WPS6551

Policy Research Working Paper 6551

Factors Influencing Energy Intensity in Four Chinese Industries

Karen Fisher-Vanden
Yong Hu
Gary Jefferson
Michael Rock
Michael Toman

The World Bank
Development Research Group
Environment and Energy Team
July 2013

Abstract

Energy intensity has declined significantly in four Chinese industries—pulp and paper; cement; iron and steel; and aluminum. While previous studies have identified technological change within an industry to be an important influence on energy intensity, few have examined how industry-specific policies and market factors also affect industry-level intensity. This paper employs unique firm-level data from China's most energy-intensive large and medium-size industrial enterprises in each of these four industries over a six-year period from 1999 to 2004. It empirically examines how China's energy-saving programs, liberalization of domestic markets, openness to the world economy, and other policies, contribute to the decline in energy intensity in these industries. The results suggest that rising energy costs are a significant contributor to the decline in energy intensity in all four industries. China's industrial policies targeting scale economies—for example, "grasping the large, letting go off the small"—also seem to have contributed to reductions in energy intensity in these four industries. However, the results also suggest that trade openness and technology development led to declines in energy intensity in only one or two of these industries. Finally, the analysis finds that energy intensities vary among firms with different ownership types and regional locations.

This paper is a product of the Environment and Energy Team, Development Research Group. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The World Bank co-author, Michael Toman, may be contacted at mtoman@worldbank.org.

Factors influencing energy intensity in four Chinese industries*

Karen Fisher-Vanden, Yong Hu, Gary Jefferson, Michael Rock, Michael Toman

JEL Classifications: O13, O14, Q55, Q56, L61
Keywords: energy intensity; industrial policy; energy pricing; Chinese manufacturing.
Sectors: Energy, Environment

*Author affiliations: Fisher-Vanden, Pennsylvania State University; Hu, Pennsylvania State University; Jefferson, Brandeis University; Rock, Resources for the Future and Bryn Mawr College; Toman, Development Research Group, World Bank. The authors acknowledge with gratitude financial support for the research from the World Bank Knowledge for Change Program. The findings in the paper are the authors' alone and should not be attributed to the World Bank or any of its member countries. Responsibility for errors also is the authors' alone.

Factors influencing energy intensity in four Chinese industries

I. Introduction

Since the onset of economic reforms in 1978, China's economy has experienced rapid growth, with GDP (in constant price) growing at an average annual growth rate of 9.7% between 1978 and 2006 (He and Wang, 2007). Such significant economic development usually drives up energy usage, but China's energy intensity, defined as total energy consumption in physical quantities over real GDP, has steadily declined over the years, on average 3.6% annually from 1993–2005 (He and Wang, 2007).

The reason behind this energy intensity decline has been widely investigated and is usually separated into two main contributing factors: structural change and technological change. Structural change refers to a shift in the sectoral composition of the economy; e.g., a shift away from heavy industry to light industry. Technological change, on the other hand, is related to process changes made at the firm level to improve productivity. A number of market reforms have been instituted in China that have implications for structural and technological change. In 1998, 21 ministries—including industrial sector-line ministries that provide macro-planning for each industry sector—were eliminated by the central government (Naughton 2003). In 2003, the National Development and Reform Commission (NDRC) was formed to regulate China's social market economy and to shift the government's role more toward market coordination (Naughton 2003). Furthermore, in order to compete with international markets and to capture the benefits of scale economies, China's State Council implemented industrial policies focused on "grasping the large, letting go the small" whereby smaller facilities were either shut down or consolidated with other facilities (Sutherland 2003).

As a result of these policies, selected enterprises in 57 targeted, state-owned industrial groups received preferential treatment, including the allocation of a greater share of state assets within their respective groups, and targeted investment to improve R&D capabilities via a closer relationship with state research institutions. Many empirical studies have investigated whether these policies have contributed to the decline of energy intensity in China. Although Fan, Liao, and Wei (2007) point out that China's energy intensity fell faster prior to market reforms initiated in 1992, they find that the own-price elasticity for energy was positive prior to 1992 and negative afterwards, providing further support that reforms are providing the necessary incentives for firms to reduce energy use in response to higher energy prices. Fisher-Vanden (2009) also argues that China's transition to a market economy has induced a large decline in energy intensity. Using provincial panel data, He and Wang (2007) find that economic transition—including market liberalization, decentralization, and globalization—contributed to provincial energy efficiency improvements between the years 1996 and 2007. Lastly, Fisher-Vanden, Jefferson, Liu, and Tao (2004), the only study using firm-level data, find that sectoral shift (i.e., structural change) can explain almost 50% of the decline in total energy intensity over the period 1997-1999.

Technological change, including subsector productivity changes and R&D input, has been shown to be the most effective factor driving China's decline in energy intensity after 1979. For example, shifting from vertical shaft kilns to more efficient rotary kilns accounted for 21% of the total reduction in CO_2 emissions in the cement industry in 2008 (Rock, 2011). Garbaccio, Ho, and Jorgenson (1999), in their decomposition analysis using input-output tables from 1987 and 1992, find sectoral technological change to be the largest factor explaining the decline in Chinese enterprises' energy intensity between 1987 and 1992. Fan, Liao, and Wei (2007), using a similar decomposition analysis employing sub-sector data at the two-digit level, find that the efficiency effect contributed more than structural change to the decline in China's energy intensity. Ma and Stern (2008) also conduct a similar analysis but look at the role of inter-fuel substitution in sub-sector energy intensity decline. Like the earlier studies, they find technological change to be the most important factor explaining the reduction in sub-sector energy intensity from 1980–2003 but also find that inter-fuel substitution had no effect on this decline. He and Wang (2007) also show that foreign direct investment induced reductions in provincial energy intensity between 1996 and 2007.

Rising energy costs throughout China have also induced energy savings. By 1999, the allocation of energy through the state plan was almost totally eliminated (Fisher-Vanden et al. 2004), causing state-owned enterprises to face world prices for energy at the margin. This shift from plan-market allocation to market-oriented allocation has led to an increase in energy prices, especially for state-owned enterprises. Fisher-Vanden et al. (2004) find that rising energy prices contributed significantly to the decline of firm-level energy intensity, with 54.4% of the decline in aggregate energy-use explained by rising energy costs. Hang and Tu (2007) find that higher energy prices helped to decrease the intensity of aggregate energy up until 1995; after 1995, however, the effects were negligible or even non-existent.

In this paper, we investigate the factors explaining the decline in energy intensity in four Chinese industries: Pulp and Paper; Cement; Iron and Steel; and Aluminum. There are many studies specifically on Chinese industry; e.g., Wei, Liao, and Fan (2007), Garbaccio, Ho, and Jorgenson (1999), Ma and Stern (2008), Zheng, Qi, and Chen (2011). Wei, Liao, and Fan (2007) show that

China's iron and steel industry has reduced its energy intensity by 60% from 1994–2003, while variation in energy intensity across firms in China's iron and steel sector has become larger during the same period. However, unlike our present study, these past studies employ industry- not firm-level data and are therefore unable to examine what is happening at the firm-level.

In this paper, we utilize a unique set of firm-level data from China's most energy-intensive large- and medium-size industrial enterprises in each of these four industries over a six-year period, 1999–2004. We empirically examine to what extent China's energy-saving programs, liberalization of domestic markets, and openness to the world economy contributed to the decline in energy intensity within these industries. We estimate firm-level energy intensity on factors such as energy prices, technology development expenditures, region, and ownership type, expecting that higher energy prices, technology development (including process innovation and product innovation), more openness to world markets (including regional location), and ownership reform have all contributed to the decline in energy intensity in these four industries.

We find rising energy prices to be one of the main factors explaining the decline in energy intensity in these industries. Scale economies, encouraged by policies such as "grasping the large, letting go off the small" are another important factor explaining the decline within each industry. However, technology development, trade openness, and regional and ownership differences are only contributors in one or two of the four industries. Additionally, in the case of Pulp and Paper, firms in the Northern and Eastern regions of China have lower energy intensity than firms in the South. In the Cement industry, the energy intensity of firms in the North, East, and South is less than firms in the Southwest. In the Iron and Steel industry, energy intensity of firms in the South and Southwest is less than firms in the North and East.

The paper is organized as follows. Section II describes the relevant energy and development policies in these four industries that might affect firm-level energy intensity. Section III provides a literature review that summarizes previous work on the analysis of China's energy intensity decline, including investigations on specific industries and the overall economy. Section IV presents the data set used in this analysis and section V describes our estimation approach. Section VI discusses the empirical results and offers interpretation while Section VII provides results from various robustness tests. Lastly, Section VIII offers concluding remarks.

II. Energy consumption and development policies in four Chinese industries

Understanding the factors influencing energy intensity in these four industries in China is important as these industries lead the nation in energy consumption and, combined, comprise a large share of China's industrial output. For example, the share of industrial output from the top-ten Chinese cement firms has increased from 4% in 2000 to 13.5% in 2005 (Rock, 2011) and, in 2007, energy consumption in the cement industry accounted for 5.6% of China's total energy consumption (Cai et al. 2011). China's iron and steel industry became the largest producer of crude steel in the world in 1996 (Wei et al. 2007) and, more recently, has become the largest energy consuming sector in the nation. According to Dao (2010), this industry accounts for approximately 11% of China's total energy consumption in 2010, with coal and gas comprising 47% of total primary energy consumption in this sector.

In recent years, these industries have reduced their energy intensity dramatically—energy intensity in the cement industry fell by 10.2% between 2002 and 2007 (Cai et al. 2011) while the energy intensity of large- and medium-sized enterprises in the iron and steel industry decreased by almost 50% between 1990–2006 (Dao 2010). While the output of China's pulp and paper industry doubled from 1995–2005, energy consumption per unit of output fell by 60% over the same period (Zhang et al. 2008). Over the period 2001-2006, energy consumption per unit of aluminum products and primary aluminum fell by 24.1% and 3.21%, respectively (Xiao, 2007).

Since the onset of economic reforms in the late 1970s, the Chinese government has instituted a number of policies to improve efficiency in these four industries. A key industrial development strategy introduced in 1997, "grasping the large, letting go of the small," focuses on consolidating and eliminating small-scale operations. The goal of this development strategy is to improve energy efficiency, reduce emissions, eliminate excess capacity, and improve enterprises' technological capabilities. "Grasping the large, letting go off the small" was motivated by China's desire to create large state-owned enterprises that can compete with OECD multinationals. A key feature of this policy is to give core enterprises in each of the 57 state-owned industrial groups favored access to state loans and state research institutes (Sutherland 2003).

As a result of "grasping the large, letting go of the small," the number of enterprises fell dramatically in these industries. In the cement industry, the production share of large rotary kilns-based plants reached nearly 62% of total cement production in 2008 and the top-25 publicly listed enterprises with cement as their main product accounted for 25% of total cement production (Rock, 2011). In the iron and steel industry, it is estimated that the top-10 steel producers will account for 50% of steel production by 2010, and 70% by 2020. Moreover, two of the top-10 firms in this industry will be expected to each produce at least 30 million metric tons while several others will each produce 10 million metric tons (Rock and Jiang, 2013). The number of large-scale firms producing more than 5 million metric tons rose from 8 in 2002 to 15 in 2004 and the production share of these large firms rose from 36.7% in 2002 to 40% in 2004 (Rock and Jiang, 2013).

In the aluminum industry, “grasping the large, letting go off the small” prohibited the establishment of new small aluminum plants and small primary aluminum producers with outdated technologies were forced to close. The six largest alumina producers produced almost all of China’s 6 million metric tons of alumina in 2003. In 2005, the 15 largest aluminum producers accounted for 45% of total production with the 10 largest of them accounting for 34% of total production (Rock and Wang, 2013).

In addition to the policy of “grasping the large, letting go off the small”, the Chinese government established energy intensity standards in a wide range of industrial sectors beginning in the early 1980s. Firms that fail to meet the standards were either forced to pay higher prices for energy used in excess of the standard or were forced to close. The Chinese government also created a large number of energy conservation centers to help firms improve energy efficiency (Sinton et al 1998).

In addition to policies that target the industrial sector as a whole, the Chinese government has also introduced a number of industry-specific policies that have implications for energy use. For instance, in order to reduce the number of small enterprises in the pulp and paper industry, China’s State Council issued the “Decision of the State Council on Several Issues Concerning Environment Protection” policy in 1996, which required 15 types of heavy polluting small enterprises to be closed before September 30, 1996 (China State Council, 1996). In addition, the “Technical Policy for Pollution Prevention of Wastewater from Straw Pulp Papermaking Industry”—issued by the Ministry of Environmental Protection—required pulp and paper firms to meet new discharge standards and to close all chemical pulp mills with output less than 5000 metric tons per year by the end of the year 2000 (State Environmental Protection Agency of China, 1999). As a result, the number of pulp and paper enterprises fell dramatically from 12,000 in year 1995 to 3,700 in year 2009 (Rock and Song, 2013) with many large integrated pulp and paper producers emerging that are similar in scale to OECD multinationals.

Also, in China's Tenth Five Year Plan (2001-2005), the pulp and paper industry was encouraged to shift from straw and reed pulp to wood pulp and wastepaper pulp in an attempt to improve efficiency and product quality. Non-wood pulp drop from 48.5% of total pulp production in 1994 to 15.7% in 2008, while wood pulp and wastepaper pulp rose from 24.7% and 22.8% in 1985 to 31% and 53.4% in 2008, respectively (Rock and Song 2011).

Technology-related process changes were also encouraged in other industries. In the cement industry, the State Building Materials Bureau in China, in an attempt to improve energy efficiency, has emphasized the conversion from wet to dry process kilns, increased adoption of co-generation, and improved efficiency in the preparation of raw materials (Rock, 2011). In the iron and steel industry, firms were encouraged by the Chinese government to make process changes to reduce the iron-to-steel ratio, to establish energy management centers, and to utilize more than 50% of waste heat by 2015 (China State Council, 2012). In the aluminum industry, the Chinese government required enterprises to upgrade to more efficient pre-baked cell production technology or face closure. In addition, aluminum producers were required to upgrade to meet more stringent energy efficiency standards (Rock and Wang, 2013).

III. Literature Review & Research Hypotheses

Over the past ten years, China's industrial sector has made substantial reductions in energy intensity through the implementation of market reforms. Fisher-Vanden et al. (2004) point out that there has been a nearly 70% decline in Chinese energy intensity during the 1980s and 1990s, attributing market-oriented reforms as one of the main reasons behind this decline. Fan, Liao, and Wei (2007) estimate changes in own-price elasticity and elasticities of substitution between energy, capital and labor, and find that accelerated market-oriented reforms have contributed significantly to the decline in energy intensity since 1993. He and Wang (2007), using panel data on energy intensity across 30 Chinese provinces from 1998–2005, examine the relationship between economic transition—including market liberalization, decentralization, and globalization—and the decline in energy intensity among Chinese enterprises. Their empirical results show that economic transition made a substantial contribution to the decline in energy intensity over this time period.

Rising energy prices are another important factor. Fisher-Vanden et al. (2004) suggest that rising energy prices have contributed significantly to intensity declines across several energy types. Hang and Tu (2007) estimate energy-price elasticities to evaluate the effects of price changes on aggregate energy intensity and find, for each energy type, rising energy prices have led to a decline in energy intensity.

Research and development activities have also contributed to declines in industrial energy intensity. Since the late 1990s, the Chinese government has undergone the process of privatizing R&D institutes. As a result of these policies, commercial R&D expenditures as a share of China's total R&D expenditures has risen from 32% in 1994 to 60% in 2000 (Fisher-Vanden 2009). It is expected that this increase in R&D expenditures will lead to more efficient production processes and, therefore, lower energy intensity. Garbaccio, Ho, and Jorgenson (1999) find that technical change rather than structural change explains most of the decline in China's energy intensity from 1987–1992. Using logarithmic mean Divisia index techniques to examine changes in energy use per unit from 1980–2003, Ma and Stern (2008) also find technical change to be the most important factor explaining energy intensity decline.

Foreign direct investment (FDI) has also contributed to the decline in energy intensity. Fisher-Vanden et al. (2004) find the energy intensity of foreign firms in China, on average, to be lower than that of local firms. Empirical results in Fisher-Vanden et al. (2009) show that spillover effects of FDI tend to be energy-saving. He and Wang (2007) also provide empirical evidence to suggest that foreign capital has had an effect on lowering the energy intensity of Chinese enterprises.

This paper contributes to the literature in a number of ways: First, except for Fisher-Vanden et al (2004), previous studies examining China's decline in energy intensity have been at the sector- or regional-level. Like Fisher-Vanden et al (2004), we will utilize a data set of Chinese industrial enterprises in order to identify the factors contributing to lower energy intensity at the firm-level. Second, we extend the analysis of Fisher-Vanden et al (2004) by (a) focusing on a longer time period (1999-2004) over which a number of policies related to energy use have occurred and (b) focusing on four specific industries which will allow us to examine how the impacts of common industrial policies differ across industries.

Given the above review of the literature and summary of policies affecting firm-level energy intensity, a number of hypotheses emerge which we will test in this paper. We organize these testable hypotheses below under six general categories—energy prices; trade openness; technology development; foreign influence; scale economies; and regional effects.

Energy prices

H1: Fisher-Vanden et al. (2004) find that rising energy prices have resulted in lower energy intensity. Prior to the mid-1980s, energy prices were set by the central government. In the early 1980s, tiered pricing systems were introduced where firms were required to sell up to a predetermined quota at government set prices but were allowed to sell above the quota at market prices. To a large extent, quotas were removed and energy prices were liberalized as part of sweeping price reforms initiated in 1993. As a result, relative energy prices have risen dramatically over the last 30 years. Based on this, we expect that higher energy prices will have a negative and significant effect on energy intensity. Moreover, since non-state-owned enterprises (non SOEs) are likely more market-oriented than state-owned enterprises (SOEs), we expect that non SOEs will lower energy intensities more than SOEs in response to higher energy prices.

Trade openness

H2: We expect that China's increasing openness to the world market—beginning with China's accession to the World Trade Organization (WTO) in 2001—will also be an important factor explaining differences in firm-level energy intensity in these four industries.

Technology development

H3: As discussed in Rock (2012), Worrell et al. (2008), in their study of the cement industry, find that shifting from vertical shaft kilns to rotary kilns (a more efficient technology) and shifting to blended cement together accounted for a 21% reduction in CO_2 emissions in 2008. We therefore expect that technology development activities, including process innovation and product innovation, contribute significantly to lower energy intensities in industries such as cement.

H4: As energy prices rise, firms may respond by increasing technology development activities targeting improvements in energy efficiency. The R&D intensity in China (i.e., R&D expenditures/real GDP) has risen from 0.6 in 1996 to 1.3 in 2003 (Fisher-Vanden and Ho, 2010). Therefore, we expect a negative relationship between the interaction of energy price and technology development, and energy intensity.

Foreign influence

H5: Foreign direct investment (FDI) is thought to introduce advanced technologies and managerial skills to the host country, improving firm efficiency. For example, Mielnik and Goldemberg (2002) find that developing countries with higher foreign direct investment have lower energy intensity. We therefore expect FDI will lead to lower energy intensity in these four industries.

H6: Firms with higher technology development activity are expected to have larger adaptive capacities,[1] which will utilize FDI more efficiently. Based on this, we expect the interaction of technology development and FDI to lead to lower energy intensity.

[1] For example, Kinoshita (2001) finds that the learning effect of R&D is more important than the innovation effect.

H7: Fisher-Vanden et al. (2004) find that foreign-owned enterprises experience larger declines in energy intensity. Therefore, we expect foreign-owned enterprises in these four industries to have lower energy intensities than other ownership types.

<u>Scale economies</u>

H8: Since larger enterprises have many advantages over smaller enterprises—most importantly, scale economies—we expect that China's policy of "grasping the large, letting go of the small," discussed in the previous section, will lead to lower energy intensity in these four industries.

<u>Regional effects</u>

H9: Since the onset of economic reforms in 1979, the industrial structure in China has become more decentralized, with variations in the implementation of market reforms and exposure to international markets across regions. Given this, we expect firms in the more developed regions, such as the North and East, will have lower energy intensities than firms in other regions.

IV. Data

The data set used in our analysis is the combination of three firm-level data sets collected annually by China's National Bureau of Statistics (NBS). The first data set consists of economic and financial variables, comprising approximately 22,000 large- and medium-sized industrial enterprises. The second data set comprises science and technology (S&T) variables and includes the same number of enterprises as the economic and financial data set. The third data set contains a number of energy variables for the most energy intensive enterprises (approximately 1500 enterprises).

To create a balanced data set, we drop any firm that does not report in all ten years. Missing years often occur when the size of a firm shrinks below the large and medium enterprise size threshold, or a firm experiences a change in ownership due to industry reform, mergers, or changes in location. Many firms are missing at least one year between 1995 and 2004, and in order to maintain the continuity of data (and to be able to create technology development stocks), we were forced to drop these firms from the study. Our final balanced data set consists of 2,000 firms per year from 1995–2004, or 20,000 observations in total.[2]

We then combine the economic and S&T data sets with the energy data set, which includes measures of approximately 20 individual energy types in both quantity and value terms. Merging with the energy data set reduces the number of observations significantly, largely for two reasons: (1) the energy data set focuses only on the most energy-intensive enterprises and therefore is not as comprehensive as the economic and S&T data sets; and (2) it only covers the period 1999–2004 while the economic and S&T data sets cover a longer period, 1995-2004. Although the number of observations is significantly reduced when the energy data set is included, total energy consumption in our balanced dataset comprises a significant portion of total energy consumption in each industry. For example, total energy consumption of the enterprises in our merged dataset accounts for 40% of total industrial energy consumption in 1999.[3]

Most variables used in the analysis are included in the original data set. However, a few variables had to be constructed, namely the technology development stock variable:

---

[2] We examine the implications of using a balanced versus unbalanced data set in Section VII ("Robustness tests")

[3] National Bureau of Statistics of China, 2000.

$K_{R,i,t} = (1-\delta)K_{R,i,t-1} + I_{R,i,t-1}$

where

$K_{R,i,t} \equiv$ technology development stock of firm i at time t;

$I_{R,i,t-1} \equiv$ technology development expenditures of firm i at time t-1; and

$\delta \equiv$ depreciation rate (assumed to be 15%).

The NBS data set provides the flow of technology development expenditures by firm over the period 1995-2004. We estimate the technology development stock in the initial year 1995 as follows:

$$K_{R,i,1995} = I_{R,i,1995} / (\delta+\gamma)$$

where γ is the growth rate of $I_{R,}$ estimated as the average annual growth rate of the 2-digit industry of firm i over the period 1995-2004.

Obviously, after narrowing our merged dataset to the four industries that are the focus of this study, we lose a considerable number of firms. Specifically, we have 49 firms and 294 observations in the pulp and paper industry; 115 firms and 690 observations in the cement industry; 70 firms and 420 observations in the iron and steel industry; and 27 firms and 162 observations in the aluminum industry.

China's National Bureau of Statistics classifies enterprises into seven ownership types (state-owned, collective-owned, HKMT (Hong Kong SAR, China; Macao; and Taiwan, China), foreign, shareholding, private, and other) and six regional locations (North, Northeast, East, South, Southwest, and Northwest). Tables 1 and 2 provide distributions across ownership type and region by industry in our dataset. In all four industries, most enterprises are either state-owned or shareholding, and are located in the South or, in particular, the East where more than half of the total number of firms in the data set are located. Table 3 provides a breakdown of foreign capital and technology development intensities by industry and by year. We find that the cement industry has the highest foreign capital intensity while the iron and steel industry has the highest technology development intensity.

V. Model specification

The estimation equations used in this analysis are derived from cost minimization, assuming the following Cobb-Douglas cost function:

$$C(P_K, P_L, P_E, P_M) = A^{-1} P_K^{\alpha_K} P_L^{\alpha_L} P_E^{\alpha_E} P_M^{\alpha_M} Q$$

where C is cost, Q is the quantity of output, P_K is the price of capital input, P_L is the price of labor input, P_E is the price of energy input, P_M is the price of material input, α_X is the elasticity of input X (X=capital, labor, energy, material), and $\sum_{X=K,L,E,M} \alpha_X = 1$. A is the total factor productivity term defined as:

$$A = \exp(\theta \ln(RDE) + \sum_{t=1999}^{2004} \delta_t T_t + \sum_{j=1}^{7} \lambda_j OWN_j + \sum_{k=1}^{6} \varphi_k REG_k + \eta FCI + \rho FCI * \ln(RDE))$$

where RDE is the stock of technology development expenditures; T_t represents year dummy variables from 1995–2004, capturing the autonomous change of energy intensity each year;

OWN_i are ownership dummy variables; REG_k are regional dummy variables; and FCI is foreign capital intensity.

From Shephard's Lemma, we know that the factor demand for an input is equal to the derivative of the cost function with respect to the input price. Deriving the factor demand for energy:

$$E = \frac{\alpha_E A^{-1} P_K^{\alpha_K} P_L^{\alpha_L} P_E^{\alpha_E} P_M^{\alpha_M} Q}{P_E}$$

If we assume $P_Q = P_K^{\alpha_K} P_L^{\alpha_L} P_E^{\alpha_E} P_M^{\alpha_M}$, then the above formula can be rewritten as:

$$\frac{E}{Q} = \frac{\alpha_E A^{-1} P_Q}{P_E}$$

Combining with the expression for *A*, and taking the log of both sides, we obtain the following:

$$\ln\left(\frac{E}{Q}\right) = \alpha + \beta \ln(RDE) + \sum_{t=995}^{2004} \gamma_t T_t + \sum_{i=1}^{7} \lambda_i OWN_i + \sum_{k=1}^{6} \varphi_k REG_k + \eta FCI + \rho FCI * ln(RDE) + \mu \ln\left(\frac{P_E}{P_Q}\right) + \varepsilon_i$$

In order to capture technology development's effect on energy intensity induced by changes in energy prices, we also include an interaction term of energy price and technology development stock in the above estimation equation.

The dependent variable in the above equation is the log of energy intensity; thus, we are assuming that scale has no effect on a firm's energy intensity. In a separate estimation, we relax this assumption by moving output to the right-hand side of the equation, in order to test scale effects on energy consumption:

$$\ln(E) = \alpha + \beta \ln(RDE) + s \ln(Q) + \sum_{t=995}^{2004} \gamma_t T_t + \sum_{i=1}^{7} \lambda_i OWN_i + \sum_{k=1}^{6} \varphi_k REG_k + \eta FCI + \rho FCI * \ln(RDE) + \mu \ln\left(\frac{P_E}{P_Q}\right) + \upsilon \ln\left(\frac{P_E}{P_Q}\right) * \ln(RDE) + \varepsilon_i$$

We estimate the above models (i.e., with and without scale effects) both as a pooled regression and including firm fixed effects, using the balanced data set consisting of firm-level data over the period 1999-2004. As discussed above, we lose a significant number of observations when we move from the unbalanced to the balanced data set since many firms do not report in each year.[4] However, as discussed in Fisher-Vanden et al. (2009), although there are significantly fewer firms in the balanced data set, these firms consume approximately 40% of total industrial energy consumption.

As a robustness test, however, we run the regressions on an unbalanced data set obtained by dropping firms with only one year of observations over the period 1997-2004. (See section VII). As shown in Table 4, most firms with only one year of observations are only reporting for the year 2004 since this is a census year. These firms are also smaller in size as shown in Table 5—the mean of gross value industrial output of firms in the balanced data set is five times higher than in the unbalanced data set. The discontinuity of the unbalanced data set across years also implies that we are unable to construct technology development stocks based on continual annual flows of technology development expenditures. Instead, we must use technology development flows rather than stocks in our robustness tests using the unbalanced data set which introduces potential timing and endogeneity issues.

VI. Results and interpretation

[4] The unbalanced data set contains 7934 observations, while the balanced data set only contains 1548 observations.

Tables 6 through 12 present results from variations on our main estimation strategy. Since it is possible that unobserved productivity differences across firms exist, we control for firm fixed effects in the regression results presented in Tables 6 and 7. Table 6 presents results from alternative specifications for the combined four industries. Across all four specifications, we find that the coefficient associated with the relative energy price is negative and significant which suggests that firms are reducing energy intensity in reaction to higher relative energy prices in support of our first hypothesis. We also find the coefficient associated with technology development to be negative and significant in three of the four specifications, confirming our second hypothesis that greater technology development at the firm level will reduce energy intensity. We also find that the interaction between relative energy price and technology development is also negative and significant. This implies that firms increased technology development to reduce energy intensity in response to higher relative energy prices. These results confirm our fourth hypothesis which predicted that higher energy prices will induce technology development expenditures targeting improvements in energy efficiency.

We test our fifth hypothesis, that foreign direct investment will encourage firms to be more energy efficient, by adding foreign capital intensity and foreign capital intensity interacted with technology development to the regression. As shown in the last column of Table 6, although the coefficients on these variables are negative (as expected), neither of these coefficients is found to be significant.

Lastly, we include year dummy variables to control for underlying trends unrelated to the independent variables. As expected, we find that the coefficients are all significant and are becoming more negative for each successive year (relative to 1999, which is included in the constant term). Thus, firms are becoming less energy intensive over time due to reasons unrelated to changes in energy prices, technology development, or foreign direct investment. Possible explanations include process changes and outsourcing of energy intensive intermediate products in response to increased competition from abroad. This provides evidence in support our second hypothesis which predicts that China's increased openness to the world will induce efficiency improvements leading to declines in firm-level energy intensity.

Table 7 shows results for this same estimation by industry. In general, these industry-specific results are consistent with the aggregate industry results shown in Table 6, but lack significance. Due to the small number of firms in some of these industries, statistical power is limited when firm fixed effects are included. We will therefore also examine results from pooled regressions which do not include firm fixed effects, but include other time invariant controls (i.e., ownership type and region dummy variables).

As shown in Table 7, the coefficient on relative energy price is negative in three of the four industries but only significantly negative for the iron and steel industry. This implies that higher energy prices induce a decline in energy intensity in the iron and steel industry. This coefficient is positive and significant for the Aluminum industry, which would imply that higher energy prices increase energy intensity, but this is offset by the interaction between energy prices and technology development.

Similarly, technology development induces declines in energy intensity in each of these industries, as implied by the negative coefficient, but this result is only significant for the Aluminum industry. The interaction between technology development and energy price is also only negative and significant for Aluminum. These results, do not overwhelmingly confirm our fourth hypothesis which predicted that higher energy prices will induce technology development expenditures targeting improvements in energy efficiency. Foreign capital intensity also seems to lead to declines in energy intensity, but this coefficient is only significant for the Aluminum industry.

Lastly, the underlying trend in energy intensity is significantly declining only in the case of the Iron and Steel industry, and for the last year (2004) in the case of aluminum. This result suggests that China's increased openness to world markets may have contributed to the decline in energy intensity of iron and steel, and aluminum firms in China during these years for reasons other than increases in energy prices, and greater technology development and FDI. It is well-known that these industries have greater exposure to international competition. This is further evidence to support our second hypothesis

Table 8 provides industry specific pooled results without firm fixed effects. Recognizing that not controlling for firm fixed effects will bias the estimators upward, it is still useful to examine the pooled results since it allows us to assess the importance of time invariant factors such as ownership type and region which, in the fixed effects estimation, would be absorbed in the firm dummy variable.

As reported in Table 8, the pooled results are qualitatively similar to the fixed effects results, although with more significance. A couple of key differences are that the interaction of technology development and energy price is now negative and significant for the cement industry and foreign capital intensity is positive and significant for the iron and steel, and aluminum industries. A possible explanation for this positive result is that FDI is leading firms to take measures to improve product quality which may require a more energy intensive production process. However, the coefficient associated with the interaction of technology development and FDI is negative and significant in the iron and steel industry. This would suggest that firms with higher technology development capacity can employ FDI more efficiently to lower energy intensity. Thus, hypothesis H6, which predicts that the interaction will lead to lower energy intensity, only holds for one industry.

As shown in Table 8, we find evidence of the importance of ownership type on energy intensity. For example, in the cement, iron and steel, and aluminum industries, foreign firms have lower energy intensities than state-owned firms (which was omitted from the regression and thus captured in the constant term). This feature holds as well when we pool the four industries. This result is consistent with hypothesis H7 which predicted that foreign and private firms would have more incentive and capacity to lower energy intensity. Chinese firms still lag behind foreign firms in efficiency over the period 1999-2004, as the result of differences in managerial skills and access to advanced technologies.

There are also regional differences in energy intensity in the pulp and paper industry; namely, firms in the Northern and Eastern regions of China have lower energy intensity than firms in the Southern region (Table 8). This result is consistent with hypothesis H9 which predicted that firms in the more developed regions would experience larger declines in energy intensity. In the cement and aluminum industries, firms in the East have lower energy intensity than firms in China's other regions. Varying levels of economic development, R&D activities, and government policies may account for this difference.

We further explore how differences in ownership can affect firm efficiency by running these regressions separately for state-owned enterprise (SOE) (Table 9) and non-state-owned enterprises (non SOE) (Table 10). We find that, if we aggregate the four industries together, the magnitude of the coefficient on relative energy price for non SOEs is larger than for SOEs. This is consistent with our first hypothesis which predicted that non SOEs, due to their greater exposure to the market, would be more responsive to changes in relative energy prices. This result holds for the cement, and iron and steel industries.

To further test our second hypothesis, that greater openness to world markets through WTO accessions would induce Chinese firms to become more responsive to market prices, we also run these regressions separately for the period 1999-2001 and for the period 2002-2004 (Tables 11 and 12). We find that relative energy prices have a larger impact on energy intensity for all four industries in the period 2002-2004 than in the period 1999-2001—the coefficient on relative energy price for all four industries is about 35% greater in the period 2002-2004. We also find that technology development has a greater energy saving effect in the period 2002-2004. In the iron and steel, and aluminum industries, the energy-saving effect of technology development is significant only in the period 2002-2004, and the coefficient is more negative for the cement industry and the four-industry aggregate.

The results shown in Table 13 relax our constant returns to scale assumption. As shown in Table 13, the coefficient on log of output is less than one and significant in all industries. This suggests that larger firms use less energy per unit output than smaller firms. This supports our hypothesis H8 that policies focused on increasing scale, e.g., "grasping the larger, letting go of the small," have likely contributed to lower energy intensity in these four industries. However, these scale economies are largest for pulp and paper and cement, and lower for iron and steel, and aluminum which suggests that this policy did not uniformly reduce energy intensity in all industries.

Another interesting finding is that this scale effect varies over the two different periods. Tables 13 and 14 report that for the pulp and paper, cement, and aluminum industries, firms had larger scale economies over the period 2002-2004 than over the period 1999-2001.

VII. Robustness tests

To test the robustness of our results, we conduct a number of variations on our original estimation. Our previous estimations were conducted on a balanced dataset, which comprises firm-level data over the period 1999-2004. Using a balanced data set allows us to construct stocks of technology development which, due to difficulties associated with determining the correct time lag for flows of technology development, are better to use than flows. The shortcoming of using the balanced data set is that we lose many observations when we move from the unbalanced to the balanced data set. This results in a much smaller sample size which could affect estimation power and lead to sample selection bias since the only firms in the data set are those firms reporting in all six years.

To see how our use of a balanced data set affects the results, we run the regression on an unbalanced data set. The unbalanced data set is constructed by dropping firms that only have one year of observations over the period 1997-2004 in the original unbalanced data set. (Most firms with only one year of observations are reporting in year 2004 since this is a census year). However, since it is not the case that each firm in the unbalanced data set reports continuously over the period 1997-2004, we are not able to construct technology development stocks for each firm and we are therefore forced to use contemporaneous flows of technology development expenditures rather than a stock. This obviously raises possible endogeneity issues when using contemporaneous flows since energy productivity may influence a firm's choice of technology development expenditures in a given year. Therefore, results using the unbalanced data set will only supplement our main results.

As expected, due to the much larger number of observations in the unbalanced data set, the standard errors are smaller in the unbalanced regressions, but the coefficients are in general robust across both data sets. The coefficients associated with technology development expenditures, however, are in general insignificant likely due to the lagged effects of technology development.

Lastly, as already discussed, we relax the assumption of constant returns to scale in our main results. As shown previously, we find that scale economies matter for firm-level energy consumption. We also find that whether or not we assume CRS, the coefficients associated with the other variables in the regression do not change.

VIII. Conclusion

Energy intensity in four Chinese industries—pulp and paper, cement, iron and steel, and aluminum—has decreased continuously over the last 30 years. Many factors, including rising energy costs, increased research and development activity, market-oriented reforms, and imports of foreign technology, are possible factors explaining this decline. In this paper, our empirical results show that rising energy prices and policy of "grasping the large, letting go off the small" have substantially induced declines in firm-level energy intensity. Similarly, increased investments in research and development in Cement firms have also led to decreases in energy intensity.

When considering the effect of ownership type on energy intensity in these four industries, our results are consistent with previous studies on the cement, iron and steel, and aluminum industry; e.g., within a given industry, foreign firms in China are usually less energy intensive than state-owned firms. However, in our analysis, this does not seem to be the case in the pulp and paper industry.

Similar to the regional disparities of economic development that exist in China, there are also regional disparities in energy intensity within Chinese industry. In the pulp and paper and cement industries, firms in the Eastern regions of China are less energy intensive than firms in other regions. These regions are more exposed to world markets which may be inducing process improvements and greater outsourcing. In the iron and steel industry, firms experience large declines in energy intensity after year 2002. More openness to world markets and increased foreign competition are likely explanations for this decline.

Table 1: Firm distribution by ownership type (number of enterprises)

Ownership	Pulp and paper	Cement	Iron and steel	Aluminum
SOE (state-owned)	12	45	38	12
COE (collective-owned)	4	12	9	3
HKMT (Hong Kong SAR, China; Macao; and Taiwan, China)	7	8	4	2
(Foreign)	7	5	3	2
(Shareholding)	18	36	15	7
(Private)	1	8	1	1
(others)	0	1	0	0
Total	**49**	**115**	**70**	**27**

Table 2: Firm distribution by region (number of enterprises)

Region (provinces)	Pulp and Paper industry	Cement	Iron and Steel	Aluminum
North (Beijing, Tianjin, Hebei, Shanxi,Inner Mongolia)	5	14	13	4
Northeast (Liaoning, Jilin, Heilongjiang)	3	12	5	1
East (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong)	27	51	36	11
South (Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan)	14	37	14	6
Southwest (Chongqing, Sichuan,Guizhou, Yunnan, Tibet)	0	1	2	2
Northwest （Shanxi, Gansu, Ginghai, Ningxia, Xinjiang）	0	0	0	3
Total	**49**	**115**	**70**	**27**

Table 3
Intensity of foreign capital and technology development stocks by industry, 1999-2004 (relative to total capital stock)

	Foreign capital stock						Technology development stock					
	1999-2004	1999	2000	2001	2002	2004	1999-2004	1999	2000	2001	2002	2004
Pulp and Paper	13.9%	7.8%	16.2%	16.8%	19.2%	9.5%	36.8%	31%	34.8%	34.4%	36.7%	43%
Cement	20%	22.6%	20%	20.6%	18.8%	20%	4.7%	2.7%	3.4%	3.7%	5.3%	6.9%
Iron and Steel	1.5%	1.4%	1.1%	1.3%	1.3%	2.5%	38%	40%	32.4%	33.6%	35.9%	35%
Aluminum	4%	7.2%	4.3%	4%	3.8%	1%	15%	6.6%	7.4%	12%	14%	27.5%

Table 4: Number of firms with missing years of observations

Missing years of observations	Pulp and Paper industry	Cement industry	Iron and Steel industry	Aluminum industry
0	28	58	35	11
1	24 (8)*	59 (23)*	24 (9)*	14 (3)*
2	32	114	47	16
3	45	80	34	7
4	63	146	52	13
5	71	171	95	37
6	153	415	232	64
7	517 (405)**	921 (610)**	1597 (1459)**	306 (249)**

* Number of firms only missing year 2004 inside parenthesis
** Number of firms only reporting in year 2004 inside parenthesis

Table 5: Mean of gross value industrial output (2004)

	Unbalanced data set	Balanced data set
Pulp and Paper industry	237,508	565,843
Cement industry	132,386	162,739
Iron and Steel industry	619,253	3,538,707
Aluminum industry	504,413	1,386,412

Table 6: Determinants of energy intensity, Four Industries (CRS, Firm Fixed Effects)

Dependent variable=ln(energy/output)	(1)		(2)		(3)		(4)	
	Coeff	p-value	Coeff	p-value	Coeff	p-value	Coeff	p-value
Constant	-2.7187	0	-2.6804	0	-2.6304	0	-2.6141	0
Ln(price of energy/price of output)	-0.0844	0	-0.0587	0.003	-0.0582	0.004	-0.0595	0.003
Ln (technology development)	-0.0033	0.205	-0.0067	0.021	-0.0066	0.022	-0.0063	0.031
Ln(price of energy/price of output)*Ln(technology development)	-	-	-0.0048	0.007	-0.0048	0.007	-0.0046	0.011
Foreign capital intensity	-	-	-	-	-0.1625	0.298	-0.1535	0.328
Foreign capital intensity*Ln(technology development)	-	-	-	-	-	-	-0.0071	0.585
Year 2000	-0.0212	0.464	-0.0221	0.444	-0.0231	0.423	-0.0225	0.436
Year 2001	-0.0468	0.109	-0.0460	0.115	-0.0460	0.115	-0.0456	0.118
Year 2002	-0.0728	0.015	-0.0741	0.013	-0.0752	0.012	-0.0744	0.013
Year 2003	-0.1446	0	-0.1463	0	-0.1458	0	-0.1451	0
Year 2004	-0.1559	0	-0.1610	0	-0.1616	0	-0.1613	0
Adj. R^2(obs.)	0.9186 (1530)		0.9190 (1530)		0.9188 (1528)		0.9188 (1528)	

Table 7: Determinants of energy intensity (CRS, Firm Fixed Effects)

Dependent variable=ln(energy/output)	Pulp and Paper industry		Cement industry		Iron and Steel industry		Aluminum industry	
	Coef.	P-value	Coef.	P-Value	Coef.	P-Value	Coef.	P-Value
Constant	-1.1964	0	-0.1392	0.177	-2.6302	0	-2.174	0
Ln(price of energy/price of output)	-0.0127	0.856	-0.0318	0.14	-0.1791	0.022	0.5892	0
Ln (technology development)	-0.0112	0.132	-0.0008	0.811	-0.006	0.517	-0.018	0.08
Ln(Price of energy/price of output)*Ln(technology development)	0.0014	0.819	0.0004	0.83	-0.004	0.542	-0.06	0
Foreign capital intensity	-0.0378	0.891	-1.3637	0.182	-0.303	0.875	-3.26	0
Foreign capital intensity*Ln(technology development)	-0.0466	0.075	-0.1089	0.22	0.0662	0.785	0.2836	0
Year 2000	0.003	0.962	0.0145	0.651	-0.0964	0.17	0.012	0.891
Year 2001	0.0196	0.761	0.0106	0.743	-0.1773	0.016	-0.001	0.99
Year 2002	0.0057	0.932	0.0063	0.848	-0.2468	0.001	-0.031	0.734
Year 2003	0.0061	0.927	-0.038	0.249	-0.4074	0	-0.137	0.148
Year 2004	-0.0426	0.533	-0.0147	0.666	-0.4696	0	-0.215	0.029
R^2(obs.)	0.8435 (290)		0.8192 (677)		0.9299 (418)		0.9036 (143)	

Table 8: Determinants of energy intensity (CRS, Pooled Effects)

Dependent variable=ln(energy/output)	Four industries		Pulp and Paper industry		Cement industry		Iron and Steel industry		Aluminum industry	
	Coef.	P-value	Coef.	P-value	Coef.	P-Value	Coef.	P-Value	Coef.	P-Value
Constant	-0.3196	0.001	-0.8013	0	0.143	0.045	-0.5174	0.052	-1.226	0
Ln(price of energy/price of output)	-0.5391	0	-0.4112	0	-0.2297	0	-0.7303	0	-0.129	0.48
Ln (technology development)	-0.0396	0	-3.9E-05	0.996	-0.0108	0	-0.0114	0.445	-0.011	0.501
Ln(price of energy/price of output)*Ln(technology development)	-0.0199	0	0.0125	0.202	-0.0081	0.003	-0.0018	0.906	-0.009	0.603
Foreign capital intensity	0.1264	0.638	-0.5138	0.279	-0.0048	0.984	6.3715	0.013	3.4486	0.022
Foreign capital intensity*Ln(technology development)	-0.0166	0.242	0.0215	0.539	-0.0066	0.597	-0.6037	0.011	0.0152	0.88
Collectives	-0.6109	0	0.0435	0.785	-0.417	0	-1.3253	0	-0.137	0.48
Foreign	-0.5531	0.002	0.3844	0.095	-0.3889	0.039	-1.1923	0.002	-2.932	0
Hong Kong SAR, China; Macao; Taiwan, China	-0.46	0	-0.1459	0.274	-0.0634	0.358	-0.3965	0.106	-1.055	0
Shareholding	-0.1981	0	0.1447	0.17	-0.2003	0	-0.3153	0.025	-0.598	0
Private	-0.0724	0.551	0.145	0.625	-0.1534	0.026	-1.1842	0.058	-0.774	0.021
Other	0.3063	0.618	(omitted)		0.0748	0.806	(omitted)		(omitted)	
North	-0.6237	0	-0.9509	0	-0.264	0	-0.3122	0.188	-0.351	0.193
Northeast	(omitted)		(omitted)		(omitted)		(omitted)		(omitted)	
East	-0.5403	0	-0.8415	0	-0.4445	0	-0.2796	0.193	-0.841	0.001
South	-0.4563	0	-0.4094	0.012	-0.3897	0	-0.518	0.031	-0.677	0.006
Southwest	-1.2901	0	(omitted)		-0.1151	0.528	-0.6779	0.082	-0.937	0.001
Year 2000	0.0863	0.258	0.0033	0.979	0.0492	0.382	-0.0163	0.928	0.1242	0.451
Year 2001	0.0948	0.215	-0.012	0.924	0.0588	0.296	-0.0543	0.765	0.1212	0.471
Year 2002	0.0222	0.773	0.011	0.931	0.0238	0.675	-0.1498	0.412	0.0799	0.644
Year 2003	-0.0735	0.344	-0.0288	0.823	-0.0171	0.764	-0.3569	0.053	-0.08	0.651
Year 2004	-0.0719	0.362	-0.03	0.818	0.0223	0.703	-0.4386	0.018	-0.12	0.516
R^2(obs.)	0.4022 (1528)		0.2469 (290)		0.3144 (677)		0.4149 (418)		0.5962 (143)	

Table 9: Determinants of energy intensity (SOE, CRS, Pooled effects)

Dependent variable=ln(energy/output)	Four industries (SOE)		Pulp and Paper industry (SOE)		Cement industry (SOE)		Iron and Steel industry (SOE)		Aluminum industry (SOE)	
	Coef.	P-value	Coef.	P-value	Coef.	P-Value	Coef.	P-Value	Coef.	P-Value
Constant	-1.9677	0	-1.8773	0	0.1651	0.088	-0.6023	0.067	-1.034	0.002
Ln(price of energy/price of output)	-0.4553	0	-1.0257	0	-0.0376	0.338	-0.6904	0.002	-0.56	0.092
Ln (technology development)	-0.0372	0	0.0545	0.01	0.0018	0.622	-0.0092	0.658	-0.047	0.075
Ln(Price of energy/price of output)*Ln(technology development)	-0.0216	0	0.0611	0.002	0.0009	0.801	0.0003	0.989	0.0397	0.282
Foreign capital intensity	-2.4650	0.04	-1.8239	0.091	-18.946	0.107	-199.339	0.341	(omitted)	
Foreign capital intensity*Ln(technology development)	0.0299	0.783	-0.0831	0.35	-1.5012	0.142	18.627	0.335	0.4117	0.252
Collectives	(omitted)		(omitted)		(omitted)		(omitted)		(omitted)	
Foreign	(omitted)		(omitted)		(omitted)		(omitted)		(omitted)	
Hong Kong SAR, China; Macao; Taiwan, China	(omitted)		(omitted)		(omitted)		(omitted)		(omitted)	
Shareholding	(omitted)		(omitted)		(omitted)		(omitted)		(omitted)	
Private	(omitted)		(omitted)		(omitted)		(omitted)		(omitted)	
Other	(omitted)		(omitted)		(omitted)		(omitted)		(omitted)	
North	1.1595	0.001	-0.4153	0.064	0.0059	0.952	-0.1281	0.619	-0.622	0.081
Northeast	1.4381	0	(omitted)		(omitted)		(omitted)		(omitted)	
East	1.2714	0	-0.1712	0.516	-0.3748	0	-0.2601	0.276	-0.904	0.002
South	1.3147	0	0.2137	0.313	-0.1953	0.014	0.1014	0.706	-0.575	0.043
Southwest	(omitted)		(omitted)		(omitted)		(omitted)		-1.021	0.003
Year 2000	0.1013	0.356	-0.1233	0.487	0.0297	0.679	-0.0027	0.99	0.2326	0.377
Year 2001	0.0212	0.849	-0.0926	0.603	0.0295	0.687	-0.1779	0.44	0.2772	0.288
Year 2002	-0.0556	0.626	-0.1843	0.299	0.0445	0.559	-0.2505	0.281	0.2887	0.283
Year 2003	-0.1790	0.13	-0.1531	0.41	0.0775	0.325	-0.5579	0.021	0.134	0.629
Year 2004	-0.1114	0.358	0.1405	0.468	0.1151	0.155	-0.5663	0.023	-0.101	0.728
R^2(obs.)	0.3278 (636)		0.6112 (70)		0.1821 (270)		0.3233 (227)		0.3908 (69)	

Table 10: Determinants of energy intensity (Non SOE, CRS, Pooled effects)

Dependent variable=ln(energy/output)	Four industries (Non SOE)		Pulp and Paper industry (Non SOE)		Cement industry (Non SOE)		Iron and Steel industry (Non SOE)		Aluminum industry (Non SOE)	
	Coef.	P-value	Coef.	P-value	Coef.	P-Value	Coef.	P-Value	Coef.	P-Value
Constant	-1.3186	0.041	-0.2213	0.571	-0.076	0.831	-1.1251	0.17	-3.275	0
Ln(price of energy/price of output)	-0.6317	0	-0.1944	0.157	-0.362	0	-0.9531	0	-0.392	0.338
Ln (technology development)	-0.0414	0	-0.0106	0.281	-0.018	0	0.0077	0.722	0.0597	0.158
Ln(Price of energy/price of output)*Ln(technology development)	-0.0154	0.004	-0.0088	0.499	-0.0101	0.011	0.0131	0.582	0.0154	0.698
Foreign capital intensity	0.1936	0.482	-0.3472	0.51	0.0568	0.824	8.3915	0.002	5.959	0.067
Foreign capital intensity*Ln(technology development)	-0.0042	0.772	0.0263	0.496	0.0027	0.829	-0.8053	0.001	-0.199	0.404
Collectives	-0.859	0.164	-0.164	0.63	-0.418	0.184	-0.1746	0.786	0.4664	0.188
Foreign	-0.8337	0.19	0.0557	0.887	-0.477	0.188	0.2386	0.746	-2.507	0.001
Hong Kong SAR, China; Macao; Taiwan, China	-0.7083	0.252	-0.3873	0.243	-0.0903	0.777	1.3253	0.048	-0.531	0.159
Shareholding	-0.4689	0.445	-0.0735	0.814	-0.2505	0.419	1.0711	0.086	0.1096	0.716
Private	-0.3986	0.523	(omitted)		-0.2119	0.504	(omitted)		(omitted)	
Other	(omitted)		(omitted)		(omitted)		(omitted)		(omitted)	
North	0.4631	0.023	-1.4105	0	-0.2164	0.245	-1.2514	0.023	0.6849	0.069
Northeast	1.5179	0	(omitted)		0.3391	0.073	(omitted)		(omitted)	
East	0.5908	0.001	-1.1058	0	-0.2887	0.113	-1.1588	0.017	0.1337	0.611
South	0.6925	0	-0.7022	0.001	-0.267	0.151	-2.1873	0	0.0215	0.934
Southwest	(omitted)		(omitted)		(omitted)		-1.542	0.005	(omitted)	
Year 2000	0.0801	0.444	0.0173	0.911	0.0654	0.401	-0.0391	0.891	-0.097	0.658
Year 2001	0.1704	0.102	0.0459	0.766	0.0794	0.304	0.0393	0.89	-0.160	0.485
Year 2002	0.0979	0.344	0.0494	0.755	0.0193	0.801	-0.0691	0.808	-0.230	0.334
Year 2003	0.0331	0.748	0.0047	0.976	-0.042	0.577	-0.2094	0.454	-0.412	0.096
Year 2004	-0.0009	0.993	-0.0839	0.595	0.0055	0.944	-0.4252	0.127	-0.326	0.229
R^2(obs.)	0.4364 (892)		0.2285 (220)		0.4075 (407)		0.429 (191)		0.6064 (74)	

Table 11: Determinants of energy intensity (1999-2001, CRS, Pooled effects)

Dependent variable=ln(energy/output)	Four industries		Pulp and Paper industry		Cement industry		Iron and Steel industry		Aluminum industry	
	Coef.	P-value	Coef.	P-value	Coef.	P-Value	Coef.	P-Value	Coef.	P-Value
Constant	-1.4609	0	-1.7028	0	0.1924	0.481	-0.399	0.26	-0.916	0.016
Ln(price of energy/price of output)	-0.4991	0	-0.371	0.006	-0.152	0	-0.7829	0	-0.063	0.741
Ln (technology development)	-0.0265	0	0.0128	0.3	-0.008	0.041	0.0135	0.478	-0.012	0.491
Ln(Price of energy/price of output)*Ln(technology development)	-0.0075	0.108	0.022	0.086	-0.0007	0.847	0.0183	0.327	-0.01	0.595
Foreign capital intensity	0.2682	0.504	-0.4612	0.629	0.044	0.893	7.2048	0.05	5.2162	0.003
Foreign capital intensity*Ln(technology development)	-0.0227	0.282	0.0311	0.575	0.0077	0.672	-0.7852	0.033	0.0512	0.658
Collectives	-0.6779	0	0.1165	0.571	-0.404	0	-1.458	0	-0.196	0.412
Foreign	-0.6576	0.009	0.4423	0.244	-0.27	0.25	-1.0436	0.09	-3.886	0
Hong Kong SAR, China; Macao; Taiwan, China	-0.5208	0	-0.0959	0.597	0.0964	0.351	-0.5563	0.111	-1.065	0
Shareholding	-0.2648	0.001	0.1605	0.281	-0.1647	0.007	-0.4114	0.068	-0.537	0.003
Private	0.0574	0.807	(omitted)		-0.1934	0.112	(omitted)		(omitted)	
Other	0.2943	0.642	(omitted)		0.0162	0.96	(omitted)		(omitted)	
North	0.5462	0.028	(omitted)		-0.233	0.388	-0.5075	0.154	-0.607	0.129
Northeast	1.3922	0	0.9264	0.001	0.0552	0.84	(omitted)		(omitted)	
East	0.6389	0.007	0.009	0.965	-0.4532	0.091	-0.4557	0.149	-1.271	0
South	0.6292	0.009	0.4762	0.013	-0.4825	0.073	-0.8097	0.026	-0.936	0.011
Southwest	(omitted)		(omitted)		(omitted)		-0.6082	0.287	-1.195	0.003
Year 2000	0.069	0.379	-0.016	0.897	0.049	0.411	-0.0612	0.743	0.1147	0.477
Year 2001	0.0698	0.377	-0.0355	0.776	0.0532	0.374	-0.113	0.551	0.1058	0.523
R^2(obs.)	0.3690 (770)		0.2740 (146)		0.2725 (342)		0.4048 (210)		0.6740 (72)	

Table 12: Determinants of energy intensity (2002-2004, CRS, Pooled effects)

Dependent variable=ln(energy/output)	Four industries		Pulp and Paper industry		Cement industry		Iron and Steel industry		Aluminum industry	
	Coef.	P-value	Coef.	P-value	Coef.	P-Value	Coef.	P-Value	Coef.	P-Value
Constant	-0.8562	0	-0.8998	0.003	-0.2463	0.025	-1.7287	0.002	-1.063	0.071
Ln(price of energy/price of output)	-0.7619	0	-0.4585	0.018	-0.464	0	-0.6985	0.019	0.1842	0.81
Ln (technology development)	-0.0571	0	-0.0142	0.313	-0.017	0	-0.0577	0.023	-0.102	0.055
Ln(Price of energy/price of output)*Ln(technology development)	-0.0402	0	0.0032	0.862	-0.0188	0	-0.0467	0.082	-0.103	0.225
Foreign capital intensity	-0.037	0.913	-0.61	0.301	0.0602	0.875	4.5695	0.192	-21.3	0.257
Foreign capital intensity*Ln(technology development)	-0.0142	0.429	0.0255	0.64	-0.017	0.285	-0.4026	0.195	1.7709	0.244
Collectives	-0.4721	0	-0.0512	0.855	-0.3727	0	-0.9786	0	-0.104	0.755
Foreign	-0.3521	0.125	0.3376	0.355	-0.5466	0.077	-0.9174	0.061	-0.132	0.889
Hong Kong SAR, China; Macao; Taiwan, China	-0.3336	0.004	-0.152	0.453	-0.1994	0.02	-0.0609	0.854	-0.727	0.009
Shareholding	-0.1274	0.065	0.1649	0.294	-0.2243	0	-0.2541	0.142	-0.579	0
Private	-0.1111	0.402	0.0801	0.806	-0.1352	0.076	-1.1279	0.054	-1.114	0.002
Other	(omitted)		(omitted)		(omitted)		(omitted)		(omitted)	
North	-0.258	0.043	-0.867	0.004	-0.1765	0.044	0.9218	0.057	0.1285	0.743
Northeast	(omitted)		(omitted)		(omitted)		0.833	0.102	(omitted)	
East	-0.1097	0.338	-0.6622	0.008	-0.2021	0.01	0.9543	0.036	0.0509	0.883
South	0.0662	0.575	-0.2483	0.32	-0.0736	0.357	0.88	0.069	0.1164	0.733
Southwest	-1.0961	0	(omitted)		-0.0865	0.699	(omitted)		-0.306	0.408
Year 2003	-0.1107	0.114	-0.0416	0.754	-0.0434	0.376	-0.2629	0.119	-0.109	0.456
Year 2004	-0.0996	0.161	-0.0392	0.769	0.0272	0.59	-0.3607	0.034	-0.119	0.447
R^2(obs.)	0.5126 (758)		0.2586 (144)		0.4802 (335)		0.5059 (208)		0.6798 (71)	

Table 13: Determinants of energy consumption (Non CRS, Pooled Effects)

Dependent variable=ln(energy/output)	Four industries		Pulp and Paper industry		Cement industry		Iron and Steel industry		Aluminum industry	
	Coef.	P-value	Coef.	P-value	Coef.	P-Value	Coef.	P-Value	Coef.	P-Value
Constant	2.0149	0	1.886	0	1.9939	0	-0.0593	0.918	-0.59	0.376
Ln(price of energy/price of output)	-0.5281	0	-0.508	0	-0.2271	0	-0.7399	0	-0.161	0.384
Ln (technology development)	-0.0213	0	0.0179	0.042	-0.005	0.04	-0.006	0.706	-0.003	0.863
Ln(Value of industry output at constant price)	0.7993	0	0.7376	0	0.834	0	0.9611	0	0.9448	0
Ln(Price of energy/price of output)*Ln(technology development)	-0.0188	0	0.01208	0.191	-0.0078	0.003	-0.0009	0.953	-0.007	0.684
Foreign capital intensity	0.2561	0.321	-0.4599	0.303	-0.1457	0.545	6.1411	0.017	3.6265	0.017
Foreign Capital intensity*Ln(technology development)	-0.0300	0.028	0.006	0.855	-0.021	0.076	-0.5768	0.016	-0.003	0.975
Collectives	-0.6553	0	0.066	0.659	-0.447	0	-1.325	0	-0.044	0.834
Foreign	-0.5586	0.001	0.5369	0.014	-0.164	0.368	-1.23	0.002	-2.869	0
Hong Kong SAR, China; Macao; Taiwan, China	-0.4334	0	0.1495	0.267	-0.0442	0.504	-0.405	0.099	-1.023	0
Shareholding	-0.2576	0	0.1814	0.069	-0.2085	0	-0.3288	0.02	-0.582	0
Private	-0.1957	0.095	0.2646	0.345	-0.1854	0.005	-1.1898	0.057	-0.747	0.026
Other	0.2347	0.69	(omitted)		0.0713	0.806	(omitted)		(omitted)	
North	-0.566	0	-0.7231	0	-0.3217	0	-0.2828	0.237	-0.385	0.157
Northeast	(omitted)		(omitted)		(omitted)		(omitted)		(omitted)	
East	-0.4117	0	-0.4876	0.004	-0.4105	0	-0.2504	0.249	-0.825	0.001
South	-0.3950	0	-0.1259	0.43	-0.3882	0	-0.4957	0.04	-0.648	0.008
Southwest	-1.1746	0	(omitted)		-0.1503	0.39	-0.6974	0.074	-0.894	0.002
Year 2000	0.0676	0.356	-0.029	0.805	0.051	0.344	-0.0207	0.909	0.1048	0.527
Year 2001	0.0860	0.241	0.0044	0.97	0.066	0.221	-0.0573	0.752	0.1042	0.537
Year 2002	0.0332	0.654	0.0642	0.594	0.0436	0.423	-0.147	0.421	0.0622	0.72
Year 2003	-0.0396	0.596	0.029	0.811	0.0184	0.737	-0.3469	0.06	-0.092	0.602
Year 2004	-0.0261	0.731	0.0166	0.892	0.0625	0.268	-0.4229	0.024	-0.121	0.513
R^2(obs.)	0.6873 (1528)		0.7354 (290)		0.7778 (677)		0.7236 (418)		0.8617 (143)	

Table 14: Determinants of energy consumption (1999-2001, Non CRS, Pooled effects)

Dependent variable=ln(energy/output)	Four industries		Pulp and Paper industry		Cement industry		Iron and Steel industry		Aluminum industry	
	Coef.	P-value	Coef.	P-value	Coef.	P-Value	Coef.	P-Value	Coef.	P-Value
Constant	0.8884	0.029	2.0243	0.007	1.8058	0	0.1756	0.838	-0.255	0.788
Ln(price of energy/price of output)	-0.4914	0	-0.483	0	-0.1520	0	-0.7942	0	-0.102	0.607
Ln (technology development)	-0.0106	0.053	0.029	0.02	-0.0036	0.363	0.0192	0.351	-0.006	0.734
Ln(Value of industry output at constant price)	0.8081	0	0.7355	0	0.8541	0	0.9524	0	0.9447	0
Ln(Price of energy/price of output)*Ln(technology development)	-0.0067	0.142	0.0216	0.075	-0.0002	0.953	0.0194	0.303	-0.007	0.708
Foreign capital intensity	0.3797	0.329	-0.0268	0.976	-0.0762	0.815	6.9901	0.058	5.3497	0.002
Foreign capital intensity*Ln(technology development)	-0.0358	0.082	0.0027	0.958	-0.0062	0.733	-0.7559	0.041	0.0335	0.777
Collectives	-0.7103	0	0.1809	0.355	-0.4367	0	-1.4585	0	-0.11	0.679
Foreign	-0.6565	0.007	0.4506	0.21	-0.0881	0.706	-1.1067	0.075	-3.787	0
Hong Kong SAR, China; Macao; Taiwan, China	-0.4755	0	0.213	0.258	0.0987	0.328	-0.5517	0.114	-1.022	0
Shareholding	-0.3146	0	0.194	0.169	-0.1830	0.002	-0.4197	0.064	-0.527	0.004
Private	-0.0772	0.735	(omitted)		-0.2379	0.047	(omitted)		(omitted)	
Other	0.2081	0.734	(omitted)		0.0021	0.995	(omitted)		(omitted)	
North	0.4830	0.044	-0.7866	0.003	-0.2625	0.32	-0.4807	0.179	-0.669	0.103
Northeast	1.2883	0	(omitted)		0.0837	0.755	(omitted)		(omitted)	
East	0.6302	0.006	-0.6885	0.005	-0.4119	0.116	-0.4343	0.172	-1.262	0
South	0.5743	0.014	-0.2558	0.256	-0.4529	0.085	-0.7951	0.029	-0.915	0.013
Southwest	(omitted)		(omitted)		(omitted)		-0.6325	0.269	-1.153	0.005
Year 2000	0.055	0.468	-0.0471	0.691	0.0523	0.368	-0.0643	0.731	0.1043	0.521
Year 2001	0.066	0.385	-0.0102	0.931	0.0619	0.29	-0.1144	0.547	0.0992	0.551
R^2(obs.)	0.6566 (770)		0.7351 (146)		0.7348 (342)		0.7118 (210)		0.883 (72)	

Table 15: Determinants of energy consumption (2002-2004, Non CRS, Pooled effects)

Dependent variable=ln(energy/output)	Four industries		Pulp and Paper industry		Cement industry		Iron and Steel industry		Aluminum industry	
	Coef.	P-value	Coef.	P-value	Coef.	P-Value	Coef.	P-Value	Coef.	P-Value
Constant	1.4423	0	1.8669	0.007	1.7057	0	-1.4922	0.076	0.2480	0.812
Ln(price of energy/price of output)	-0.7373	0	-0.5032	0.006	-0.4571	0	-0.7060	0.018	0.6096	0.466
Ln (technology development)	-0.0376	0	0.0026	0.852	-0.0125	0.001	-0.0541	0.046	-0.049	0.459
Ln(Value of industry output at constant price)	0.803	0	0.7290	0	0.8264	0	0.9783	0	0.8732	0
Ln(Price of energy/price of output)*Ln(technology development)	-0.039	0	-0.0040	0.818	-0.0189	0	-0.0461	0.087	-0.155	0.102
Foreign capital intensity	0.111	0.73	-0.5649	0.306	-0.1244	0.727	4.4088	0.212	-17.97	0.34
Foreign capital intensity*Ln(technology development)	-0.027	0.115	0.0134	0.794	-0.0320	0.032	-0.3858	0.219	1.4775	0.333
Collectives	-0.5292	0	-0.0810	0.757	-0.3927	0	-0.9783	0	-0.067	0.84
Foreign	-0.373	0.087	0.4846	0.159	-0.2611	0.365	-0.9321	0.058	-0.035	0.97
Hong Kong SAR, China; Macao; Taiwan, China	-0.3337	0.002	0.1265	0.527	-0.1607	0.044	-0.0738	0.825	-0.758	0.007
Shareholding	-0.1973	0.003	0.2011	0.173	-0.2224	0	-0.2653	0.132	-0.515	0.003
Private	-0.232	0.067	0.1747	0.568	-0.1572	0.027	-1.1345	0.053	-0.964	0.009
Other	(omitted)		(omitted)		(omitted)		(omitted)		(omitted)	
North	-0.1913	0.115	-0.5328	0.065	-0.2319	0.005	0.9526	0.053	(omitted)	
Northeast	(omitted)		(omitted)		(omitted)		0.8432	0.099	-0.344	0.42
East	0.0375	0.733	-0.1876	0.462	-0.1502	0.039	0.9879	0.034	-0.156	0.542
South	0.1283	0.254	0.1239	0.618	-0.0747	0.313	0.9083	0.064	-0.087	0.758
Southwest	-0.9787	0	(omitted)	--	-0.1245	0.548	(omitted)	--	-0.596	0.128
Year 2003	-0.0877	0.187	-0.0361	0.771	-0.0263	0.563	-0.2583	0.127	-0.098	0.501
Year 2004	-0.0663	0.326	-0.0504	0.687	0.0477	0.309	-0.353	0.04	-0.129	0.408
R^2(obs.)	0.7539 (758)		0.7429 (144)		0.8512 (335)		0.7801 (208)		0.8973 (71)	

References

Cai, B., D. Cao, Y. Zhou, and Z. Zhang, 2011, “Analysis of Energy Consumption Features of Chinese Cement Plants.” Environmental Engineering, Vol.2.

China State Council, 1996, “Decision of the State Council on Several Issues Concerning Environment Protection,” available at http://www.zhb.gov.cn/epi-sepa/zcfg/w2/w2.htm.

China State Council, 2012, “12th five-year plan: energy saving and emission reduction,” available at http://www.gov.cn/zwgk/2012-08/21/content_2207867.htm.

Dao, H., 2010, “Energy Efficiency in China Iron and Steel Industry,” presentation at the China Iron and Steel Association, International workshop on industrial energy efficiency, New Delhi, available at < http://www.iea.org/work/2010/india_bee/dao.pdf>.

Fan, Y., H. Liao, and Y. Wei, 2007, “Can Market Oriented Economic Reforms Contribute To Energy Efficiency Improvement? Evidence from China,” Energy Policy, 35: 2287-2295.

Fisher-Vanden, K., 2009, “Energy in China: Understanding Past Trends and Future Directions.” International Review of Environmental and Resource Economics, 3: 217-244.

Fisher-Vanden, K. and M.S. Ho, 2010, “Technology, Development, and the Environment.” Journal of Environmental Economics and Management, 59: 94-108.

Fisher-Vanden, K., G. Jefferson, Y. Liu, and J. Qiao, 2009, “Open Economy Impacts on Energy Consumption: Technology Transfer & FDI Spillovers in China’s Industrial Economy,” manuscript, Pennsylvania State University.

Fisher-Vanden, K., G. Jefferson, H. Liu, Q. Tao, 2004, “What is Driving China’s Decline in Energy Intensity?” Resource and Energy Economics, 26: 77-97.

Garbaccio, R. F., M. S. Ho, and D. W. Jorgenson, 1999, “Why Has the Energy-Output Ratio Fallen in China?” The Energy Journal, 20 (3): 63-92.

Hang, L., and M. Tu, 2007, “The Impact of Energy Prices on Energy Intensity: Evidence from China,” Energy Policy, 35: 2978-2988.

He, C., and J. Wang, 2007, “Energy Intensity in Light of China’s Economic Transition,” Eurasian Geography and Economics, 48(4): 439-468.

Kinoshita, Y., 2001, "R&D and Technology Spillovers through FDI: Innovation and Absorptive Capacity," CEPR Discussion Papers 2775, C.E.P.R. Discussion Papers.

Ma, C. and D.I. Stern, 2008, “China’s Changing Energy Intensity Trend: a Decomposition Analysis,” Energy Economics, 30:1037-1053.

Mielnik, O. and J. Goldemberg, 2002, “Foreign direct investment and decoupling between energy and gross domestic product in developing countries”, Energy Policy 30: 87–89.

National Bureau of Statistics of China, 2000, *China Statistical Yearbook*. Beijing, China.

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

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. 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.

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. 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.

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

State Environmental Protection Agency of China, 1999, "Technical Policy for Pollution Prevention of Wastewater from Straw Pulp Papermaking Industry," available at http://www.mep.gov.cn/info/gw/huanfa/199905/t19990528_86516.htm.

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

Wei, Y., H. Liao, and Y. Fan, 2007, "An Empirical Analysis of Energy Efficiency in China's Iron and Steel Sector," Energy, 32: 2262-2270.

Worrell, E., C. Galitsky and L. Price, 2008, "Energy efficiency improvement opportunities for the cement industry," Lawrence Berkeley National Laboratory. University of California, Paper No. LBNL-72E.

Xiao, Y., 2007, "Development of a Circular Economy, Implementation of Energy Saving and Emission Reduction," People's Daily Online, China, available at http://energy.people.com.cn/GB/6346603.html.

Zhang, Y., B. Liu, and Q. Ping, 2008, "The Status Quo and an Analysis of Energy Consumption in China's Paper Industry," China Paper and Pulp Industry, available at http://www.docin.com/p-121329280.html.

Zheng, Y., J. Qi, and X. Chen, 2011, "The Effect of Increasing Exports on Industrial Energy Intensity in China." Energy Policy, 39: 2688-2698.