") policy toward state of the art industrial technologies.[34] Once the drawbacks of this autarkic strategy became evident[35], the government shifted to buying foreign technologies in turnkey factories.[36] Once that strategy proved to be too expensive[37], the government shifted to tough negotiations with foreign investors for specific technology transfers in exchange for access to the Chinese market. While the

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[30] Unfortunately, very little is known about the impact of these preferential financial practices on promoted enterprises' performance. The tiny bits of evidence we do have is somewhat contradictory. On the positive side, in an admittedly early study, Keister (1998: 423) demonstrates that 'national champion' enterprises that created their own internal finance companies after being urged to do so by the government have higher productivity than non-promoted enterprises in the same industry without internal finance companies. In the same vein, Sutherland (2007) shows that China's 'national team' enterprises have grown fast, are substantial exporters, have higher R&D expenditures and higher profitability than large non-national team enterprises. On the other hand, because all large enterprises in China are also dependent on inefficient state banks (Allen et al 2008: 514) for capital expansion, the large size of non-performing loans in these banks' portfolios (Allen et al 2008: 522-526) suggests that preferential access to finance may undermine efficient use of capital. As discussed in the Appendix, these reforms raise several other important questions. Chief among them are two key questions: Have the reforms been successful in meeting the government's objectives of creating a small number of large technologically sophisticated enterprises that have come to dominate in several pillar industries? It is equally important to ask: What has been the impact of these policies on competition.

[31] R&D expenditures as a share of GDP rose from .6% of GDP in 1994 to 1.4% of GDP in 2006 (Hu and Jefferson Forthcoming: 16).

[32] This include the 863 Program and the 973 Program which focus on basic research and frontier technologies; the TORCH Program which supports high tech industries and the SPARK Program which is aimed at developing S&T to revitalize the rural economy (Hu and Jefferson Forthcoming: 16).

[33] Some GRIs closed, others merged, while still others were absorbed by enterprises (Hu and Jefferson (Forthcoming: 15). Under these new conditions virtually all of the GRIs were forced to become more market oriented to survive.

[34] What follows draws on Naughton 2007: 356-361).

[35] In the late 1970s, China's premier cement research and design institutes set out to design, engineer and construct large, modern rotary kilns, but none of these ever worked (Interviews at Sinoma International).

[36] After the failure in indigenous innovation in cement, the old Ministry of Building Materials imported 4 turnkey cement plants that were subsequently reverse engineered (Interviews at Sinoma International).

[37] This policy was based on the assumption that China would pay for these imports by exporting oil, once oil exports failed to develop, the strategy collapsed (Naughton 2007: 357).

practice of "market access for technology" had some success, it did not work that well either (Naughton 2007: 357).[38] Subsequently, the government opened more sectors to foreign direct investment (FDI) and provided a wide range of incentives to leading enterprises willing to invest in research and development. This strategy appears to have been more successful (Hu et al 2002, 2005).[39]

The final element of China's industrial and technology modernization policies focused on improving enterprise and industry level energy efficiency (Price et al 2008). Concern with energy efficiency in industry was a consequence of several perceived energy-related vulnerabilities.[40] For industry, the two biggest energy concerns related to coal use. Even though coal mining is well developed, China possesses a weak infrastructure for coal washing, shaping, transport and distribution, and for coal slurry (Wu and Storey 2007: 191). In addition, since current technology for coal use tends to be heavily polluting, China has faced growing problems between coal use and the environment.[41] In light of these concerns, beginning in the early 1980s, the government built energy efficiency into its command economy by establishing energy intensity standards for a large number of industrial subsectors and limiting the supply of energy to enterprises based on those standards (Sinton et al 1998: 821). Enterprises that failed to meet mandated energy intensity standards were closed, had their energy supplies cut-off, or faced significantly higher prices for energy used above the standard (Sinton et al 1998: 822). The "energy quota" management system was accompanied by significant enterprise investments in energy conservation[42]; creation of a large number of energy conservation centers[43] charged with providing energy efficiency services to enterprises; and development of a credible energy statistics collection and reporting system that enabled central planners to track enterprise and industry performance relative to established energy intensity standards.

As the economy continued its shift from plan to market, however, this set of policies and institutions became less useful and many elements of it simply withered away. Consequently,

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[38] As Naughton (2007: 357) says, China tried implementing this policy be engaging in high stakes negotiations with several world technology leading MNCs. While China achieved some success with this strategy, notably with the Belgian Bell subsidiary of ITT, in the end this approach failed as it led to long protracted negotiations, delays in implementation, and subsequent disputes over compliance.

[39] Hu et al (2005) find that FDI and enterprise own R&D expenditures exert positive impacts on enterprise productivity. They also demonstrate that an interactive term composed of FDI and own expenditures on R&D complement enterprise productivity.

[40] Wu and Storey (2007:191-192) identify six vulnerabilities: a need to meet rapidly increasing energy requirements, a need for high quality clean energy, structural problems with individual energy supplies – particularly for coal, growing oil demand, a growing conflict between energy use and environmental protection, lack of a well managed regulatory framework for energy, and inefficient supply of energy to rural areas.

[41] The two biggest environmental problems associated with coal use are acid rain and the effects of air pollutants on human health (Wu and Storey (2007: 192).

[42] Between 1981 and 1985 energy conservation investments (ECIs) were about 10% of total energy supply investments, ECIs equaled 8% of total energy supply investments between 1986 and 1990 (Sinton, et al 1998: 818).

[43] As Sinton et al (1998: 825) say, the sheer scale of China's energy efficiency institutional capacity during this period was unique as the government created over 200 Energy Conservation Centers staffed with over 7000 technical personnel attached to line ministries and their counterparts in provinces and municipal governments. These Centers carried out policy research, engaged in project designs and feasibility studies and carried out energy audits. Over time the ECCs developed substantial hands on experiences with energy users (Sinton et al 1998: 825).

substantial declines in energy intensity gave way to annual increases of almost 4% per year between 2002 and 2005 (Zhou et al, 2010: 1).[44] In response to this turnaround, the central government developed a new set of policies and institutions to put the economy back on an intensity reduction track.[45] The government did so by setting an energy intensity improvement goal of 20% between 2005 and 2010 (Price et al 2011). To achieve this goal, the government re-doubled efforts to eliminate and/or reduce production from inefficient industrial processes, technologies and facilities. It created a program for improving energy efficiency in the country's Top 1000 industrial enterprises (Price et al, 2010). It identified Ten Key Projects to improve energy efficiency in such areas as industrial boilers and industrial motor systems. It revitalized the country's energy conservation centers and rebuilt the statistical system for tracking performance from enterprises, counties, and provinces relative to energy intensity improvement targets.

In addition, the government linked this new energy intensity standards system to the cadre personnel evaluation system. And it adopted a number of incentives to encourage enterprises to reduce their energy intensity, including use of higher prices for energy for high energy consuming industries alongside generally rising prices for energy. The government also used tax policy (exemptions for approved energy saving projects or equipment) and fiscal policy (awards to enterprises of from $26 to $33 per ton of coal equivalent saved) (Zhou et al 2010: 7) to encourage energy conservation. During this period, the energy intensity of GDP fell by nearly 4% per year (Rock 2012: 27).

III. Technological Learning within Enterprises and Impacts on CO_2 Intensities

How has the evolution of China's industrial and technology policies affected energy use and CO_2 emissions in China's energy intensive industries? We answer this question by focusing on the impact of specific enterprise investments in technological learning on energy and CO_2 intensities.[46] Our aim is to demonstrate that enterprise investments in technological learning went hand in hand with significant declines in energy and CO_2 intensities. We focus on four enterprises—two in cement (the Luzhong Cement Company and Sinoma International), one in pulp and paper (Yueyang Paper Company) and one in iron and steel (Baosteel).

A. Technological Learning in Cement[47]

1. Luzhong Cement Factory

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[44] These increases reflected increases in the rate of growth of output in China's energy intensive industries. Cement production grew at 10% per year between 1985 and 2001 and rose to 12.7% per year between 2002 and 2005. Increases in growth were even more dramatic in iron and steel (growth increased from 7.7% per year between 1985 and 2002 to 23.8% per year between 2002 and 2005), aluminum (growth increased from 12.3% to 23.4%) and pulp and paper (where growth rates rose from 8.9% per year to 15% per year).

[45] Unless otherwise noted, what follows draws on Zhou et al (2010).

[46] Of course we recognize that other factors affect energy intensity, but as argued in section 2, all of those other variables require enterprises to invest in learning if they are to reap environmental technique effects.

[47] What follows draws on Rock and Cui (2011).

Our detailed enterprise level study of technological capabilities building at one medium sized cement enterprise, Luzhong Cement Factory, in Zibo City, Shandong Province, shows that the enterprise's investments in long-run technological learning enabled it to make substantial improvements in energy efficiency. As a result, comprehensive energy consumption per metric ton of cement fell from 152 kilograms of coal equivalent per metric ton in 1980 to 109 kilograms of coal equivalent in 2009—a drop in energy use per metric ton of cement by nearly 30%. More importantly, Luzhong's investments in building its technological capabilities enabled the enterprise to maintain a substantial energy efficiency advantage over other plants using similar technologies.[48]

Luzhong started in 1976 as a small scale cement collective following establishment of China's five small scale industries program. At that time, the enterprise had one earthen shaped pit kiln that produced about 1000 tons per year of low quality cement. In 1984, with help from a local research institute, the collective transformed into a shareholding TVE that invested in mechanical-vertical shaft kilns with production capacity reaching almost 1 million tons per year by 2000. It relied on its own staff and assistance from engineers at larger cement enterprises to help with successive investment capacity upgrades. By 2003, Luzhong had two of the largest mechanical VSKs in China.[49]

Subsequently, Luzhong invested in building its production and linkage capabilities. For example, it solved a particularly thorny production problem by finding out how to successfully use bag filters to control dust in VSKs.[50] And it expanded its production capabilities by recovering heat for co-generation and heating of the village (Nanhan) that 'owned' the enterprise. Between 2005 and 2008, the enterprise began building its global linkage capabilities by becoming part of China's cooperative project with the US EPA to reduce persistent organic emissions (POPs).[51] By 2010 enterprise investments in investment, production, and linkage capabilities enabled Luzhong to reduce energy intensity in its VSKs to an average of 96 kilograms of standard coal per ton of clinker or 686 kcal per ton of clinker—roughly equivalent to energy use per metric ton of clinker in large, modern rotary kilns with pre-heaters and pre-calciners.

2. Sinoma International

While Luzhong was building its technological capabilities, the government made a decision to phase out VSK cement plants and replace them with large, modern, rotary kiln

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[48] Between 1985 and 2010, average comprehensive energy consumption (kgce/t of cement) at Luzhong was 129.6 kgce/t of cement, while the VSK industry average was 176.1 kgce/t of cement.

[49] Each produced roughly 250,000 metric tons of cement per year (Interview, Luzhong Cement Factory, January 2010). Additional technological upgrades included improving production capabilities by developing and installing a system for pre-watering the raw meal, and adding an elemental analyzer for homogenizing the raw meal fed into the kilns.

[50] At the time, no one in China knew how to operate bag filters in VSKs. Technicians at Luzhong learned that if too much water is added to the bag filter, mud accumulates the temperature in the bag falls and the water in the bag collapses. On the other hand if the temperature in the bag is too high it will simply burn up (Interviews at Luzhong, December 2010).

[51] During this project, managers learned that one of the most cost effective ways to control POPs emissions was to improve the energy efficiency of its kilns.

cement plants. Because the costs of importing rotary kilns were prohibitive, the government opted to develop an indigenous technological capability to design, manufacture, install, and commission a uniquely Chinese version of large, modern rotary kilns—what ultimately came to be known as NSP kilns. The government turned to its national cement industry design and research institutes[52] to develop these capabilities. Initially, one of those institutes, the Tianjin Cement Industry Design and Research Institute (TCIDRI), attempted to design, manufacture, install, and operate a small rotary kiln (700 tons per day) without any external assistance. But this "make it by ourselves" effort failed because the system was not properly configured,[53] and the engineers could not master synchronized operation[54] of all parts of the operation.

These intractable problems led the Ministry of Building Materials to import four rotary kiln production lines.[55] While the government required the foreign engineers to oversee all aspects of these projects, it also required them to build the investment, production and linkage capabilities of the Chinese engineers who worked on them.[56] As part of the capabilities building process, engineers from the TCIDRI went to design facilities in Denmark and Japan to learn how to design modern rotary kiln cement plants.[57] This process took 18 months. Subsequently, Chinese engineers oversaw the installation and commissioning of these plants. Daily meetings among the foreign engineers, Chinese engineers, and the technicians that operated the plants were used to build production capabilities by identifying problems (such as a broken piece of equipment), working out solutions (repair or replace the equipment), allocating responsibility for fixing the problem (repair shop or purchasing), and developing an estimate of time it would take to resume production.

In the next stage of technological learning, engineers at the TCIDRI developed new investment capabilities by reverse engineering and contracting out the manufacture of equipment for new rotary kiln production lines.[58] Because the engineers at the TCIDRI were unhappy with

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[52] There were three of these, one in Tianjin, one in Nanjing, and one in Chengdu.

[53] For example, the gas volume feed into the kiln did not match the capacity of the kiln and they were not sure how to fix this (Interviews at SI, April 2011).

[54] For example, because the fuel-feeder to the pre-heater had been incorrectly designed, the pre-heater kept jamming. Similarly, they could not get the bucket elevator that transported raw material to the kiln to operate at the correct speed. Sometimes it was too slow, other times it sped up, when this happened they were forced to stop the whole system (Interviews at SI, April 2011).

[55] Three were 4000 tons per day lines imported from Europe, while the other was a 3200 ton per day line from Japan.

[56] This appears to have been part of the institutionalization of a more sophisticated "trade of market access for technology" policy. Our interviews at Sinoma International highlighted that the Chinese government does not permit foreign engineers to design new manufacturing facilities—they must do so by training and overseeing Chinese engineers who do the actual engineering design work.

[57] This began with basic discussion about the conceptual design, followed by the actual process design which required intimate knowledge about numerous basic parameters such as, the best operating temperature for the kiln, optimal size of the kiln, the sizing of raw material feed, the size of the pre-calciner, and the capacity of the raw mill. The Chinese engineers learned these things and many others by peppering the foreign engineers with technical questions based on what the Chinese engineers knew, including requests for justification of designs at the various stages of the production process the way the foreign engineers wanted.

[58] Initially they focused on replacing worn out parts from the four imported production lines. Because they had trouble replacing some specific pieces of equipment, the Ministry of Building Materials purchased technology licenses with detailed engineering drawings for that equipment.

their equipment suppliers[59] they acquired three manufacturing workshops thereby enhancing their investment capabilities. Over time engineers at the TCIDRI mastered complete configuration of new Chinese NSP rotary kiln production lines and as the demand for cement expanded, the TCIDRI began producing hundreds of new NSP production lines per year. As part this process design engineers enhanced their investment capabilities by reducing the investment cost of new NSP production lines from roughly 1,200 yuan per ton of cement to roughly 500 yuan per ton of cement.[60] And they enhanced their production capabilities by learning how to adapt their designs to Chinese conditions.[61]

Following administrative reforms that eliminated central line ministries and reduced government support for ministries' national research institutes, engineers at the Nanjing Cement Industry Design and Research Institute and the Chengdu Cement Industry Design and Research Institute founded a quasi-public, quasi private cement engineering enterprise, Sinoma International (SI) in 2001. SI went on to become a publicly traded enterprise "owned" by the State Owned Assets Supervision and Administration Commission. In 2005 the TCIDRI joined SI and the combined enterprise dominated the Chinese market for new rotary kiln cement production lines—capturing between 80% and 90% of this market each year. SI also built its global linkage capabilities by capturing a significant share of the non-Chinese international market for new rotary kiln cement production lines.[62]

3. Technological Learning in Pulp and Paper[63]

Our case study of Yueyang Paper Co., LTD[64] in Hunan Province showed how the enterprise's investments in long-run technological learning—in acquiring the know-how and know-why in new investment capabilities[65], new production capabilities[66], and new linkage capabilities[67] —enabled the enterprise to make substantial improvements in energy efficiency .

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[59] Some of the equipment they purchased did not work to specification. Other pieces of equipment were not delivered on time. Several suppliers charged exorbitant prices.

[60] Among other things, they reduced investment costs by reducing automation and replacing it with well trained but low cost labor (Interview at Sinoma International, January 2011).

[61] For example, when the government bought technology licenses for pre-calciners, they burned heavy oil, but given the rising cost of heavy oil in China, Chinese cement enterprises wanted to substitute coal for heavy oil. This required the engineers at the design institutes to completely redesign pre-calciners so they could burn coal.

[62] By 2010 SI was reputed to have captured 36% of the non-Chinese global market for new cement plants, with 70% of its revenue coming from export sales (Interview at SI, January 2011).

[63] What follows draws on Rock and Song (2011: 20-28).

[64] Unless otherwise noted, what follows is based on interviews at Yueyang Paper Co. in April 2011 and/or follow-up answers to additional questions.

[65] New investment capabilities include learning how to carry out investment feasibility studies, deciding which particular technologies to acquire, and deciding on the means to acquire those technologies (via direct foreign investment, licensing agreements, or turnkey projects) (Rock and Angel 2005: 129-130).

[66] New production capabilities include the capability to improve operation of a new production line, to optimize the operation of the new line, including raw material control, production scheduling, quality control, trouble shooting, and adaptation of production processes to changing conditions, as well as the ability to repair equipment as needed (Lall 1992: 171).

[67] New linkage abilities include the ability to transmit new information, skills, and technology and receive information, skills and technology from component and raw material suppliers, subcontractors, and technology institutes (Lall 1992: 171).

Yueyang began as a state-owned enterprise in 1958. At this time, the enterprise had the first imported (from Finland) turn-key Kraft pulp production line in China. By 1968 it had become the largest producer of offset printing paper in China. Capacity subsequently more than tripled over the decade prior to China's reform program.

When the enterprise was established in 1958, Yueyang did not make any significant investments in technological capabilities building or technological know-how or know-why. This turnkey method for acquiring new plant and equipment caused serious problems for the enterprise. Following a natural disaster in the early 1960s, the enterprise's imported paper machine had to be re-built. Because Yueyang had not invested in building its technological capabilities in new investments, no one at Yueyang knew how to rebuild the imported paper machine. As a result, technical experts from all over China came to help. This was a bitter and embarrassing lesson for managers and technicians at Yueyang that they promised never to repeat.

To that end, the enterprise established a Technical Center that subsequently became the hub of an extensive technological learning program, and later a center for a substantial research and development program. In addition whenever Yueyang acquired new technology or equipment, managers insisted that its engineers and technicians work closely with foreign technology and equipment suppliers. This began in earnest in 1995 when Yueyang technologically upgraded its investment capabilities in pulp-making investing in a state of the art chemical-mechanical pulp production line from Andritz, a global leader in this technology.[68] As part of that process, engineers and technicians were involved in pre-engineering studies as well as the design, fabrication, installation and commissioning of this new pulping line.

One important consequence of the daily collaboration between Yueyang and Andritz was enhanced production capabilities as Yueyang and Andritz worked together to get the new pulp line to operate under Chinese conditions. Initially, chemical use was excessive, costs of operation were too high, pulp yields were too low, and the pulp produced was of poor quality.[69] It took more or less constant interaction between Yueyang and Andritz for over a year to modify the equipment so that it could handle the poor quality of China's raw material (waste-paper). As a consequence of this effort, engineers and technicians at Yueyang gained extremely valuable experience in making technology choices, undertaking investment feasibility studies, adapting production processes to local conditions, and developing collaborative linkages with a major technology and equipment supplier. Yueyang followed a similar path with its import of an advanced anaerobic treatment process for treating pulping wastewater, from the Dutch company PAQUES.[70]

In 2000, the enterprise became the Yueyang Paper Corporation, owned by a Chinese conglomerate, the Tiger Forest and Paper Co., LTD—one of the top ten enterprises in China's

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[68] Andritz is a global supplier of plant, equipment and services for the hydro-power, steel and pulp and paper industries (http://www.andritz.com/)

[69] All of these problems were the consequence of poor raw materials—particularly the number of sticks in the raw material (wastepaper). Technicians from Yueyang's Technical Center and its operators worked closely with engineers/technicians from Andritz to solve this problem. Solving this problem also helped Andritz open up the Chinese market for its equipment.

[70] PAQUES is a global supplier of wastewater treatment and water recycling equipment (http://en.paques.nl/).

paper industry. In 2004, Yueyang was publically listed on the Shanghai Stock Exchange. Currently Yueyang is one of China's largest and most modern pulp and paper enterprises, producing a wide range of paper products from its location near abundant raw materials—bamboo, pine trees, reeds, and poplars—on the border of Dongting Lake and the Yangtze River in Yueyang City. In addition to six production lines for making pulp and 8 paper production lines, it maintains facilities for heat and power supply, water supply, and for recovery of black liquor.

In 2007, Yueyang used its experiences with Andritz and PAQUES when it acquired a new state of the art mechanical pulping and printing line from Voith Paper. As in the past, engineers and technicians from Yueyang worked closely with Voith's engineers to increase their capabilities in pre-engineering, as well as in the design, fabrication, installation and commissioning of this new production line. As part of Yueyang's contract Voith Paper agreed to train 30 Yueyang operators at Voith's facilities in Germany.[71]

In addition to working with OECD technology and equipment suppliers, Yueyang's Technical Center invested in building its own independent technological capabilities. This began in the 1970s when the Center experimented with a chemical recovery system for reed pulping. Subsequently, the Technical Center successfully invested in adaptive technological learning by modifying its Finnish paper machine and re-training its technicians who learned to operate this refurbished paper machine at a world-class "advanced" level. Yueyang also learned how to build linkage capabilities to local and national technology institutes and universities. For example, when technicians at Yueyang's Technical Center had difficulty in creating a black liquor recovery system for straw pulp, they turned to the Hunan Paper Research Institute and a local university to work with them to solve this problem. Between 2006 and 2010, the enterprise invested nearly 3% of annual sales each year in research and development and its Technical Center employed between 200 and 300 technicians with university degrees.[72] Long term investment helped Yueyang solve a host of technical problems; take the lead in a number of government funded pilot projects[73]; and it helped the enterprise to develop a significant number of Chinese patents (between 40 and 100 per year between 2006 and 2010).[74]

By 2008 Yueyang had installed electrostatic precipitators on all of its furnaces and chemical recovery boilers to capture fine particulate matter. In that same year Yueyang invested

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[71] In subsequent capacity expansions starting in 2008, engineers at Voith and Yueyang jointly commenced pre-engineering work; as Voith started fabrication of machine components, engineers at Yueyang commented on and tracked progress on-line. Mutual trust and close collaboration between engineers at Voith and Yueyang increased Yueyang's investment capabilities contributing to a substantial reduction in time from pre-engineering work to commissioning to 16 months—in what appears to be the shortest time ever for completion of such a project in China.

[72] This number is extraordinarily high by Chinese standards, but it is not unheard of—Baosteel, China's leading steel giant has an even larger R&D staff (Rock and Jiang 2013).

[73] Yueyang is currently the lead researcher in a national pilot whitewater reuse project that will investigate which equipment and which chemical work age works best.

[74] One of these patents was for a new white mud recovery process using APMP pulping machines. In another instance, the Technical Center at Yueyang took the second prize in a National Science and Technology Award Program in 2003.

20 million RMB in a desulphurization unit with an efficiency of more than 90%. In 1999 the company produced 120 thousand metric tons of paper with daily wastewater emissions of 100 thousand metric tons. Because of investments in water saving and water recycling, daily wastewater discharge remained at this level even as enterprise production rose to nearly 800 thousand metric tons of paper in 2010. In addition, the company invested roughly 600 million RMB to integrate wastewater treatment[75].

Our interviews indicated that the energy intensity of pulp and paper production at Yueyang declined by nearly 20% between 2005 and 2010. This decline was achieved largely through a number of relatively minor process and minor technology changes such as improving the heat efficiency of boilers, adjusting the composition of pulping materials so a mechanical pulping line could be converted to a chemical-mechanical line; and generating power from chemical recovery.

4. Technological Learning in Steel [76]

Baosteel began as a large, turnkey, integrated iron and steel enterprise conceived in the early days of the post-Mao era.[77] It was one of some 120 large-scale projects that was part of a Ten Year Plan to modernize China's industrial sector. Each of these projects was expected to rely on state of the art imported technologies and they were to be financed by rising exports of oil. While many of the planned projects were cancelled or scaled back once expected oil exports failed to materialize, Baosteel's integrated iron and steel facilities were completed in three phases (Sun 2005).

The project marked a radical departure in steelmaking in China. Instead of relying on indigenous technology, Baosteel's production facilities were designed, installed, and commissioned by Japan's Nippon Steel Corporation.[78] The size and scale of this project dwarfed that of China's First Five Year Plan when the Soviet Union provided iron and steel factory designs but few pieces of equipment (Jackson 1994: 114). In addition, unlike the rest of the industry, Baosteel was located on China's coast in Shanghai so it could take advantage of imported high quality iron ore.

From the very beginning, China used the Baosteel project to build its technological capabilities in modern iron and steel-making. To insure this, the Vice Minister of the Ministry of Metallurgical Industry was sent to oversee the project. He was joined by the country's top iron and steel engineers, including those from the Shanghai Metallurgical Design and Research

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[75] Currently, Yuyang's wastewater treatment system consists of 2 anaerobic systems with treatment capacities of 9,600 m^3 per day and 8,400 m^3 per day to treat organic waste from a poplar chemical-mechanical pulping line and wastepaper de-inking for a wastepaper pulping line. Yueyang also has an aerobic system with a capacity of 42,000 m^3 per day for bio-chemical treatment of whitewater. And it has an aeration system with a capacity of 60,,000 m^3 per day for middle-stage treatment of wastewater and anaerobic effluent from papermaking.

[76] What follows draws on Rock and Jiang (2011).

[77] Unless otherwise noted what follows in this and the next paragraph draws on Jackson (1994).

[78] Prior to the Baosteel project, China's national metallurgical design and research institutes designed new steel mills based on modifications of designs provided by the Soviet Union. Designs were then passed on to machinery enterprises who manufactured iron and steel making equipment.

Institute.[79] For a number of years, the government also allowed Baosteel to build its human capital base by hiring a significant number of the best engineering graduates from the country's top engineering universities (Baosteel interview, January 2011).

Once a high quality human capital base was in place, China required the engineers and technicians from the Nippon Steel Corporation teach China's iron and steel engineers how to carry out all phases of the project to build their technological capabilities. What this meant in practice is that Chinese engineers did the actual work of designing, contracting out manufacture of equipment, installing, and commissioning Baosteel's new facilities while Japan's engineers guided and advised them.[80] Our interview with Baosteel indicated that the government proceeded this way because it realized that buying new technology and equipment does not guarantee mastery; acquiring it is just the first step to mastery, and learning how to use it efficiently requires a lot of hard work (Baosteel interview, January 2011).

For its part Baosteel undertook several large investments to build its technological capabilities. It built its linkage capabilities by adopting an open innovation model[81] that includes the enterprise's R&D department, employees from virtually every other department[82], customers and suppliers[83], universities[84], research institutes[85], and other world class steel enterprises[86] (Chen and Chen 2005).[87] It built its investment capabilities by manufacturing and contracting out the manufacture of iron and steel making equipment to Chinese companies – from 12% in the first phase of the project, which lasted from 1978-1985, to 80% in phase III, 1993-2001 (Sun

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[79] Engineers at the top metallurgic design and research institutes learned how to design iron and steel making equipment during China's First Five Year Plan when the Soviet Union provided designs. The design and research institutes then worked with machinery firms to make iron and steel making equipment (Jackson 1994: 114).

[80] By the time the first phase of the project was finished over 4000 Chinese engineers had been sent for training in Japan while over 8000 Japanese engineers worked on the project in China (Jackson 1994: 137)

[81] Baosteel's open innovation model is described at (http://www.baosteel.com/group_e/02about/ShowArticle.asp?ArticleID=2539)

[82] Baosteel regularly treats employees as innovators soliciting their input and implementing numerous suggestions made by employees outside the R&D center (Chen and Chen 2005:758).

[83] By 2009, Baosteel had shifted to developing strategic cooperation with suppliers to develop new products and innovative technologies (http://www.baosteel.com/group_e/03management/ShowArticle.asp?ArtileID=2368)

[84] Baosteel has established an Electromagnetic Process Research Center and a Vacuum Spraying Metallurgical Lab with a number of universities (Chen and Chen 2005:758).

[85] Currently, Baosteel is collaborating with Battelle on new energy developments (Interview at Baosteel, January 2011). It also has a collaborative relationship with the Colorado School of Mines, Northeastern University in the U.S. and the Swedish Institute of Technology (http://www.baosteel.com/group_e/02about/ShowArticle.asp?ArticleID=2539)

[86] In 2003, Baosteel joined with Nippon Steel and Arcelor in a joint venture to manufacture 1.7 million metric tons of high quality plates for domestic and foreign (particularly Toyota and VW) automakers (Sun 2005: 187). In this joint venture, Arcelor has agreed to transfer to Baosteel its leading edge technology of laser welding (Sun 2005:187). As Sun (2005:1987) says, this is an example of China and Baosteel using access to the Chinese market in exchange for the transfer of leading technologies.

[87] In 2009, Baosteel revamped its management system for technological innovation by compiling a new innovation plan, introducing an award program (gold apple program) for innovation, and by establishing and integrating three management systems for innovation.

2005: 180). Over time, Baosteel's technology capabilities grew so strong that it was able, by itself, to design and manufacture much of its own iron and steel-making equipment.[88]

A similar process was used to acquire production capabilities in the automation side of iron and steel making. In 1979, Baosteel acquired a computer controlled energy management system for its rolling mills from Fuji Motors, but Chinese computers did not work well with the acquired system (Baosteel interview, January 2011). This led Baosteel to send 10 computer engineers to Siemans VAI in Germany to learn how to design, manufacture, install, and commission such systems. By the time they returned to Baosteel, they had developed the best computer controlled energy management system for the iron and steel industry in the world (Baosteel interview, January 2011). Subsequently, management took advantage of this technological capability by creating the Baosight Software Company as the automation division of the Baosteel Group (Baosight 2011: 1). Its automated EMS (Energy Management System) is reputed to be among the best in the world (Baosteel Interview, January 2011) and is in use at Baosteel and numerous other large iron and steel producers in China.[89]

Baosteel's energy saving programs emphasize elimination and modernization of backward iron and steel facilities; adoption of a centralized and automated energy management system; and diffusion of new energy saving process technologies (Zou 2008). For example, after being forced by the Shanghai Municipal and the central government to take over several failing state owned iron and steel enterprises (the Shanghai Metallurgical Holdings Group and the Meishan Iron and Steel in Nanjing), Baosteel used its managerial know how and technological prowess to write off bad debt, eliminate substantial backward capacity[90], and downsize workforces at both enterprises (Sun 2005: 181). And it used Baosight's real time and networked computerized energy management system (EMS) to save energy in these acquired facilities as well as in all other Baosteel facilities.

Not surprisingly, Baosteel's investments in technological learning have enabled the core enterprise and its subsidiaries to make substantial improvements in energy efficiency. As a result, comprehensive energy consumption per metric ton of steel fell from roughly 1,133

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[88] Baosteel established its own design and research institute in 1984, its own equipment manufacturing department in 1992, and its own equipment and engineering subsidiary in 1996. In 1999, the Shanghai Baosteel Equipment, Engineering, and Technology Company was renamed the Baosteel Engineering and Technology Company. In 2004, this company merged with the Shanghai Metallurgical Design and Research Institute and the Baosteel Design and Research Institute to form an expanded Baosteel Engineering Co., LTD (Baosteel Engineering 2011). In addition, Baosteel Engineering turned to joint ventures with firms in Japan and Europe to build certain technological capabilities.

[89] This includes Meishan Iron and Steel, Nanjing Steel, Ningbo Steel, Maanshan Iron and Steel, Xinyu Iron and Steel, Jilin Iron and Steel, and Rizhao Iron and Steel (Baosight 2011b: 4). In addition, Baosight has become a leader in China in development of a Manufacturing Execution System (MES) that enables plant managers to optimize production activities from the time orders are placed to delivery of finished goods. Baosight has become so good at designing, installing, and commissioning MES systems for iron and steel manufacturers that it has captured over 50% of China's MES market in this industry. To date it has designed, installed and commissioned MES systems for over 30 iron and steel enterprises, including virtually all of China's leading iron and steel producers and China's leading aluminum conglomerate—CHINALCO.

[90] Boasteel eliminated 4.93 million tons of backward iron smelting capacity, 6.08 million metric tons of outdated steel smelting capacity, and 5 million metric tons of backward steel rolling capacity (Baosteel 2009).

kilograms of coal equivalent per metric ton in 1985 to 730 kilograms of coal equivalent per metric ton in 2007—a drop in energy use per metric ton of steel of 36%. By 2010 energy efficiency at Baosteel was 25% better than the rest of China's steel industry and it was near the energy efficiency achieved by POSCO, Korea's iron and steel giant (Baosteel interviews, January 2011 and annex tables in Rock and Jiang 2013).[91]

IV. Tracking Industry Level CO_2 Emissions and Intensities

If China's industrial and technology policies promoted the kind of technological learning and energy savings within enterprises described in our case studies, we should be able to see significant improvements in energy efficiency at the industry level in China's cement, iron and steel, and pulp and paper industries. An econometric study by Fisher-Vanden, et al (2013) provides evidence of these broader industry developments. The paper uses a KLEM type model on a panel sample of large and medium sized enterprises between 1999 and 2004 for the three abovementioned industries, as well as for aluminum. In a panel regression of the four industries, three characteristics of enterprises—the relative price of energy, own enterprise investments in technological learning and own enterprise investments in technological learning interacted with the relative price of energy —all reduce energy intensity.

While our enterprise level case studies and empirical work are indicative of the impact of technological learning on energy and CO_2 intensities in these four industries, neither tells the whole story itself. Our case studies might not be indicative of industry wide developments. In addition, our econometric work covers a relatively narrow time frame. . To broaden our information base, we asked the highly skilled Chinese technical experts with whom we collaborated in studies of the four industries to develop industry wide estimates of improvements in energy efficiency and CO_2 intensity from specific investments in a myriad of minor process innovations[92] and major technological transformations.[93] In addition to this technological information, we collected industry level data from 1985 to 2010 on physical production, energy use by energy type, composition of the production scale of enterprises, and production technology in use. By combining these data with the technological information on efficiency improvements, we can provide a general picture of large reductions in CO_2 intensity and CO_2 emissions in these industries relative to what would have occurred in a counterfactual "business as usual" with the same rates of production, but without the technical improvements.

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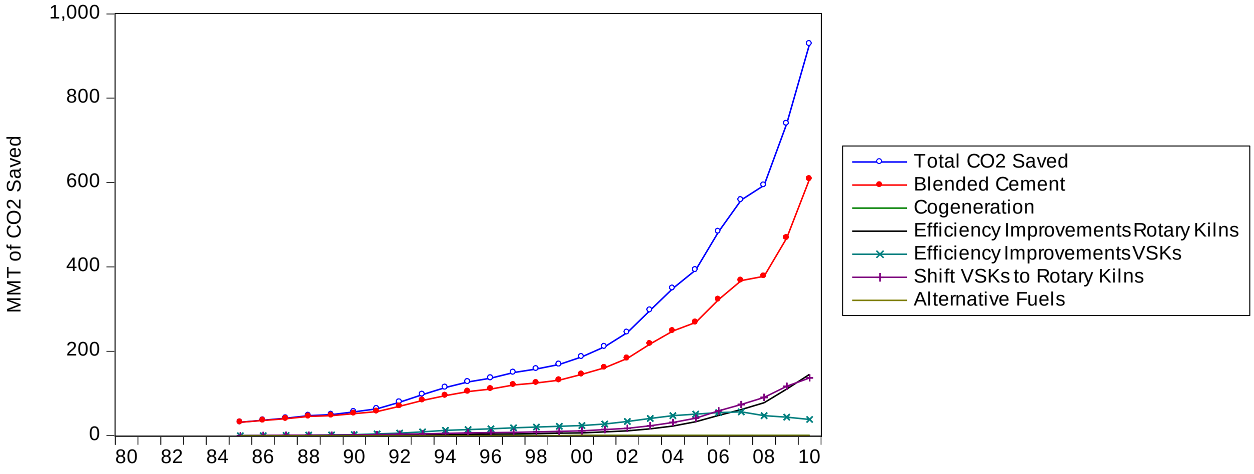
[91] The decline in energy efficiency in 2000 occurred as China dismantled its mandatory energy efficiency program as it was shifting from a planned to a more market oriented economy.

[92] Minor process improvements include improving the energy efficiency of vertical shaft and rotary kilns and recovering heat to generate electricity in cement (Rock and Cui 2013), materials substitution, soda recovery, and recovering heat to generate electricity in pulp and paper (Rock and Song 2013).

[93] Major technological transformations include closing small plants using antiquated technologies in all four industries and replacing them with large scale state of the art production facilities, shifting to blended cement (Rock and Cui 2013); reducing the iron to steel ratio by replacing blast furnaces with electric arc furnaces, closing antiquated beehive coke ovens and replacing them with advanced coke ovens, and adopting coke dry quenching (Rock and Jiang 2013); and shifting from the energy inefficient Sinter and Bayer-Sinter processes for making alumina to the Bayer process, as well as phasing out Soderberg cells for making primary aluminum and shifting to large cells (Rock and Wang 2013).

In cement, figure 4 identifies year by year industry-level savings in CO_2 from (1) improving energy efficiency in rotary and vertical shaft kilns, (2) shifting from vertical shaft kilns to rotary kilns, (3) shifting to blended cement, (4) using alternative waste fuels, and (5) recovering heat to co-generate electricity. Three aspects of figure 4 are important. First, the largest single savings in CO_2 comes from the shift to blended cement—by 2010, 40% of cement production in China (745 million metric tons) was blended cement. This shift alone accounts for 608 million metric tons of CO_2 saved or 65% of total CO_2 savings. Roughly 20% of total savings (183 million metric tons) come from efficiency improvements in vertical shaft kilns and rotary kilns, while 15% of total savings (136 million metric tons) come from the closing of vertical shaft kilns and the switch to rotary kilns. So far, very little savings have come from use of alternative fuels or cogeneration of electricity.

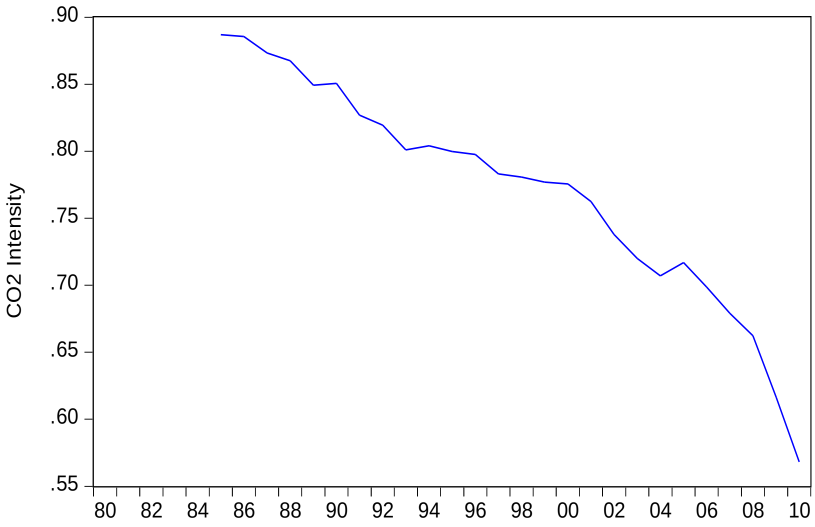
Figure 4
China
CO2 Saved Cement
(Million Metric Tons)



Source: Rock and Cui (2011)

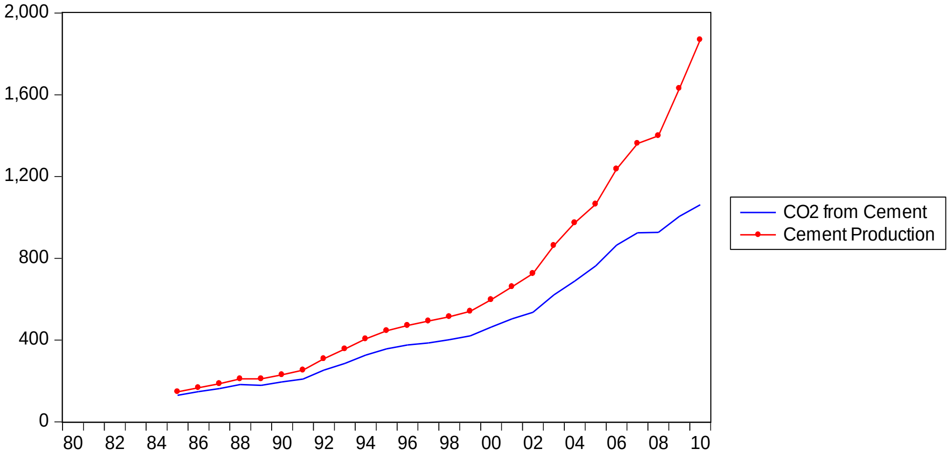
Taken together, CO_2 savings (relative to the counterfactual) in 2010 from the ongoing advance of technology in this sector were 928 million metric tons. As a result, the CO_2 intensity of cement production fell from roughly 0.9 metric tons of CO_2 per metric ton of cement in 1985 to about 0.6 metric tons of CO_2 per metric ton of cement in 2010 (figure 5). While the scale effect of growth has swamped the technique effect, it is clear that China has weakened the link between cement production and CO_2 emissions (figure 6). As Rock and Cui (2011) argue, China has several significant further opportunities to reduce CO_2 emissions from cement production. If adopted, they, along with a looming peak in demand for cement, might enable near-term CO_2 emissions in the sector to peak and then decline.

Figure 5
China
CO2 Intensity of Cement
(Metric Tons of CO2 per metric Ton of Cement)



Source: Rock and Cui (2011)

Figure 6
China
Cement Production and CO2 Emissions
(Million Metric Tons)



Source: Rock and Cui (2011)

In iron and steel, figure 7 shows that following the large scale technological changes in China's iron and steel industry (Rock and Jiang 2013), the CO_2 intensity of production fell from 6.2 metric tons of CO_2 per metric ton of steel in 1985 to 2.3 metric tons of CO_2 per metric ton in 2009.[94] Given the very large increase in steel production, this technological shift "saved" 2.25 billion metric tons of CO_2 in 2009 relative to our counterfactual point of comparison (figure 8).

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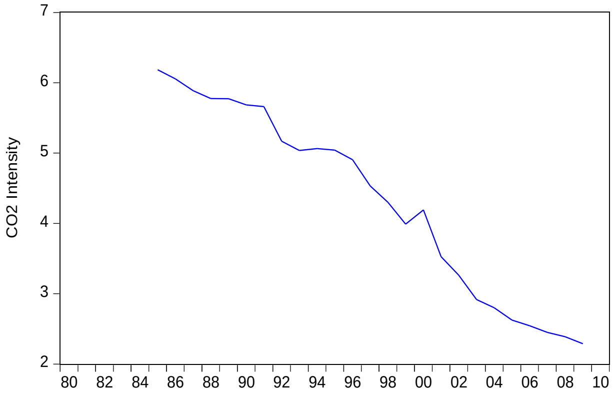
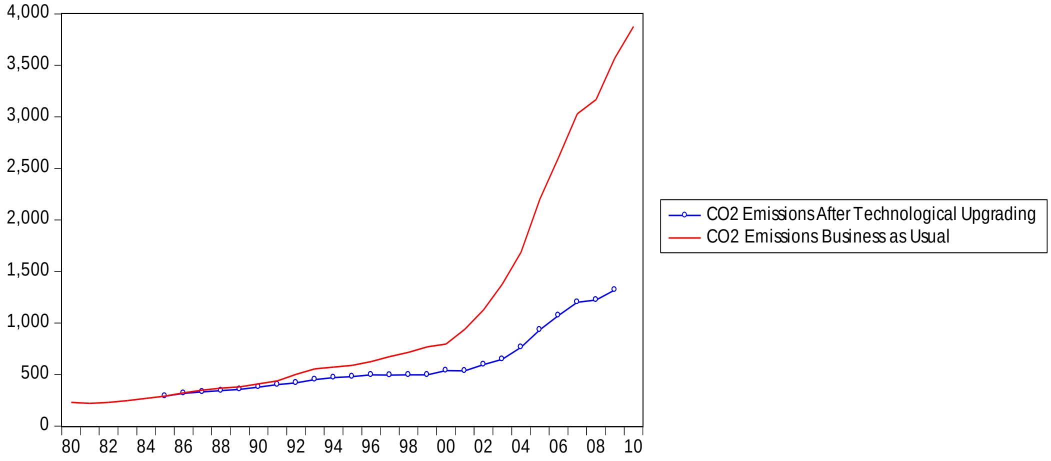
[94] At the same time, energy efficiency in iron and steel production improved from 1,662 kgce per metric ton of steel in 1985 to 1,016 kgce per metric ton of steel in 2007 (Rock and Jiang 2013).

Figure 7
China
CO2 Intensity of Iron and Steel Production
(Metric Tons of CO2 per Metric Ton of Steel)



Source: Rock and Jiang (2011)

Figure 8
China's Iron and Steel Industry
CO2 Emissions Under Business as Usual
and After Technological Upgrading
(Million Metric Tons)



Source: Rock and Jiang (2011)

While lack of data availability made it impossible to account for all of this saving of CO_2, we were able to identify CO_2 savings from reducing the iron to steel ratio[95] (984 MMT), modernizing and increasing the size of blast furnaces (74 MMT) and basic oxygen furnaces (59 MMT), adopting advanced sintering machines (54 MMT) and advanced coke ovens (68 MMT), and by adoption of coke dry quenching (70 MMT) (Rock and Jiang 2013). Taken together, these interventions saved 1.3 billion metric tons of CO_2 or nearly 60% of total CO_2 savings in 2010 reported in figure 8.

Similar developments are visible in China's pulp and paper industry. After the large scale technological transformation in China's pulp and paper industry described in Rock and

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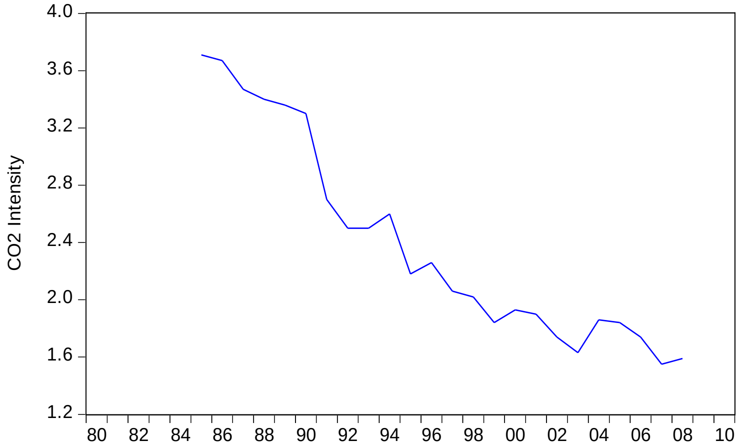
[95] By shifting to electric arc furnaces using scrap steel.

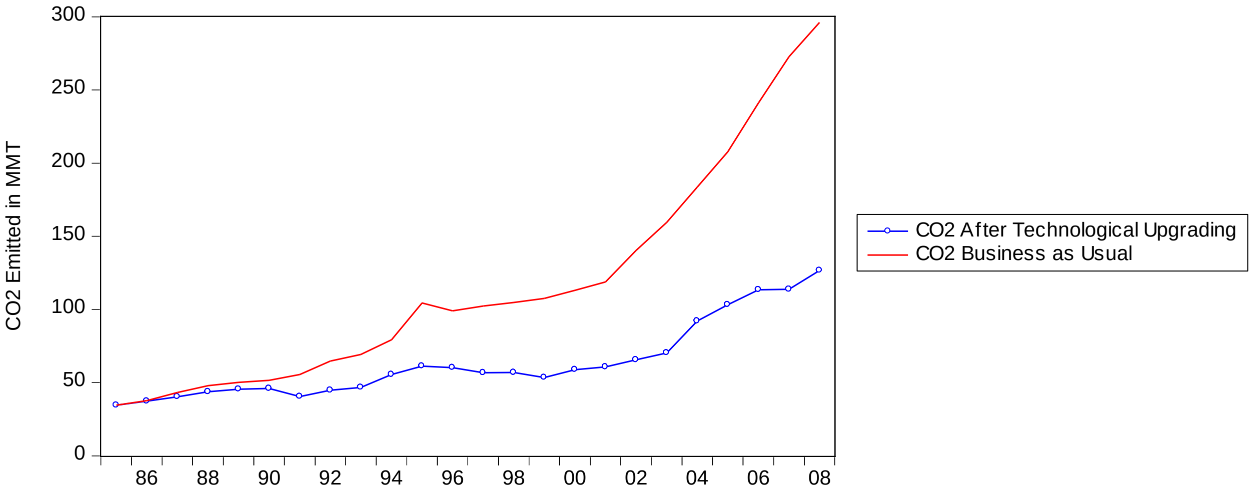
Song (2011), the CO_2 intensity of production declined by nearly 60% between 1985 and 2008, the last year for which we have data (figure 9)[96]. This resulted in CO_2 savings of about 170 million metric tons in 2008 (figure 10). Nearly all of the savings came from closing outdated facilities (77%) and materials substitution[97] (27%) (Rock and Song 2013).

Figure 9
China
CO2 Intentsity of Pulp and Paper
(Metric Tons of CO2 per Metric Ton of Paper)



Source: Rock and Song (2011)

Figure 10
China
CO2 Emissions from Pulp and Paper
(Million Metric Tons)



Source: Rock and Song (2011)

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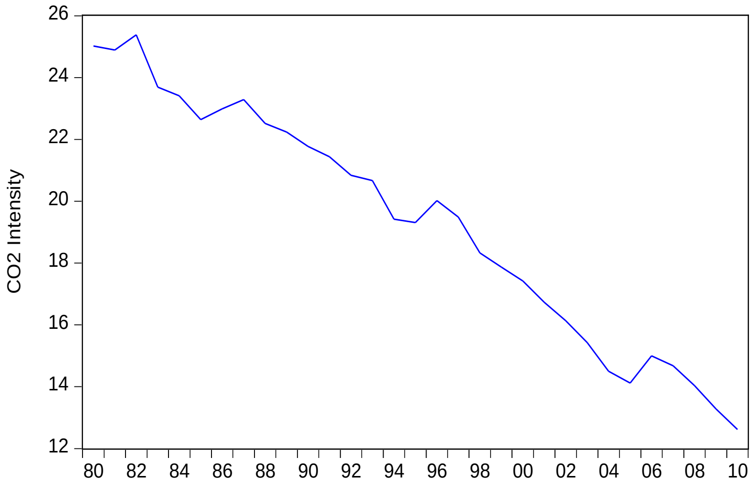
[96] At the same time energy efficiency in paper production improved from 1.39 metric tons of coal equivalent per metric ton of paper in 1985 to .5 metric tons of coal equivalent per metric ton of paper in 2008 (Rock and Song 2013: Annex Table 2).

[97] The biggest materials substitution involved used waste-paper instead of raw materials (wood, reeds, and straw) for pulping.

Finally, the technological transformation in China's aluminum industry described by Rock and Wang (2011) has resulted in equally large CO_2 savings. In the industry as a whole, the CO_2 intensity of aluminum production declined by 50% from 25.0 metric tons of CO_2 per metric ton of aluminum in 1980 to 12.6 metric tons of CO_2 per metric ton of aluminum in 2010 (figure 11). This saved 194 million metric tons of CO_2 over business as usual (figure 12). Most of the savings (118 million metric tons of CO_2 or 61% of total CO_2 saved) comes from technological upgrading of primary aluminum production, especially the closing of facilities using older Soderberg in-situ cells and shifting to more modern and technologically advanced 160 kA pre-baked and 350 kA pre-baked cells (Rock and Wang 2013). The rest (76 million metric tons of CO_2) comes from a shift in technology used to make alumina—a shift from the energy intensive Sinter process to the less energy intensive Bayer-Sinter and Bayer processes.[98]

Figure 11
China
CO2 Intensity of Aluminum Production
(Metric Tons of CO2 per Metric Ton of Aluminum)



Source: Rock and Wang (2011)

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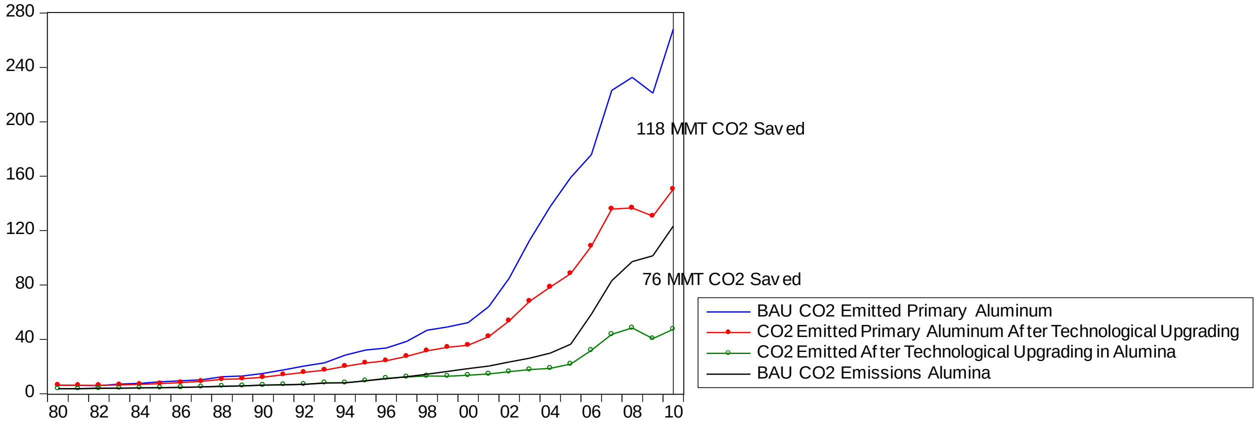
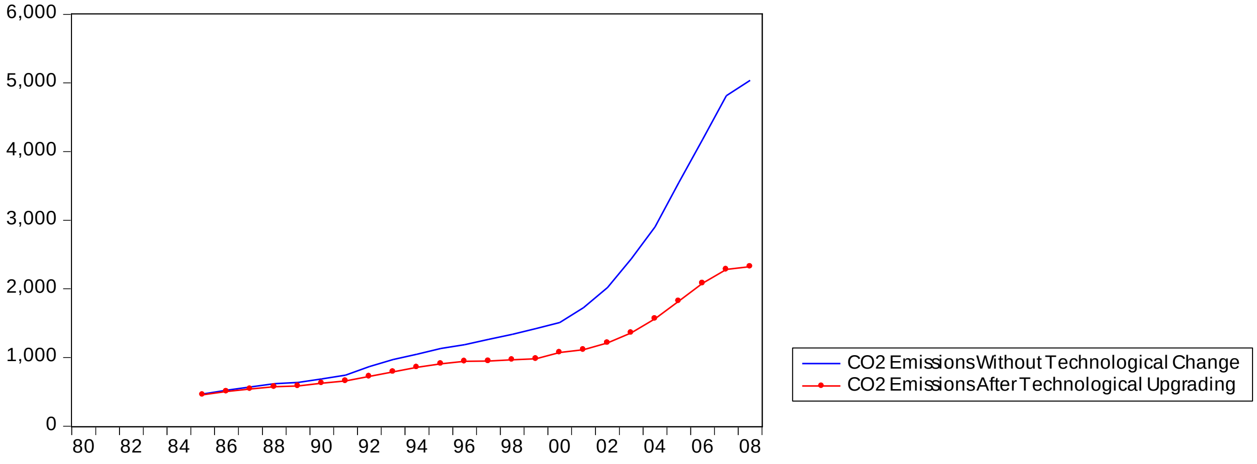
[98] In China in 2010 the Sinter process used 28.14 GJ of energy per metric ton of alumina, while the Bayer-Sinter process used 21.95 GJ per metric ton of alumina and the Bayer process used only 10.42 GJ per metric ton of alumina (Rock and Wang 2013).

Figure 12
China
CO2 Emissions from Primary Aluminum Production
and from Alumina Production
(Million Metric Tons)



Taken together, improvements in energy efficiency within existing technological regimes and technological upgrading of those regimes in China's cement, aluminum, iron and steel, and pulp and paper industries have had a remarkable impact. Without these changes CO_2 emissions from these four industries would have been nearly 2.3 times higher (5.04 billion metric tons in 2008 instead of actual emissions of 2.18 billion metric tons, figure 13). This would have pushed total CO_2 emissions from fossil fuels up by nearly 45% to 9.41 billion metric tons in 2008.[99]

Figure 13
China
CO2 Emissions from Cement,
Aluminum, Iron and Steel
and Paper Production
(Million Metric Tons)



Source: Authors Calculations

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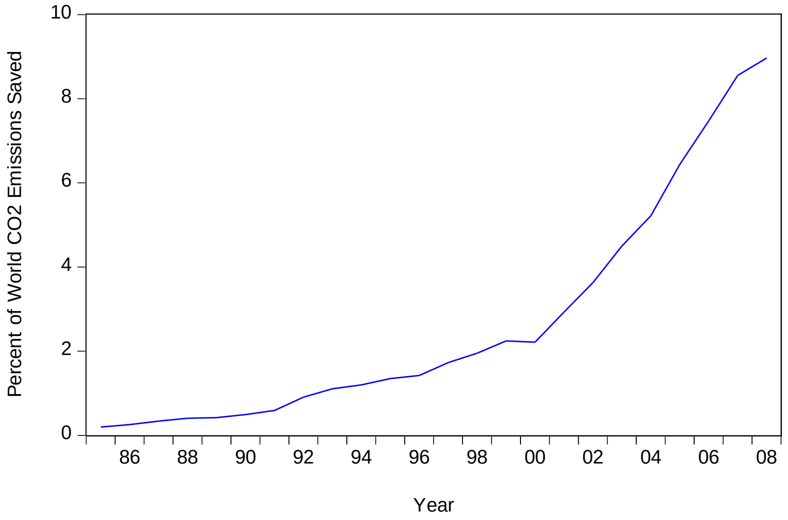
[99] Authors calculations where actual CO2 emissions from burning fossil fuels are from IEA Data Services on Line (2012).

Moreover, if China had not saved as much CO_2 as it did, global CO_2 emissions from fossil fuels would have been 9% higher in 2008 (figure 14).

Figure 14
Reduction in World CO2 Emissions Accounted for by Technological Change in Four of China's Energy Intensive Industries
(Percent of World CO2 Emissions Saved)



Source: Author's Calculations

V. Conclusions

In 1978 China's energy intensive enterprises in aluminum, cement, iron and steel and paper were mostly small, technologically backward, and energy intensive. Over the next 30 years China slowly modernized these industries in a series of discrete steps. It began closing small, technologically backward, and energy and pollution-intensive facilities. It increased competition among enterprises within these industries by liberalizing input markets, allowing more or less freedom of entry and exit, and by opening these industries to trade and foreign investment. It encouraged mergers and acquisitions so enterprises could reap economies of scale and scope. It increased energy prices and required enterprises to reduce their energy intensity. And, most critically, it provided incentives and reformed institutions to encourage enterprises in these industries to build their technological capabilities to produce aluminum, cement, iron and steel and paper with state of the art technologies.

Taken together these steps fostered a thorough ongoing technological revolution in each of these energy intensive industries. One significant side effect has been a large and fairly rapid decline in energy and CO_2 intensity in these industries, leading to significant de-linking of production from CO_2 emissions. Further progress will require some combination of continued technological modernization of the rest of enterprises in these industries, and closing all remaining small and backward enterprises. For example, Rock and Cui (2011) argue that China has several significant further opportunities to reduce CO_2 emissions from cement production. As China's industrial transformation matures, growth in demand for energy-intensive basic manufactures also will slow. However, even greater de-linking of manufacturing output and CO_2 emissions will only happen with a great deal of further effort.

China's success in de-linking CO_2 emissions from production in these industries can offer lessons for other countries in the early stages of their urban and industrial revolutions. They too can look to closing small, polluting and technologically backward facilities. They too can liberalize input markets, encourage entry and exit, and open their industries to trade and foreign investment. They are also likely to gain by allowing energy prices in energy intensive industries to rise to market levels. But if the Chinese experience tells us anything, it is that doing all of these things may have limited impact unless governments also put in place the incentives and institutions needed to encourage enterprises to invest in the hard slog of building their technological capabilities so they can reap the energy efficiency and CO_2 intensity gains associated with technological modernization. Said another way, closing backward facilities, liberalizing input and output markets, and opening an economy to trade and investment present the possibility of reaping large scale technique effects. But actually realizing those effects, at least in China, has been highly dependent on policies and institutions that encouraged enterprises to build their technological capabilities.[100]

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[100] For an example of firms in a country (Indonesia) adopting state of the art technology in an energy intensive industry (cement), yet failing to capture win-win environmental (or energy) technique effects because the country lacks a viable technology policy see Rock (2012).

One final aspect of the Chinese experience deserves note. China’s success in reducing the CO_2 intensity of industrial production has not been easy or without cost. As we show in the Appendix, attempts to create a small number of technologically sophisticated national champion enterprises that can save large amounts of energy and dominate in each of these industries have not been entirely successful. Even where successful, there is good reason to worry about the economic costs associated with the anti-competitive effects of this strategy. Others argue that bank loans to China’s state-owned enterprises, including those to national champions, undermine an efficient allocation of capital thereby imposing additional significant economic losses on the Chinese economy. Finally, given China’s highly fragmented industrial structure (Oh 2012: 5) and its highly decentralized industrial governance system, it should not be surprising that the central government has not been entirely successful in “letting go the small” by closing nearly all of the small scale, energy inefficient, and polluting facilities in these industries.

Appendix

The reforms associated with the expansion of China's "grasp the large" industrial development strategy raise several important questions. First, have they been successful? Second, how have they affected competition? Each of these is addressed in turn.

Available evidence on the effectiveness of "grasping the large, let go of the small" in aluminum, cement, steel and paper suggest that it has been partially, but so far only partially, successful. For example, in cement, the aims of the "grasping the large" restructuring program were to close small cement enterprises, shift to larger production lines using state of the art equipment, technologies, and management practices, and consolidate the industry by encouraging the creation of a small number of very large firms (Ligthart 2003). To achieve these goals, the central government adopted a set of specific quantitative restructuring goals such as reducing the number of cement firms by 40% by 2010 by closing small enterprises using antiquated vertical shaft kilns (Price et al. 2007). When combined with planned new investment, large rotary kilns were expected to account for 70% of output by 2010 (Price et al. 2007). In addition, the government planned to foster consolidation in the industry by increasing the share of output by the top ten firms to 35% (roughly 350 million tons) (Price et al. 2007). Large new dry process rotary kilns with capacity to produce more than 5,000 tons per day increased their share of cement production from 9.6% in 2000 to 34.2% in 2005, then reached nearly 62% of production in 2008 and 81% in 2010 (Kang 2007). In addition, the top ten firms in the industry increased their share of production from 4% in 2000 to 13.7% in 2005, while the top 25 publicly listed companies whose main line of business is cement now account for 25% of production (Kang 2007).

Despite these development, the cement industry continues to be fragmented—twenty-five percent of all the kilns in China continue to be small (production is less than 1,000 tons per day), 63% produce less than 2,000 tons per day, while only 6% have the capacity to produce more than 6,000 tons per day. In addition, the government has been virtually unable to enforce its cement output ceilings (Cui et al 2004: 65-66) or stop the emergence of new antiquated small scale vertical shaft kiln-based enterprises in the provinces, even though such enterprises are strictly speaking illegal (Cui 2004: 66). Moreover, the two cement groups [the China National Building Materials Group and the Anhui Hailuo Group (Sutherland 2003: 84)] it has promoted are relatively small producers of cement and they are not among the ten largest groups in the country (Cui et al 2004: 33-34). While "only" 19% of cement continues to be produced in small and inefficient plants, the sheer scale of the industry in China means that this share reflects substantial ongoing inefficiency, both economically and in energy use.

Very similar pictures are visible in iron and steel (Rock and Jiang 2013), aluminum (Rock and Song 2013), and pulp and paper (Rock and Song 2013). The government's mixed experience in creating large scale conglomerates in cement, iron and steel, aluminum, and pulp and paper mirrors experience in other Chinese industries. While there is some evidence that efforts to create national champions have partially succeeded in oil and petrochemicals (Nolan 2001 and Zhang 2004), for the most part they appear to have not been very successful in autos

(Eun and Lee 2002 and Huang 2002), information technology (Wang 2006) and aircraft (Goldstein 2005). The most probable cause for limited success lies in China's highly fragmented industrial structure (Oh 2012: 5) and its highly decentralized industrial governance structure.

In the context of China's ongoing liberalization program, a fragmented industrial structure and a decentralized industrial policy-making apparatus (World Bank 2012) have limited the ability of the central government to direct, control, and sometimes to even influence industrial policy outcomes. The most serious obstacle to the central government's industrial policies is local protectionism or what the Chinese label regional blockades. Regional blockades occur when provincial governments encourage and protect local enterprises from the consolidating tendencies of national industrial policies. This can happen when local governments block the merger of local enterprises with bigger enterprises in other provinces (World Bank 2012: 116) or when local governments promote their own regional champions in particular industries, as Shandong Province did in the iron and steel industry (World Bank 2012: 115).

It also it pays to consider the impact of these policies on competition. If successful, the creation of a small number of large enterprises in strategic industries [such as electricity, petroleum, petro-chemicals, telecom, civil aviation and waterway transportation where the government will keep absolute control (World Bank 2012: 1130] and pillar industries [such as machinery, automobiles, iron and steel, base metals, construction materials and chemicals where the state will maintain "somewhat strong influence" (World Bank 2012: 113)] has the potential to reduce competition by creating monopoly like, or at least oligopolistic markets, in these industries.

As the newly released joint China World Bank, China 2030 Report (World Bank 2012) argues, the "grasp the large let go of the small" policy has enabled China to use both ad hoc informal administrative actions [such as designation of deals between enterprises, regional blockades, and restrictions on bidding, entry and competition (Owen et al 2007: 27) as well as administrative inspections, mandatory closings, and administrative approvals for certain actions (World Bank 2012: 115)] and formal industrial policies [such as use of state resources and direct administrative actions to privilege large scale enterprises, control capacity expansion, concentrate fragmented sectors, and encourage technological development (World Bank 2012)] to attempt to shape overall industrial structure and the structure within particular industries.

Because administrative actions and industrial policies are often connected to each other and sometimes aimed at reducing what some public officials see as excessive competition by encouraging enterprises within particular industries to engage in price setting (Owen et al 2007: 19), the anti-competitive effects of these policies can be substantial. Unfortunately, there are no good studies of the anti-competitive effects of these policies. That said, one way to assess the impact of administrative and industrial policies on competition is to look at the evolution of four and eight firm concentration ratios within promoted industries. The best evidence on this topic comes from Sutherland and Ning (2008: 17) who show that four firm concentration ratios for 37 three digit standard industrial classification industries ranged from a low of 4.3 (in manufacture of textiles) to a high 119 (extraction of petroleum and natural gas). Moreover, only five industries had four firm concentration ratios above 40 (extraction of petroleum and natural gas (CR4=119), mining and processing of ferrous metal ores (CR4=52.7), manufacture of tobacco (CR4=45.2), processing of petroleum, coke and nuclear fuel (CR4=82.1), and production and distribution of electricity (CR4=65.6). In addition, no other industry had a four firm concentration ratio above 31 in 2000 or above 28 in 2006 (Sutherland and Ning 2008:17-18). Moreover, the eight firm concentration ratios are not much higher than the four firm ratios and both appear to be stable over time. For example, the CR4 for pulp and paper rose from 7.8 in 2000 to 8.9 in 2006 while the CR8 rose from 10.9 to 12.3. At the same time, the CR4 and 8 for smelting and pressing of ferrous metals actually fell—the CR8 fell from 39.5 in 2000 to 22.4 in 2008 (Sutherland and Ning 2008: 17). Thus from this perspective, it appears that China's industrial policies may be less anti-competitive than thought. That said, the World Bank (2012:112) fears that industrial policies may be more anti-competitive than is suggested by concentration ratios because they may stifle competition between state and non-state parts of industries.

References

Allen, F., J. Qian and M. Qian (2008) China's Financial System: Past, Present and Future. In L. Brandt and T.G. Rawski (eds.) *China's great economic transformation*. Cambridge: Cambridge University Press. Pp. 506-568.

Amsden, A. (1989) *Asia's Next Giant*. New York: Oxford

Baosteel Engineering n.d. Downloaded at http://bsee.baosteel.com/english/history.htm

Baosight Solutions for Iron and Steel Manufacturers downloaded at http://en.baosight.com/uploadfile/nwdown/Solutions%20For%20Iron%20And%20Steel%20Manufacturers.pdf

Baosteel (2009) 2009 Baosteel CSR Report. Shanghai, China: Baosteel. Downloaded at http://tv.baosteel.com/web/plc/csr/2009CSR_E.pdf

Baosteel Interview (2011) Interview with Mr. Zou Kuan, Vice Chariman, Planning Committee, Baosteel Corporation, Baoshan, China. January 13.

Bell, M. and K. Pavitt (1992) Accumulating technological capability in developing countries. In *Proceeding of the World Bank annual conference in development economics*. Washington, D.C.: World Bank. 257-281

Chen, J, and Y. Chen (2005) Open innovation management and the allocation of technological innovation resources: a case in China. IEEE International Engineering Management Conference. St. John's, Newfoundland and Labrador. Piscataway, NJ: IEEE Operations Center. November 11-13. Pp. 756-759.

Copeland, B.R. and S. Taylor (2003) *Trade and the Environment: Theory and Evidence*. Princeton: Princeton University Press.

Cui, Y., Fu, L., Rong, P., Li, Q., Li, Y., Shen, W., Lie, Q., Li, T., Qin, Z., Ding, K., Cong, P. and Li, H. (2004) "Final report to United Nations Industrial Development Organization (UNIDO) for cement sub-sector survey: For the project energy conservation and GHG emissions reduction in Chinese TVEs-phase II". Beijing: Institute of Technical Information for Building Materials Industry (ITIBMI).

Dahlman, C. Bruce Ross-Larson and Larry Westphal (1987) Managing technological development: Lessons from the newly industrializing economies (NICs). *World Development*. 15 (6): 759-775.

Dutz, Mark A., Ioannis Kessides, Stephen O'Connell, and Robert D. Willig (2011) Competition and innovation-driven inclusive growth. World Bank Policy Research Working Paper 5852, October.

Eun, Jong-Hak and Keun Lee (2002) Is an industrial policy possible in China?: The case of the automobile industry. *Journal of International and Area Studies*. 9 (2): 1-21.

Fisher-Vanden, K., Y. Hu, G. Jefferson, M. T. Rock and M. Toman (2013) Factors influencing energy intensity in four Chinese industries. Forthcoming Working Paper, Washington, DC: The World Bank.

Fisher-Vanden, Karen, Gary Jefferson, Hongmei Liu and Quan Tao (2004) What is driving China's decline in energy intensity? *Resource and Energy Economics*. 26: 77-97.

Goldstein, A. (2005) The political economy of industrial policy in China: The case of aircraft manufacture. William Davidson Institute Working Paper No. 779. Ann Arbor: University of Michigan.

Gu, S. B. Lundvall, J. Liu, F. Malerba and S. S. Serger (2009) China's system and vision of innovation: An analysis in relation to the strategic adjustment and the Medium and Long-Term S&T Development Plan (2006-20). *Industry and Innovation*. 16: 405. 369-388.

Hobday, M. (1995) Innovation in East Asia: The Challenge to Japan. Lyme, U.S.: EdwardElgar.

Hu, A.G.Z., G.H. Jefferson and Q. Jinchang (2005) R&D and technology transfer: Firm level evidence from Chinese industry. *Review of Economics and Statistics*. 87 (4): 780-786.

Hu, A. G. Z. and G.H. Jefferson (2002) FDI impact and spillover: Evidence from China's electronics and textile industries. *World Economy*. 25 (8): 1063-1076.

Huang, Y. (2002) Between two coordination failures: Automotive industrial policy in China with a comparison to Korea. *Review of International Political Economy*. 9 (3): 538-573.

Huff, W. G. (1994) *The Economic Growth of Singapore*. Cambridge: Cambridge University Press.

Jackson, S. F. (1994) In whose image: Policy diffusion and policy process in the Chinese steel industry, 1977-1991. PhD. Dissertation. Ann Arbor: University of Michigan.

Kang, Xiiangzhang (2007) Overview of China's cement industry. Beijing: China Cement Association.

Keister, L. A. (1998) Engineering growth: Business group structure and firm performance in China's transition economy. *American Journal of Sociology*. 104 (2): 404-440.

Kim, L. (1997) *Imitation to Innovation: The Dynamics of Korea's Technological Learning.* Cambridge, M.: Harvard University Press.

Lall, S. (1992) Technological capabilities and industrialization. *World Development*. 20 (2) 165-186.

Lee, K. Y. (2000) *From Third World to First*. New York: Harper Collins.

Ligthart, A. (2003) The cement industry in China: Present structure, Restructuring programme, Opportunities. Power Point Presentation. June 25, London, U.K.

Naughton, B. (2007) *The Chinese economy: Transitions and growth*. Cambridge: MIT Press.

Naughton, B. (2003) Government Reorganization: Lui Mingkang and Financial Restructuring. China Leadership Monitor. No. 7 Summer. Downloaded at www.hoover.org/publications/clm/issues/2904276.html.

Nelson, R. R. (2005) *Technology, Institutions and economic growth*. Cambridge, MA: Harvard University Press.

Nolan, P.(2001) *China and the global business revolution. Houndsmill: Palgrave.*

Oh, S. Y. (2012) Fragmented Liberalization in the Chinese Automotive Industry: The Political logic behind Beijing Hyundai's success in the Chinese market. Processed.

Owen, B. M., S. Sun, and W. Zheng (2007) China's competition policy reforms: The anti-monopoly law and beyond. Stanford, CA: Stanford Institute for Economic Policy Research. SIEPR Discussion Paper No. 06-32.

Perkins, D., Parish, W., DeAngelis, A., Rawski, T., Dernberger, R., Simmons, K., Hallford, S., Stinchcombe, A., Khan, A., Timmer, P., Livingston, O., and Van Slyke, L. (1977) *Rural small scale industry in the People's Republic of China*. Berkeley: University of California Press.

Price, L., M. D. Levine, N. Zhou, D. Fridley, N. Aden, H. Lu, M. McNeil, N. Zheng, Y. Qina and Yowarganab, P. (2011). Assessment of China's Energy-Saving and Emission-Reduction Accomplishments and Opportunities During the 11th Five Year Plan. *Energy Policy* 39(4): 2165-2178.

Price, L. X. Wang, J. Yun (2008) China's top-1000 enterprise program: Reducing energy consumption of the 1000 largest industrial enterprises in China. Berkeley: Lawrence Berkeley National Laboratory. LBNL-519E.

Price, L. X. Wang, J. Yun (2010) The challenge of reducing energy consumption of the Top 1000 enterprises largest industrial enterprises in China. Energy Policy. 38 (11): 6485-6498.

Price, L. and Galitsky (2007) Opportunities for improving energy efficiency and increasing economic output in Chinese cement kilns. ACEEE Summer study on energy efficiency in industry. Lawrence Berkeley National Laboratory.

Rawski, T. (1980) *China's Transition to Industrialism*. Ann Arbor: University of Michigan Press.

Rhee, Y. H., Ross-Larson, B. and Westphal, L. (1984) Korea's Competitive Edge: Managing Entry into World Markets. Baltimore: Johns Hopkins University Press.

Rock, M. T. (2012) What Can Indonesia Learn from China's Industrial Energy Saving Programs? *Bulletin of Indonesian Economic Studies*. 48 (1): 33-55.

Rock, M. T. (2013) China's Industrial Development Strategy and Energy Use. In M.T. Rock and M. Toman, *China's Technological Catch-Up Strategy for Industrial Development: Impact on Energy Efficiency and* CO_2 *Emissions.* Oxford: Oxford University Press, forthcoming.

Rock, Michael T. and David P. Angel (2005) *Industrial transformation in the developing world*. Oxford: Oxford University Press.

Rock, M. T. and Y. Cui (2013) Breaking the Link between Production and CO_2 Emissions in China's Cement Industry: The Role of Technological Learning. In M.T. Rock and M. Toman, *China's Technological Catch-Up Strategy for Industrial Development: Impact on Energy Efficiency and* CO_2 *Emissions.* Oxford: Oxford University Press, forthcoming.

Rock, M. T. and Y. Wang (2013) Modernizing the aluminum industry. In M.T. Rock and M. Toman, *China's Technological Catch-Up Strategy for Industrial Development: Impact on Energy Efficiency and* CO_2 *Emissions.* Oxford: Oxford University Press, forthcoming.

Rock, M. T. and Y. Song (2013) Technological change in pulp and paper. In M.T. Rock and M. Toman, *China's Technological Catch-Up Strategy for Industrial Development: Impact on Energy Efficiency and CO_2 Emissions.* Oxford: Oxford University Press, forthcoming.

Rock, M. T. K., Jiang (2013) Saving energy and CO_2 in iron and steel. In M.T. Rock and M. Toman, *China's Technological Catch-Up Strategy for Industrial Development: Impact on Energy Efficiency and CO_2 Emissions.* Oxford: Oxford University Press, forthcoming.

Sinton, J., Levine, M., Wang, Q., 1998. Energy efficiency in China: accomplishments and challenges. Energy Policy 26 (11), 813–829.

Sirgudson, J. (1997) *Rural Industrialization in China*. Cambridge, MA: Council on East Asian Studies, Harvard University.

Sun, P. (2005) Industrial Policy, Corporate Governance, and the Competitiveness of China's National Champions: The Case of Shanghai Baosteel Group. *Journal of Chinese Economic and Business Studies* Vol. 3(2) 173-192

Sutherland, D. (2003) *China's large enterprises and the challenge of late industrialism*. London: Routledge Curzon.

Sutherland, D. (2007) China's "national team" of enterprise groups: How has it performed? Discussion Paper no. 23. China Policy Institute. Nottingham, U.K.: The University of Nottingham.

Sutherland, D. and L. Ning (2008) Exploring and explaining the extent of concentration and diversification in Chinese business groups. Processed.

UNIDO (2002) *Industrial Development Report, 2002/2003: Competing through Innovation and Learning.* Vienna: United Nations Industrial Development Organization.

Wade, R. H. (1990) Governing the Market. Princeton: Princeton University Press.

Wang, J. (2006) China's dualist model on technological catching up: a comparative perspective. *The Pacific Review*. 19 (3): 385-403.

Westphal, L. (1981) Korea's Industrial Competence: Where It Came From. World Bank Staff Working Paper No. 469. Washington, D.C.: World Bank.

Wong, C. P. W. (2003) Legacies of the Maoist development strategy: Rural industrialization from the 1970s to the 1990s. In Law, K. (ed.) *The Chinese Cultural Revolution reconsidered*. London: Palgrave-MacMillan.

Wong, C. P. W. (1979) *Rural industrialization in China: Development of the "five small industries"*. PhD. dissertation. University of California, Berkeley.

World Bank (2012) *China 2030: Building a modern, harmonious, and creative high-income society*. Washington, DC: The World Bank

World Bank (2012) World Development Indicators (WDI) On-Line. Washington, D.C.: World Bank.

Wu, K. and I. Storey (2007) Energy security in China's capitalist transition: Import dependence, oil diplomacy, and security imperatives. In McNally, C. A. (ed.) China's Emergent Political Economy: Capitalism in the Dragon's Lair. New York: Routledge. Pp. 190-208.

Zhang, J. (2004) *Catch-up and competitiveness in China: The case of large firms in the oil industry*. London: Routledge Curzon.

Zhou, N., Levine, M. D. and L. Price (2010) Overview of current energy-efficiency policies in China. Energy Policy. 38: 6439-6452

Zou, K. (2008) Baosteel Energy-saving and Emission-reducing Practice. April 15, 2008. Busan Korea. Downloaded at http://www.asiapacificpartnership.org/pdf/Steel/5th_meeting/4-3%28Baosteel%29.pdf

Zweig, D. (2001) China's Stalled Fifth Wave: Zhu Rongji's Reform Package of 1998-2000. *Asian Survey*. 41 (2): 231-241.