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Factors Influencing Energy Intensity in Four Chinese Industries

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

ABSTRACT

In this paper, we investigate the determinants of decline in energy intensity in four Chinese industries—pulp and paper, cement, iron and steel, and aluminum. This paper attempts to answer the following key question: For the purpose of promoting energy efficiency, do prices, technology, enterprise restructuring and other policy-related instruments affect various sectors uniformly so as to justify uniform industrial energy conservation policies, or do different industries respond significantly differently so as to require policies that are tailored to each sector separately? In this paper, we examine this question using data for China's most energy-intensive large and medium-size enterprises over the period 1999–2004. Our results suggest that in all four industries rising energy costs are a significant contributor to the decline in energy intensity over our period of study. China's industrial policies encouraging consolidations and scale economies also seem to have contributed to reductions in energy intensity in these four industries.

Keywords: China, Energy intensity, Industrial sector

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I. INTRODUCTION

Since the onset of economic reforms in 1978, China's economy has experienced rapid growth, with GDP (in constant prices) growing at an average annual rate of 9.7% between 1978 and 2006 (He and Wang, 2007). Such robust rates of economic growth generally drive up energy usage. While China is no exception, its energy intensity, defined as total energy consumption in physical quantities over real GDP, has steadily declined over the years. Overall, during 1993–2005, China experienced an annual average decline of 3.6% (He and Wang, 2007).

The reasons behind this decline in energy intensity have been widely investigated (see, e.g., Fisher-Vanden, Jefferson, Liu, and Tao, 2004; Garbaccio, Ho, and Jorgenson, 1999: Fan, Liao, and Wei, 2007; Ma and Stern, 2008) and are 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. These studies show that technological change has contributed at least 50% to the reduction in China's energy intensity. Therefore, to understand the factors behind China's impressive decline

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in energy intensity, it is important to understand what factors are driving improvements in energy efficiency at the firm level.

A key issue in understanding the factors that have achieved improvements in energy efficiency and which are shaping the potential for further gains in energy efficiency is the extent to which sectors and firms within Chinese industry are relatively homogeneous in the sense that they respond to the relevant range of policy instruments, including pricing, technology development, and enterprise restructuring, in a uniform way or, alternatively, if China's industrial sector represents a highly differentiated, heterogeneous collection of sub-sectors and firms that may be highly variable in their responsiveness to the policy instruments available to the Chinese government for the purpose of enhancing industrial energy efficiency. This paper focuses on this key issue concerning the extent to which various sectors of Chinese industry respond in uniform or notably disparate ways to various policy instruments.

Specifically, we investigate the factors explaining the decline in energy intensity in four Chinese industries: pulp and paper; cement; iron and steel; and aluminum. The econometric analysis utilizes 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 test the extent to which various policies, programs, and development trends specific to the industry or common across industries have contributed to the decline in energy intensity within each of these industries. Among the potential contributing factors included in the analysis are changes in energy prices, technology development expenditures, firm scale, ownership restructuring, and regional differences.

We find rising energy prices to be the most significant and consistent factor explaining the decline in energy intensity in these industries over our period of study. Scale economies, encouraged by the shut-down of small-scale polluting factories and enterprise restructuring programs, such as "grasping the large, letting go of the small," is another important factor explaining the decline in energy intensity within each industry in varying degrees. However, by comparison, whereas pricing and scale effects impact all four industries, technology development, trade openness, and ownership differences exhibit robust impacts within only one or two of the four industries. Additionally, regional differences exhibit surprisingly different effects. 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 intensities of firms in the North, East, and South are 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. We explore some possible explanations for these differences.

This paper is unique in a number of ways. First, unlike past studies that examine policies, programs, and development trends either specific to the industry or common across industries, we consider both. Second, existing studies that focus 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) employ industry—not firm-level data—and are therefore unable to examine the drivers of changing energy efficiency at the firm-level. By employing firm-level data, this study is able to identify these drivers.

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 and 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 III presents the data set used in this analysis, and section IV describes our estimation approach. Section V discusses the empirical results and offers interpretation, while Section VI describes and reports on the results of various robustness tests. Lastly, Section VII offers concluding remarks.

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Table 1: Four Industries, Summary Statistics

	Pulp and paper	Cement	Iron and steel	Aluminum
Share of manufacturing GVIO				
1999	1.8%	3.5%	8.7%	0.8%
2004	1.7%	1.7%	11%	0.5%
Share of output from SOEs				
1999	1.1%	2.0%	12.7%	1.2%
2004	0.2%	0.4%	6.6%	0.3%
Share of manufacturing energy consumption				
1999	2.5%	15.5%	25.4%	5.0%
2004	2.7%	15.7%	27.5%	5.6%
Energy intensity (energy consumed (10,000 tons SCE)/output (100 million Yuan))				
1999	1.31	4.26	2.85	6.40
2004	0.91	5.30	1.43	6.02

Source: National Bureau of Statistics (2000, 2005)

II. ENERGY CONSUMPTION AND DEVELOPMENT POLICIES IN FOUR CHINESE INDUSTRIES

Understanding the factors influencing energy intensity in the four industries in China under study in this paper is important as these industries occupy leading positions in the nation in energy consumption. Combined, they comprise a large share of China's manufacturing output. As shown in Table 1, although these industries do not comprise a large share of manufacturing output, they make up a large share of energy consumption in the manufacturing sector. In recent years, these industries have reduced their energy intensity dramatically. As shown in Table 1, the energy intensities of the pulp and paper and iron and steel industries almost fell by 50% between 1999 and 2004. The energy intensity of the Aluminum industry fell by less while the energy intensity of the Cement industry grew during this period.

A number of reforms have been instituted in China that have implications for China's industrial energy efficiency. In 1998, 21 ministries—including industrial sector-line ministries that provided 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 socialist 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 shutting down smaller polluting facilities and rationalizing ownership structure.

During the latter half of the 1990s, continuing into the 2000s, China's move toward privatization through "grasping the large, letting go the small" led to extensive restructuring both within the state and non-state sectors, including the shutting down or consolidation of many inefficient factories (Sutherland 2003).[1] One goal of this enterprise restructuring strategy was to improve

1. The "grasping the large, letting go of the small" policy was adopted in September 1997 at the 15th Communist Party Congress as a key policy element of the Central Government's industrial reforms that were enacted during this time.

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industrial energy efficiency, reduce emissions, eliminate excess capacity, and improve enterprises' technological capabilities. "Grasping the large, letting go off the small" was partially motivated by China's desire to create large state-owned enterprises that can compete with OECD multinationals. A key feature of this policy was 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-size rotary kilns-based plants reached nearly 62% of total cement production in 2008 (from 21% in 1992) and the share of cement production from the top-10 firms grew from 4% in 2000 to 13.7% in 2005 (Rock, 2011). In the iron and steel industry, the share of production from large firms grew from 60% in 2000 to 84% in 2010 (Rock and Jiang, 2011). 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. As for aluminum, the 15 largest aluminum producers accounted for 45% of total production in 2005 with the 10 largest of them accounting for 34% of total production (Rock and Wang, 2011).

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 failed 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).

Rising energy costs throughout China have also induced energy savings. By 1999, the allocation of energy through the state plan was substantially reduced (Fisher-Vanden et al. 2004), causing state-owned enterprises at the margin to more closely encounter world energy prices. 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.

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. Although not specific to China, Mielnik and Goldemberg (2002) find that developing countries with higher foreign direct investment have lower 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-

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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.

In addition to policies that target the industrial sector as a whole, the Chinese government has also introduced a number of sector-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 (e.g., small paper plants, small leather plants, small "open air" coking facilities) 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 1995 to 3,700 in 2009 (Rock and Song, 2011) 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 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 make process changes to reach a goal of more than 50% of waste heat utilized 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, 2011).

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; technology development; foreign influence; trade openness; regional effects and scale economies:

H1: Energy prices. Higher energy prices will have a negative and significant effect on energy intensity. Non-SOEs will lower their energy intensity more than SOEs in response to higher energy prices.

H2: Technology development. The impact of technology development expenditures will be weakly to strongly energy-saving, as we expect that technology development activities, including process innovation and product innovation, facilitated by technology development expenditure contribute significantly to lower energy intensities.

H3: Price-TDE interaction. As energy prices rise, firms may respond by using technology development expenditures to achieve energy-saving efficiencies. As R&D and technology development spending rise within our LME sample, we expect a negative relationship between the interaction of energy price and technology development and energy intensity.

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H4: Foreign capital influence. The presence of foreign capital will generally improve efficiency. Foreign direct investment (FDI) is thought to introduce advanced technologies and managerial skills to the host country, improving firm efficiency.

H5: TDE-Foreign capital interaction. Firms with higher technology development activity have larger adaptive capacities;[2] likewise, firms with FDI may have more access to foreign technology. Hence, we expect the interaction of technology development and FDI to lead to lower energy intensity.

H6: Trade openness: China's increasing openness to the world market will be significant in explaining differences in firm-level energy intensity in these four industries. Specifically, we test how the reduction in tariffs associated with China's ascension to the WTO in 2001 and the export orientation of firms affects their energy intensity, assuming that greater openness to foreign markets—and world prices—induces greater energy efficiency.

H7: Ownership effects. Foreign-owned firms in these four industries will have lower energy intensities than other ownership types, as we assume that foreign-owned firms have greater access to more advanced technologies.

H8: Regional effects. Firms in the more developed regions, such as the East, North, and South, will have lower energy intensities than firms in other regions. Since the onset of economic reforms in 1979, China's industrial structure has become more decentralized, with variations in the implementation of market reforms and differential exposure to international markets across regions.

H9: Scale economies. The efficiency advantages typically associated with scale will enable larger firms to exhibit lower levels of energy intensity than smaller firms. Since a variety of Chinese policy initiatives—namely the shuttering of small polluting factories and the policy of rationalizing firms through ownership restructuring, e.g., "grasping the large, letting go of the small," have emphasized the development of scale efficiencies, we expect scale effects will lead to lower energy intensity in these four industries. Although we test this hypothesis later in the study, we anticipate that it is among the most important of the potential drivers of industrial energy efficiency.

III. DATA

The data set used in our analysis combines three firm-level data sets collected annually by China's National Bureau of Statistics (NBS).[3] All three surveys focus on the population of large- and medium-size enterprises (LMEs), thereby omitting the larger number of small-scale enterprises. Nonetheless, in 2000, the LMEs in our data set accounted for 38% of China's total industrial output and 59% of China's total industrial energy consumption. The first NBS data set consists of economic and financial variables (such as sales, fixed assets, and employment by enterprise and year), comprising approximately 22,000 large- and medium-sized industrial enterprises—e.g., 3,325 enterprises in 1999 and 19,088 in 2004. The second data set, constructed from the same LME population, comprises science and technology (S&T) variables, such as R&D expenditures and R&D personnel, by enterprise and year. The third data set contains a number of energy variables (such as the value

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

3. These data are not publically available and were made available for this research through a research collaboration between the National Bureau of Statistics in China, Brandeis University, and Pennsylvania State University.

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and quantity of energy consumed by enterprise and year) for approximately 1,500 of the most energy-intensive LMEs, a subset of the other two data sets.

To create a balanced data set, we first create a balanced data set for two inclusive data sets, i.e., the economic and financial data set and the S&T data set. The combined balanced data set omits all the firms that do not report in all six years. Missing years often result from one or more of the following circumstances: (1) the size of a firm shrinks below the large and medium enterprise size threshold, (2) a firm may be assigned a new identification number as a result of a change in its formal ownership classification, a change in address, or a shift in its 4-digit SIC classification, or (3) a merger or acquisition occurs. The motivations for a balanced data set include the need to construct a stock of R&D capital[4] and also the wish for robust within- estimates with the application of fixed effects. A substantial number of firms are missing at least one year between 1999 and 2004. Most of the firms with missing years are firms that only report in the census year, 2004, and therefore only have one year of observations and are dropped from the data set. Our final balanced data set, prior to merging with the energy data set, consists of 2,000 firms per year from 1999–2004, or 12,000 observations in total.

We then take the energy data set, which is itself a subset of the LMEs, consisting of China's largest industrial energy consumers, and combine it with the balanced economics-finance and S&T data set. The energy data set is remarkably detailed, including measures of both the quantity and value of consumption for 20 individual energy types. Using the quantity and value data, it is possible to infer prices for each of the energy types consumed by each firm and allows us to construct firm-level energy-intensity, the dependent variable in our estimation. Merging the balanced economics-finance and S&T data set with the energy data set further reduces the number of observations, largely because the energy data set focuses only on the most energy-intensive enterprises and therefore is not as comprehensive as the economic-finance and S&T data sets. 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. Overall, in 1999, total energy consumption of the enterprises in our merged dataset accounts for over 40% of total industrial energy consumption.[5]

Most variables used in the analysis are included in the original data set. However, a few variables had to be constructed; namely the R&D stock using the following method

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

where

$K_{R,i,t} \equiv$ R&D stock of firm i at time t;
$I_{R,i,t-1} \equiv$ R&D 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 R&D expenditures by firm over the period 1995–2004. We use the perpetual inventory approach to estimate the R&D stock in the initial year 1995 as follows:

4. Data back to 1995 were used to construct these stocks.
5. National Bureau of Statistics of China, 2000.

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Table 2: Firm Distribution by Ownership Type, 2004 (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
HMT (Hong Kong, Macao, and Taiwan)	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

*The ownership classifications are those used by the National Bureau of Statistics.

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

where γ is the growth rate of I_R, estimated as the average annual growth rate of R&D expenditures in the 2-digit industry of firm *i* over the period 1995–2004.

After narrowing our merged dataset to the four industries that are the focus of this study, we lose an additional number of firms. Specifically, once the three data sets have been merged into a single balanced data set, 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. For the pooled data set, these amount to 261 firms and 1,566 observations.[6]

China's National Bureau of Statistics classifies enterprises into seven ownership types (state-owned, collective-owned, HKMT (Hong-Kong, Macao, and Taiwan), foreign, shareholding, private, and other) and six regional locations (North, Northeast, East, South, Southwest, and Northwest). Tables 2 and 3 provide distributions across ownership type and region by industry in our dataset. In all four industries, most enterprises are either state-owned or shareholding firms and are most likely located in the East where more than half of the total number of firms in the data set are situated, followed by the South. Table 4 provides a breakdown of foreign capital[7] and R&D intensities by industry and by year. Among the four industries, the cement industry has the highest foreign capital intensity while the iron and steel industry has the highest R&D intensity.

IV. MODEL SPECIFICATION

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

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

6. The unbalanced data set contains 7,934 observations, while the balanced data set only contains 1,566 observations.
7. Excluding capital from Hong Kong, Macao and Taiwan (HKMT)

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Table 3: Firm Distribution by Region, 2004 (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

*The regional classifications are those used by the National Bureau of Statistics.

Table 4: Intensity of Foreign Capital and R&D 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%

*Excludes capital from Hong Kong, Macao, and Taiwan (HKMT).

where:

$C \equiv$ total cost of production,
$Q \equiv$ gross value of industrial output in constant prices,
$P_K \equiv$ price of fixed assets, which is calculated as (value added − wage bill − welfare payments)/(net value fixed assets),
$P_L \equiv$ price of labor, which is calculated as (wage bill + welfare payments)/employment),
$P_E \equiv$ price of aggregate energy, which is calculated as (energy expenditures)/(quantity of energy purchased in standard coal equivalent (SCE)), and
$P_M \equiv$ industry-level price of materials.

Except for the price of materials, these variables are constructed using firm-level data from the NBS LME data set described above. In order to compute the price of materials, we use data on industrial prices by year from the China Statistical Yearbook (CSY) published by the National Bureau of Statistics. We compute the price of materials for a given firm in a specific industry as a composite of annual industry prices weighted by input-output shares for that firm's industry. Thus, firms within the same industry face the same materials prices over time—i.e., these prices vary annually for each industry.

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The parameter α_X is the price elasticity of input X (X = capital (K), labor (L), energy (E), materials (M)), and $\sum_{X=K,L,E,M} \alpha_X = 1$. A is the total factor productivity term defined as:

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

where TDE is the stock of R&D 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. Again, these variables are constructed using firm-level data acquired from the NBS LME data set.

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 estimation equation:

$$\ln\left(\frac{E}{Q}\right)_{i,t} = \alpha + \beta \ln(TDE)_{i,t} + \sum_{tt=1999}^{2004} \gamma_{tt} T_{tt} + \sum_{j=1}^{7} \lambda_j OWN_{j,i,t} + \sum_{k=1}^{6} \varphi_k REG_{k,i,t} + \eta FCI_{i,t}$$
$$+ \rho FCI_{i,t}^{*}\ln(TDE)_{i,t} + \mu \ln\left(\frac{P_E}{P_Q}\right)_{i,t} + \upsilon \ln\left(\frac{P_E}{P_Q}\right)_{i,t}^{*}\ln(TDE)_{i,t} + \varepsilon_i \quad (1)$$

where i refers to firm, t refers to year, j refers to ownership type, and k refers to region. 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 firm scale has no effect on a firm's energy intensity. In a separate estimation, we relax and test this assumption by moving output to the right-hand side of the equation:

$$\ln(E)_{i,t} = \alpha + s\ln(Q)_{i,t} + \beta \ln(TDE)_{i,t} + \sum_{tt=1999}^{2004} \gamma_{tt} T_{tt} + \sum_{j=1}^{7} \lambda_j OWN_{j,i,t} + \sum_{k=1}^{6} \varphi_k REG_{k,i,t}$$
$$+ \eta FCI_{i,t} + \rho FCI_{i,t}^{*}\ln(TDE)_{i,t} + \mu \ln\left(\frac{P_E}{P_Q}\right)_{i,t} + \upsilon \ln\left(\frac{P_E}{P_Q}\right)_{i,t}^{*}\ln(TDE)_{i,t} + \varepsilon_i \quad (2)$$

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

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Table 5: 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 (1,459)**	306 (249)**

* Number of firms only missing year 2004 are inside parentheses.
** Number of firms only reporting in year 2004 are inside parentheses.

Table 6: 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

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.[8] However, as discussed in Fisher-Vanden et al. (2009), although there are significantly fewer firms in the balanced data set, these firms consume over 40% of total industrial energy consumption.

We understand that dropping such a substantial number of firms may result in serious sample selection bias. Firms that drop out may, for example, be systematically less efficient overall and with respect to their energy efficiency than the surviving firms. To address this concern, as a robustness test, in Section VI, we run the regressions on an unbalanced data set obtained by dropping firms with only one year of observations over the period 1999–2004. As shown in Table 5, most firms with only one year of observations are only reporting for the year 2004, since this is a census year. These omitted firms are also smaller; Table 6 reports that the mean of the gross value of 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 R&D stocks based on continual annual flows of R&D expenditures. Instead, we use R&D flows rather than stocks in our robustness tests using the unbalanced data set, which introduces issues related to time structure and endogeneity.

V. RESULTS AND INTERPRETATION

Tables 7 through 13 present results from variations on our estimation strategy. Table 7 presents results using the pooled data for the four industries as well as the estimation results for

8. The unbalanced data set contains 7,934 observations, while the balanced data set only contains 1,566 observations.

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Table 7: Determinants of Energy Intensity (CRS, OLS)

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	−0.320	0.001	−0.801	0	0.143	0.045	−0.517	0.052	−1.226	0
Ln(price of energy/ price of output)	−0.540	0	−0.411	0	−0.230	0	−0.730	0	−0.129	0.480
Ln (R&D stock)	−0.040	0	−3.9E-05	0.996	−0.011	0	−0.011	0.445	−0.011	0.501
Ln(price of energy/ price of output)*Ln(R&D stock)	−0.020	0	0.013	0.202	−0.008	0.003	−0.002	0.906	−0.009	0.603
Foreign capital intensity	0.126	0.638	−0.514	0.279	−0.005	0.984	6.372	0.013	3.449	0.022
Foreign capital intensity*Ln(R&D stock)	−0.017	0.242	0.022	0.539	−0.007	0.597	−0.604	0.011	0.015	0.880
Collectives	−0.611	0	0.044	0.785	−0.417	0	−1.325	0	−0.137	0.480
Foreign	−0.553	0.002	0.384	0.095	−0.389	0.039	−1.192	0.002	−2.932	0
Hong-Kong, Macao, Taiwan	−0.460	0	−0.146	0.274	−0.063	0.358	−0.397	0.106	−1.055	0
Shareholding	−0.198	0	0.145	0.170	−0.200	0	−0.315	0.025	−0.598	0
Private	−0.072	0.551	0.145	0.625	−0.153	0.026	−1.184	0.058	−0.774	0.021
Other	0.306	0.618	—		0.075	0.806	—		—	
North	−0.624	0	−0.951	0	−0.264	0	−0.312	0.188	−0.351	0.193
Northeast	—		—		—		—		—	
East	−0.540	0	−0.842	0	−0.445	0	−0.280	0.193	−0.841	0.001
South	−0.456	0	−0.410	0.012	−0.390	0	−0.518	0.031	−0.677	0.006
Southwest	−1.290	0	—		−0.115	0.528	−0.678	0.082	−0.937	0.001
Year 2000	0.086	0.258	0.003	0.979	0.0492	0.382	−0.016	0.928	0.124	0.451
Year 2001	0.095	0.215	−0.012	0.924	0.0588	0.296	−0.054	0.765	0.121	0.471
Year 2002	0.022	0.773	0.011	0.931	0.0238	0.675	−0.150	0.412	0.080	0.644
Year 2003	−0.074	0.344	−0.029	0.823	−0.0171	0.764	−0.357	0.053	−0.080	0.651
Year 2004	−0.072	0.362	−0.030	0.818	0.0223	0.703	−0.439	0.018	−0.120	0.516
R^2(obs.)	0.402 (1528)		0.247 (290)		0.314 (677)		0.415 (418)		0.596 (143)	

each of the individual industries. For the pooled results in Columns (1) and (2), we find that the estimate for the energy price elasticity is negative and robust as predicted. In addition, the impact of the R&D stock is robustly negative as is the interaction between the energy price and R&D stock. This latter result confirms that changes in energy prices, notably increases, operate through two channels—the direct channel affecting conservation and the use of more efficient energy substitutes and the indirect effect involving energy-saving technology development and adoption. Within the pooled regression results, neither the firm's foreign capital intensity nor its interaction with the R&D stock seems to have significant implications for overall energy intensity. Nonetheless, formal ownership designations do seem to matter. The results show unambiguously that certain forms of ownership, namely firms classified as foreign-invested firms, Hong Kong, Macao and Taiwan owned, and shareholding firms, are generally more energy efficient than state-owned firms. This difference, however, is not the case for private and other ownership types, which may be

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Table 8: Determinants of Energy Intensity (CRS, Firm Fixed 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	−2.614	0	−1.196	0	−0.139	0.177	−2.630	0	−2.174	0
Ln(price of energy/ price of output)	−0.060	0.003	−0.013	0.856	−0.032	0.140	−0.179	0.022	0.589	0
Ln (R&D stock)	−0.006	0.031	−0.011	0.132	−0.001	0.811	−0.006	0.517	−0.018	0.080
Ln(Price of energy/ price of output)*Ln(R&D stock)	−0.005	0.011	0.001	0.819	0.001	0.830	−0.004	0.542	−0.060	0
Foreign capital intensity	−0.154	0.328	−0.038	0.891	−1.364	0.182	−0.303	0.875	−3.260	0
Foreign capital intensity*Ln(R&D stock)	−0.007	0.585	−0.047	0.075	−0.109	0.220	0.066	0.785	0.284	0
Year 2000	−0.023	0.436	0.003	0.962	0.015	0.651	−0.096	0.170	0.012	0.891
Year 2001	−0.046	0.118	0.020	0.761	0.011	0.743	−0.177	0.016	−0.001	0.990
Year 2002	−0.074	0.013	0.006	0.932	0.006	0.848	−0.247	0.001	−0.031	0.734
Year 2003	−0.145	0	0.006	0.927	−0.038	0.249	−0.407	0	−0.137	0.148
Year 2004	−0.161	0	−0.043	0.533	−0.015	0.666	−0.470	0	−0.215	0.029
R^2(obs.)	0.919 (1528)		0.844 (290)		0.819 (677)		0.930 (418)		0.904 (143)	

explained by their typically smaller size in the presence of scale economies. (We investigate this hypothesis below in Table 10).

The pooled results also show that relative to firms in the Northeast of China, firms in all other regions are relatively energy efficient. One way to possibly understand this difference is the relatively large energy endowment of China's northeast region; also, much of China's heavy industry is located in the northeast region. Finally, the results for the pooled sample show little improvement in energy efficiency from Year 1999 (the reference) to Year 2004, although relative to 2000 and 2001, the reduction in energy efficiency may be of significance. Overall, with the exception of foreign capital intensity and the relative efficiency of the price sector, the estimation results in the first two columns of the pooled results are largely consistent with the hypotheses sketched out in Section 2 above.

Looking at each of the four sets of individual industry results, we find that the estimated coefficients for the relative energy price are all negative; while they are highly significant for three of the four industries, they are highly insignificant for the aluminum industry. Among the three industries for which energy's price elasticity is significant, the magnitudes of the elasticity estimates vary from a low of −0.230 to a high of −0.730. This result is the first in a pattern of results that show extremely varied results across the four industries: one industry (cement) shows that R&D stock is of the expected negative and robust sign; only one industry shows that the interaction of R&D and the energy price is negative and robust; only one industry (iron and steel) shows that the interaction of R&D and foreign capital intensity is negative and robust. Foreign capital intensity is negative and robust only for one industry (iron and steel); it is, in fact, robust and positive for the aluminum industry.

The three sets of dummy variables—ownership, region, and year—also exhibit a striking variety of results. For the paper and pulp industry, none of the ownership types stands out as notably

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Table 9: Determinants of Energy Consumption (Non-CRS, OLS)

Dependent variable = ln(energy)	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	2.015	0	1.886	0	1.994	0	−0.059	0.918	−0.590	0.376
Ln(price of energy/price of output)	−0.528	0	−0.508	0	−0.227	0	−0.740	0	−0.161	0.384
Ln (R&D stock)	−0.021	0	0.018	0.042	−0.005	0.040	−0.006	0.706	−0.003	0.863
Ln(Value of industry output at constant price)	0.799	0	0.738	0	0.834	0	0.961	0	0.945	0
Ln(Price of energy/price of output)*Ln(R&D stock)	−0.019	0	0.0121	0.191	−0.008	0.003	−0.001	0.953	−0.007	0.684
Foreign capital intensity	0.256	0.321	−0.460	0.303	−0.146	0.545	6.141	0.017	3.627	0.017
Foreign capital intensity*Ln(R&D stock)	−0.030	0.028	0.006	0.855	−0.021	0.076	−0.577	0.016	−0.003	0.975
Collectives	−0.655	0	0.066	0.659	−0.447	0	−1.325	0	−0.044	0.834
Foreign	−0.559	0.001	0.537	0.014	−0.164	0.368	−1.230	0.002	−2.869	0
Hong-Kong, Macao, Taiwan	−0.433	0	0.150	0.267	−0.044	0.504	−0.405	0.099	−1.023	0
Shareholding	−0.258	0	0.181	0.069	−0.209	0	−0.329	0.020	−0.582	0
Private	−0.196	0.095	0.265	0.345	−0.185	0.005	−1.190	0.057	−0.747	0.026
Other	0.235	0.690	—		0.071	0.806	—		—	
North	−0.566	0	−0.723	0	−0.322	0	−0.283	0.237	−0.385	0.157
Northeast	—		—		—		—		—	
East	−0.412	0	−0.488	0.004	−0.411	0	−0.250	0.249	−0.825	0.001
South	−0.395	0	−0.126	0.43	−0.388	0	−0.496	0.040	−0.648	0.008
Southwest	−1.175	0	—		−0.150	0.390	−0.698	0.074	−0.894	0.002
Year 2000	0.068	0.356	−0.029	0.805	0.051	0.344	−0.021	0.909	0.105	0.527
Year 2001	0.086	0.241	0.004	0.970	0.066	0.221	−0.057	0.752	0.104	0.537
Year 2002	0.033	0.654	0.064	0.594	0.0436	0.423	−0.147	0.421	0.062	0.720
Year 2003	−0.040	0.596	0.029	0.811	0.0184	0.737	−0.347	0.060	−0.092	0.602
Year 2004	−0.026	0.731	0.017	0.892	0.0625	0.268	−0.423	0.024	−0.121	0.513
R^2(obs.)	0.687 (1528)		0.735 (290)		0.778 (677)		0.724 (418)		0.862 (143)	

more, or less, energy efficient that the state-owned sector. On the other hand, all but one of the remaining 16 ownership dummy estimates are robustly negative. Among these 15 coefficients for the three industries, 11 are robustly negative, indicating that the SOEs in those industries are relatively more energy intensive. Among the region dummies, the East and South appear to host the most energy efficient firms, such that in each case three of four of the industries show these regions being significantly more efficient than the Northeast region. Finally, concerning autonomous energy efficiency improvements as represented by the year dummies, only the iron and steel industry shows a significant efficiency improvement in 2004 relative to 1999.

These least squares results share one potential drawback. That is the possibility of endogeneity bias arising from omitted variable misspecification. If, for example, an omitted variable, say managerial quality or spillovers from energy-focused research institutes, is correlated with an

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Table 10: Determinants of Energy Intensity (SOE only, CRS, OLS)

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	−1.968	0	−1.877	0	0.165	0.088	−0.602	0.067	−1.034	0.002
Ln(price of energy/ price of output)	−0.455	0	−1.026	0	−0.038	0.338	−0.690	0.002	−0.560	0.092
Ln (R&D stock)	−0.037	0	0.055	0.010	0.002	0.622	−0.009	0.658	−0.047	0.075
Ln(Price of energy/ price of output)* Ln(R&D stock)	−0.022	0	0.061	0.002	0.001	0.801	0.000	0.989	0.040	0.282
Foreign capital intensity	−2.465	0.040	−1.824	0.091	−18.946	0.107	−199.3	0.341	—	
Foreign capital intensity* Ln(R&D stock)	0.030	0.783	−0.083	0.350	−1.501	0.142	18.627	0.335	0.412	0.252
North	1.160	0.001	−0.415	0.064	0.006	0.952	−0.128	0.619	−0.622	0.081
Northeast	1.438	0	—		—		—		—	
East	1.271	0	−0.171	0.516	−0.375	0	−0.260	0.276	−0.904	0.002
South	1.315	0	0.214	0.313	−0.195	0.014	0.101	0.706	−0.575	0.043
Southwest	—		—		—		—		−1.021	0.003
Year 2000	0.101	0.356	−0.123	0.487	0.030	0.679	−0.003	0.990	0.233	0.377
Year 2001	0.021	0.849	−0.093	0.603	0.030	0.687	−0.178	0.440	0.277	0.288
Year 2002	−0.056	0.626	−0.184	0.299	0.045	0.559	−0.251	0.281	0.289	0.283
Year 2003	−0.179	0.13	−0.153	0.410	0.078	0.325	−0.558	0.021	0.134	0.629
Year 2004	−0.111	0.358	0.141	0.468	0.115	0.155	−0.566	0.023	−0.101	0.728
R^2(obs.)	0.328 (636)		0.611 (70)		0.182 (270)		0.323 (227)		0.391 (69)	

independent variable, such as R&D stock, and energy intensity, the dependent variable, then bias may occur. Fixed effects can control for such firms-specific time-invariant effects. On the other hand, a drawback of such fixed effects is that they eliminate the influence of much of the cross-sectional variation, leaving the results to reflect the within-firm variation for each firm. The differences between the OLS estimates in Table 7 and the fixed effects (FE) estimates in Table 8 are discussed below.

One notable difference is the substantial reduction in the magnitude of the price elasticity estimates. For the pooled four industry data, the magnitude of the FE price elasticity falls to 0.060, just one-ninth of the least squares estimate. Moreover, FE price elasticity estimates remain negative and significant only for the iron and steel industry, while becoming positive and significant for the aluminum industry. The key difference in these own-energy price elasticities is that the FE estimates effectively become short-run elasticity estimates based on within-firm adjustments over a relatively short period of time, contemporary associations between energy prices and quantities. By comparison, by admitting a substantial portion of the cross-section influence, even after controlling for ownership and region, the least square estimates capture a portion of the longer-run impact of price changes as reflected by firms that have adjusted to longer-term price differentials.

For R&D stock, the FE estimates for the pooled sample show a direct impact that is negative and robust and also the capacity for R&D and prices to interact robustly to achieve energy conserving effects. The interaction of R&D with foreign capital intensity is not significant. Across

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Table 11: Determinants of Energy Intensity (Non-SOE, CRS, OLS)

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	−1.319	0.041	−0.221	0.571	−0.076	0.831	−1.125	0.170	−3.275	0
Ln(price of energy/price of output)	−0.632	0	−0.194	0.157	−0.362	0	−0.953	0	−0.392	0.338
Ln (R&D stock)	−0.041	0	−0.011	0.281	−0.018	0	0.008	0.722	0.060	0.158
Ln(Price of energy/price of output)*Ln(R&D stock)	−0.015	0.004	−0.009	0.499	−0.010	0.011	0.013	0.582	0.015	0.698
Foreign capital intensity	0.194	0.482	−0.347	0.51	0.057	0.824	8.392	0.002	5.959	0.067
Foreign capital intensity*Ln(R&D stock)	−0.004	0.772	0.026	0.496	0.003	0.829	−0.805	0.001	−0.199	0.404
Collectives	−0.859	0.164	−0.164	0.63	−0.418	0.184	−0.175	0.786	0.466	0.188
Foreign	−0.834	0.19	0.056	0.887	−0.477	0.188	0.239	0.746	−2.507	0.001
Hong-Kong, Macao, Taiwan	−0.708	0.252	−0.387	0.243	−0.090	0.777	1.325	0.048	−0.531	0.159
Shareholding	−0.469	0.445	−0.074	0.814	−0.251	0.419	1.071	0.086	0.110	0.716
Private	−0.399	0.523	—		−0.212	0.504	—		—	
Other	—		—		—		—		—	
North	0.463	0.023	−1.411	0	−0.216	0.245	−1.251	0.023	0.685	0.069
Northeast	1.518	0	—		0.339	0.073	—		—	
East	0.591	0.001	−1.106	0	−0.289	0.113	−1.159	0.017	0.134	0.611
South	0.693	0	−0.702	0.001	−0.267	0.151	−2.187	0	0.022	0.934
Southwest	—		—		—		−1.542	0.005	—	
Year 2000	0.080	0.444	0.017	0.911	0.065	0.401	−0.039	0.891	−0.097	0.658
Year 2001	0.170	0.102	0.046	0.766	0.079	0.304	0.039	0.890	−0.160	0.485
Year 2002	0.098	0.344	0.050	0.755	0.019	0.801	−0.069	0.808	−0.230	0.334
Year 2003	0.033	0.748	0.005	0.976	−0.042	0.577	−0.209	0.454	−0.412	0.096
Year 2004	−0.001	0.993	−0.084	0.595	0.006	0.944	−0.425	0.127	−0.326	0.229
R^2(obs.)	0.436 (892)		0.229 (220)		0.408 (407)		0.429 (191)		0.606 (74)	

the four individual industries, outside of the aluminum industry, the direct impact of R&D, as well as its interaction with the price of energy, has little effect. Only the pulp and paper industry shows an energy conserving effect, and weak at that, resulting from the interaction of R&D and foreign capital.

Independent of price and technology, foreign capital intensity appears to be efficiency-improving only for the aluminum industry. Given the use of fixed effects, the time-invariant ownership classifications drop out. The year dummies show somewhat greater statistical robustness relative to the least squares results, exhibiting statistical significance for the aluminum industry as well as the iron and steel industry.

While the fixed effects results, shown in Table 8, are important, they do eliminate an important dimension of the efficiency of the estimates. For the remainder of the paper we report least squares results with fixed effects for ownership type and region, and not firm-level fixed effects. The industry fixed effects are accounted for by separating the industries into four individual sub-

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Table 12: Determinants of Energy Intensity (1999–2001, CRS, OLS)

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	−1.461	0	−1.703	0	0.1924	0.481	−0.399	0.260	−0.916	0.016
Ln(price of energy/price of output)	−0.499	0	−0.371	0.006	−0.152	0	−0.783	0	−0.063	0.741
Ln (R&D stock)	−0.027	0	0.013	0.300	−0.008	0.041	0.014	0.478	−0.012	0.491
Ln(Price of energy/Price of output)* ln(R&D stock)	−0.008	0.108	0.022	0.086	−0.001	0.847	0.018	0.327	−0.010	0.595
Foreign capital intensity	0.268	0.504	−0.461	0.629	0.044	0.893	7.205	0.050	5.216	0.003
Foreign capital intensity*Ln(R&D stock)	−0.023	0.282	0.031	0.575	0.008	0.672	−0.785	0.033	0.051	0.658
Collectives	−0.678	0	0.117	0.571	−0.404	0	−1.458	0	−0.196	0.412
Foreign	−0.658	0.009	0.442	0.244	−0.270	0.250	−1.044	0.090	−3.886	0
Hong-Kong, Macao, Taiwan	−0.521	0	−0.096	0.597	0.096	0.351	−0.556	0.111	−1.065	0
Shareholding	−0.265	0.001	0.161	0.281	−0.165	0.007	−0.411	0.068	−0.537	0.003
Private	0.057	0.807	—		−0.193	0.112	—		—	
Other	0.294	0.642	—		0.016	0.960	—		—	
North	0.546	0.028	—		−0.233	0.388	−0.508	0.154	−0.607	0.129
Northeast	1.392	0	0.926	0.001	0.055	0.840	—		—	
East	0.639	0.007	0.009	0.965	−0.453	0.091	−0.456	0.149	−1.271	0
South	0.629	0.009	0.476	0.013	−0.483	0.073	−0.810	0.026	−0.936	0.011
Southwest	—		—		—		−0.608	0.287	−1.195	0.003
Year 2000	0.069	0.379	−0.016	0.897	0.049	0.411	−0.061	0.743	0.115	0.477
Year 2001	0.067	0.377	−0.036	0.776	0.053	0.374	−0.113	0.551	0.106	0.523
R^2(obs.)	0.369 (770)		0.274 (146)		0.273 (342)		0.405 (210)		0.674 (72)	

samples. We return to the issue of fixed effects later in the paper. In the remaining tables, we address the issues of CRS versus scale economies and SOE versus non-SOEs.

Table 9 relaxes the assumption of constant returns to scale. In order to test for non-CRS, we employ the energy demand equation shown in Equation (2) rather than the energy intensity equation, i.e. E/Q, shown in Equation (1). With the log of industry output (lnQ) included among the regressors, we can test for the presence of increasing (or decreasing) returns to scale in energy consumption. Estimates less than unity imply that a one percent increase in output result in less than a one percent increase in energy consumption so that energy intensity (efficiency) declines (rises). One policy implication of an energy-output elasticity less than unity is that the government might encourage market competition or regulation to encourage the consolidation or liquidation of smaller, energy-inefficient plants.

In Table 9, we first note that scale effects are robust across both the pooled data and for each of the four industries. However, the extent of scale effects varies significantly across industries, with pulp and paper, followed by cement, exhibiting the most economically significant scale economies, with the iron and steel and aluminum industries significantly less and not so different from unity. While the pattern of results for the other coefficient estimates in Table 9 is hardly different

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Table 13: Determinants of Energy Intensity (2002–2004, CRS, OLS)

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	−0.856	0	−0.900	0.003	−0.246	0.025	−1.729	0.002	−1.063	0.071
Ln(price energy/price output)	−0.762	0	−0.459	0.018	−0.464	0	−0.699	0.019	0.184	0.810
Ln (technology development)	−0.057	0	−0.014	0.313	−0.017	0	−0.058	0.023	−0.102	0.055
Ln(Price energy/price output)*Ln(technology development)	−0.040	0	0.003	0.862	−0.019	0	−0.047	0.082	−0.103	0.225
Foreign capital intensity	−0.037	0.913	−0.610	0.301	0.060	0.875	4.590	0.192	−21.300	0.257
Foreign capital intensity*Ln(technology development)	−0.014	0.429	0.026	0.64	−0.017	0.285	−0.403	0.195	1.771	0.244
Collectives	−0.472	0	−0.051	0.855	−0.373	0	−0.979	0	−0.104	0.755
Foreign	−0.352	0.125	0.338	0.355	−0.547	0.077	−0.917	0.061	−0.132	0.889
Hong-Kong, Macao, Taiwan	−0.334	0.004	−0.152	0.453	−0.1200	0.020	−0.061	0.854	−0.727	0.009
Shareholding	−0.127	0.065	0.165	0.294	−0.224	0	−0.254	0.142	−0.579	0
Private	−0.111	0.402	0.080	0.806	−0.135	0.076	−1.128	0.054	−1.114	0.002
Other	—		—		—		—		—	
North	−0.258	0.043	−0.867	0.004	−0.177	0.044	0.922	0.057	0.129	0.743
Northeast	—		—		—		0.833	0.102	—	
East	−0.110	0.338	−0.662	0.008	−0.202	0.010	0.954	0.036	0.051	0.883
South	0.066	0.575	−0.248	0.320	−0.074	0.357	0.880	0.069	0.116	0.733
Southwest	−1.096	0	—		−0.087	0.699	—		−0.306	0.408
Year 2003	−0.111	0.114	−0.042	0.754	−0.043	0.376	−0.263	0.119	−0.109	0.456
Year 2004	−0.100	0.161	−0.039	0.769	0.027	0.590	−0.361	0.034	−0.119	0.447
R^2(obs.)	0.513 (758)		0.259 (144)		0.480 (335)		0.506 (208)		0.680 (71)	

from those shown in Table 7 under the assumption of CRS, one difference is notable. That is, while in Table 7, R&D spending is robust only for the cement industry, the technology coefficient for the pulp and paper industry turns highly significant when the CRS restriction is relaxed in Table 9. Because of this limited difference we observe in relaxing the CRS constraint, we investigate other variations in our specification retaining the CRS constraint. The other variations entail testing the subset of SOEs against non-SOE firms and testing for the stability of our results over the period 1999–2001 vs. 2002–2004.

Table 10 focuses on the SOE subsample only. This accounts for 636 firms or about 42 percent of the total observations. Table 11, which focuses on the subsample of 892 non-SOEs, provides the relevant comparison. Here are some of the highlights of the comparison:

1. For the pooled samples, the overall price elasticity for the non-SOEs is significantly larger than that for the SOEs. At the industry level, for the SOE subsample, the price elasticities for pulp and paper and aluminum are significantly larger, more negative, and more robust than those for the non-SOE subsample, whereas the price elasticities for cement and iron and steel are significantly larger for the non-SOEs than for the SOEs.

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2. The R&D spending estimates are quite different—within the SOE subsample, the estimates positive and marginally significant for pulp and paper and negative for aluminum. For the non-SOEs, cement is robustly negative.
3. Estimates of the interaction of the energy price and R&D spending also differ as between the state and non-state sectors. While for the state sector, the estimate for the pooled data is negative and robust, estimates for the individual industries are all positive, of which only pulp and paper is robust. The non-SOE price-technology interaction is likewise negative and robust, while only the interaction for the cement industry is robustly negative.
4. Neither subsample exhibits substantial autonomous productivity advance over the relevant sample period.

We note that overall the R-square, goodness of fit, is somewhat larger for the non-SOE subsample and, with the exception of paper and pulp, significantly larger for three of the four industries. We discuss possible implications of this disparity in the final section of the paper.

The final two tables—Tables 12 and 13—test the stability of the results over the periods 1999–2001 and 2002–2004. In particular, we surmise that during the later period, with the opening of China's manufacturing sector to the international sector, including the accession to the World Trade Organization, in December 2001, aspects of Chinese manufacturing may have become more responsive to prices and technology. The first indication that the degree of price responsiveness may have grown within the four industries is the substantial increase in the energy price elasticity from -0.400 (p-value = 0) in 1999–2001 to -0.762 (p-value = 0) for 2002–2004. Furthermore, two of the industries show substantial increases in the estimates of their energy price elasticities. With respect to R&D spending, in the later period we see more than a doubling of the magnitude of the sign of the R&D spending elasticity. At the same time, while during 1999–2001 only the cement industry exhibits any significant energy-saving responsiveness to R&D spending, during 2002–2004, the number of R&D-responsive industries rises to three of the four included in our study. We also find in the later period an increase in the responsiveness of energy efficiency to R&D spending and its energy price interactions. Whereas during 1999–2001, the interaction is largely insignificant across the board, including for the pooled data, for the later 2002–2004 subsample, the estimate for the pooled sample turns robust; for the individual industry estimates, the interaction coefficient becomes highly robust for the cement industry and modestly so for iron and steel. Overall, the comparison of Tables 12 and 13 show an impressive increase in the market and technology responsiveness of Chinese industry over the period 2002–2004 relative to the earlier period.

Summarizing, in Section 2 we advanced nine hypotheses. Here we summarize our results in Tables 7 through 13 as they relate to the nine hypotheses:

H1: Higher energy prices reduce energy intensity: Yes, among the tested hypotheses, this proposition receives the most robust support. Curiously, the one industry for which the least squares price elasticity does not show as predicted, i.e., aluminum, exhibits a robust positive price elasticity using fixed effects. The same elasticity becomes negative and modestly significant for the 69 SOEs in the aluminum industry.

H2: R&D spending tends to be energy-saving: For the pooled 4-industry sample, the impact of R&D spending on energy efficiency is robust for both the least squares and fixed effects results. Thereafter, for the individual industries, the results are uneven. Only in the 2002–2004 period are all of the results of the expected negative sign, of which three of are substantially statistically significant.

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H3: Energy-prices and R&D interact to reduce energy intensity: In six of the seven sets of pooled regressions reported in Tables 7 through 13, the interaction of R&D spending with the price of energy is of the expected sign and highly robust. In the case of the exception, the pooled regression for 1999–2001, the estimate is negative with a p-value of 0.108. Across industries and the various specifications, the estimates are uneven. The interactions appear to be most robust for the non-state-owned cement enterprises.

H4: Even controlling for formal ownership classifications, higher foreign capital intensity is associated with lower energy intensity: Among the nine hypotheses investigated in this paper, this encounters the weakest support. We find support for the importance of foreign capital intensity only in the case of the SOE subsample. This weak result is likely to reflect the fact that by including the ownership types, including foreign-owned firms, the category of foreign invested firms is included among them. Although the extent of foreign ownership varies significantly among firms that are designated as foreign-owned and many non-foreign-owned enterprises include foreign investment, thus justifying our inclusion of both foreign investment shares and formal foreign ownership designation in specifications, the two foreign variables are significantly correlated. In this regard, among the SOE sample alone, because a significant proportion report some degree of foreign asset participation, this condition turns significant for the SOE subsample. Among the SOEs, the cement and pulp and paper SOEs appear in particular to benefit from the presence of foreign investment.

H5: Foreign investment share and R&D interactions lead to lower energy intensity: As with H4, above, this hypothesis receives only limited empirical support. The two regressions for which we find evidence in the pooled sample in support of within-firm FDI and R&D interactions are the non-CRS and FE cases. The one industry that stands out is the iron and steel industry, which suggests that access to foreign technology is of particular value for China's iron and steel industry.

H6: Openness to foreign markets and investment encourage energy efficiency: This result, in which we see that the price and technology estimates for the 2002–2004 period are more robust than for the earlier 1999–2001 period are, arguably, the most striking in the paper. China's ascension to the WTO in December 2001, involving increasing liberalization during the years immediately before and after is likely to account substantially for the greater responsiveness of the sample to prices and technology investment.

H7: The firm's formal ownership classification matters. Generally, state-owned firms will be less energy efficient: In all of the relevant sets of regressions (omitting the fixed effects and SOE only regressions), the non-state ownership classifications exhibit higher energy efficiency than the SOE baseline. The exception is the private sector and "other" firms. This result may reflect the fact that many private-owned firms lack the scale for their operations that enables greater energy efficiency. Indeed, in the non-CRS estimates (Table 9), the estimate of the private dummy does rise (p-value = 0.095). We also note that for the pooled results in Tables 10 and 11, as compared with the non-SOE subsample, the SOE subsample exhibits somewhat greater autonomous advances in energy efficiency in 2003–2004 as compared with the 1999 base. We explore a possible implication of this and related findings in the section on conclusions and discussion.

H8: In part due to their relatively high levels of development and in part because they are relatively energy-scarce, the East, North, and South regions will be relatively energy efficient: As anticipated, the firms in the North, East, and South regions tend to exhibit

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higher energy efficiency than in the Northwest, although some results also show the Southeast region firms exhibiting the highest degree of efficiency, given the other control variables in the analysis. In the 1999–2001 to 2002–2004 breakout, we see that the energy efficient advantage of the East and South loses its statistical significance, suggesting a degree of energy efficiency catch-up by the relatively more backward and more richly energy-endowed regions.

H9: Scale economies are associated with relative energy efficiency: In Table 9, we find that scale matters very robustly. The p-value for each of the four industry estimates is zero (0), although the magnitudes vary substantially from near unity for the iron and steel and aluminum industries to 0.738 for the pulp and paper industry and 0.834 for the cement industry. This recognition of inefficiencies within China's more highly energy-intensive industries, such as the four on which we focus in this paper, has motivated the government to focus on the shutdown and consolidation of many of the firms within these industries.

We know that during the period 1999–2004, the number of large-scale iron and steel plants nearly doubled from 8 to 15, accounting for upwards of half of China's total steel production (Rock and Jiang, 2011). By comparison, the share of industrial output from the top-ten Chinese cement firms increased from only 4% in 2000 to 13.5% in 2005 (Rock, 2011)—it appears that a large share of cement production continues to reside in sub-optimal scale plants.

To conclude this summary of our results, two of our findings standout. The first is that most of the factors we have identified in our nine hypotheses matter. Prices, technology, scale, and regional location matter the most. Ownership, foreign investment share, and autonomous technical change matter sporatically. The second critical finding is that, even among the most consistently significant factors, the degree of significance differs substantially across the four industries we have focused on. We discuss this further in the last section of the paper.

VI. ROBUSTNESS TESTS

To test the robustness of our results, we conduct tests using an unbalanced data set. Our previous estimations were conducted using a balanced dataset comprising firm-level data over the period 1999–2004. Using a balanced data set creates several advantages relative to the unbalanced sample. First, with the balanced data set, we are able to construct stocks of R&D spending which serve as better proxies for the flow of R&D services than the alternative of our reliance on intermittent flows used in Table 14. Furthermore, when we apply fixed effects, having a relatively continuous time series enables a more robust set of results that captures the within-firm adjustments to changes in prices, R&D, and the other regressors.

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. The exclusion of firms that do not report in one or more years may also introduce an element of sample selection bias. The omission of many firms in the balanced dataset can erode estimation power as well as introduce sample selection bias. Firms that do not continuously report over the six year period might, for instance, drop out as a result of restructuring, including a change of ownership or principal product produced. Those entering may appear or reappear after the fact of such a restructuring. In either case, the restructured firms may be more or less energy efficient due to the restructuring rather than due to differences or changes in the relative price of energy, R&D intensity, or due to the established ownership status of the firm.

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Table 14: Determinants of Energy Intensity (CRS, Pooled Effect, unbalanced dataset)

	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	−0.967	0	−0.989	0	−0.178	0.008	−1.200	0	−1.332	0
Ln(price of energy/price of output)	−0.572	0	−0.423	0	−0.269	0	−0.808	0	−0.382	0
Ln (R&D expenditure, flow)	−0.013	0	0.010	0	−0.001	0.493	−0.002	0.508	−0.002	0.595
Ln(Price of energy/price of output)*Ln(R&D expenditure, flow)	0.005	0	0.015	0	0.003	0.023	0.015	0	0.014	0
Foreign Capital intensity	0.049	0.667	0.091	0.599	−0.076	0.628	−0.176	0.418	0.338	0.257
Foreign Capital intensity*Ln(R&D expenditure, flow)	0.026	0	0.037	0	−0.010	0.324	0.001	0.933	0.013	0.44
Collectives	−0.423	0	−0.264	0.001	−0.328	0	−0.932	0	−0.737	0
Foreign	−0.834	0	−0.542	0	−0.453	0	−0.895	0	−1.176	0
Hong-Kong, Macao, Taiwan	−0.743	0	−0.470	0	−0.471	0	−0.885	0	−0.773	0
Shareholding	−0.052	0.104	−0.070	0.214	−0.041	0.213	−0.238	0.002	−0.434	0
Private	−0.165	0	−0.112	0.162	−0.067	0.142	−0.341	0	−0.608	0
Other	−0.250	0.113	−0.312	0.354	−0.383	0.004	−0.652	0.159	0.251	0.781
North	−0.419	0	−0.670	0	−0.445	0	−0.372	0.002	−0.135	0.328
Northeast	−0.088	0.171	0.075	0.528	0.029	0.675	−0.264	0.056	0.206	0.19
East	−0.599	0	−0.799	0	−0.412	0	−0.786	0	−0.806	0
South	−0.252	0	−0.351	0	−0.240	0	−0.257	0.043	−0.220	0.075
Southwest	−0.233	0	−0.546	0	−0.210	0	−0.343	0.011	−0.246	0.056
Year 1998	0.046	0.426	0.109	0.245	0.027	0.641	0.141	0.338	−0.347	0.03
Year 1999	0.384	0	0.302	0.001	0.183	0.001	0.528	0	0.019	0.9
Year 2000	0.411	0	0.196	0.038	0.224	0	0.551	0	−0.051	0.758
Year 2001	0.381	0	0.242	0.011	0.184	0.001	0.628	0	−0.045	0.767
Year 2002	0.320	0	0.255	0.007	0.183	0.001	0.356	0.01	−0.178	0.223
Year 2003	0.128	0.019	0.038	0.681	−0.047	0.392	0.312	0.016	−0.146	0.287
Year 2004	−0.729	0	−0.481	0	−0.510	0	−0.692	0	−0.651	0
R^2(obs.)	10738 (0.3994)		2028 (0.4224)		4688 (0.2712)		3150 (0.4517)		872 (0.4521)	

While we do not have a systematic assessment of the firms that are exiting and entering, because these are LMEs, it is likely that rather than being merged or liquidated, many of these firms are restructuring. As a result of the restructuring, they acquire new firm identifications thus appearing as new entrants. Still other firms may be merged or acquired, while still others may be close to the medium-size/small-size scale threshold resulting in their forfeiting their LME status for certain years.

Restructuring may occur in numerous ways. Firms that disappear as a result of restructuring and do not continuously report over the six-year period may simply have altered their firm identification code. The change in ID may result from a change of ownership or principal product produced, or a change of address. The restructured firms, which appear to be exits or new entrants, may be more or less energy efficient due to the restructuring rather than due to factors that are

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explicitly captured in the model, including the relative price of energy, R&D intensity, or the established ownership status of the firm.

To test how our use of a balanced data set affects the results, we run the basic regression shown in Table 7 on an unbalanced data set. The unbalanced data set is constructed by including all firms that report observations for at least two of the six years included in the data set. By requiring the firms to include at least two observations, we are able to implement a fixed effects version of the estimation results.[9] Because most of the firms did not report continuously over the period 1997–2004, we are not able to construct technology development stocks for each firm, and we therefore use contemporaneous flows of R&D technology development expenditures rather than stocks. The use of contemporary observations for energy intensity and R&D spending raises possible endogeneity issues, since energy productivity and its potential for gains may influence a firm's choice of R&D expenditures in a given year. Nonetheless, given that R&D stocks and the intermittent observations of flows are highly correlated, contemporary flows are frequently used as a robust proxy for stocks. While we anticipate differences in the results using the balanced and unbalanced data sets, the two sets of results should be roughly consistent as between the two approaches.

Table 14 shows the results using the unbalanced data set. Overall, with the exception of the R&D-interacted variables, the results are consistent with those reported in Table 7. With one exception, the magnitudes of the price variable are all marginally larger. The exception is aluminum for which the price elasticity becomes substantially more robust for the unbalanced data set than for balanced data set.

By comparison, for R&D expenditure, where we have had to rely on intermittent flows to represent technology development, the unbalanced estimate for the pooled sample is about one-third the magnitude of the balanced estimate; it retains its p-value of 0. However, while three of the four estimates have the expected negative sign, the only robust estimate, pulp and paper, has a positive sign. Surprisingly, in the case of the interaction terms, i.e., between R&D spending and energy price and R&D and foreign capital intensity, the most robust estimates are all of the unexpected positive sign. As with the balanced data set, the foreign capital intensity variable shows little effect.

For the unbalanced data set, the ownership results are significantly more consistent and robust than those for the balanced data set. For the pooled data and all four industries, ownership dummies are negative and robust for the collectives, foreign and HMT classifications. The estimates for private and other ownership are, with one exception, negative. While the robustness of the estimates is mixed, four of the 10 estimates, including the pooled estimate for private firms, are highly significant.

Among the unbalanced estimates, the regional dummies are similar to their balanced counterparts, with the east and south, followed by the north, typically exhibiting lower levels of energy intensity than the northeast and northwest regions. Possibly, the most interesting difference between Tables 14 and 7 is the string of consistently negative dummy coefficients for 2004 for the unbalanced estimates versus far less robust estimates for the balanced sample. These estimates may compensate for the fact that in the unbalanced estimates the technology variables account for less of the decline in energy intensity, leaving the autonomous measures to capture more of that decline over the sample period.

9. It turns out that most firms that report only one observation years are those that report in 2004 and no other year. The spike in the number of firms reporting in 2004 is largely due to the administration of an economy-wide census in that year which captured many firms of the large and medium-size that had not self-reported in the previous years.

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Finally, we estimated the unbalanced data set with fixed effects. We summarize but do not include the table with these results.[10] The results were not unexpected. The estimates using the pooled sample for the price elasticity and the R&D spending effect were significantly smaller but still highly robust. Likewise, the results for the individual industries were quite varied, as they were for the individual industry estimates using the balanced data set. Like the OLS estimates for the unbalanced sample, the autonomous productivity change estimates using fixed effects for the unbalanced sample was significantly larger than the estimates shown for the balanced data set in Table 4.

In conclusion, the results between the balanced and unbalanced samples are robust mostly in line as anticipated; for the OLS estimates that include the expanded cross-section in the sample, the estimates are typically more consistent with prior expectations, larger and more robust. The key consistent exception was, not surprisingly, the estimates involving the interaction of R&D expenditures with price and foreign investment intensity. These results tended to be somewhat positive, not of the anticipated negative signs. However, given the shift from the use of an R&D stock measure using the balanced data set to an R&D flow measure, combined with the introduction of a large number of firms that appeared only sporadically in the data set, it is not surprising that these estimates would be other than the anticipated results. The positive signs may reflect endogeneity bias, since it may well be the case that within China's industrial sector, the more energy intensive firms are also more R&D intensive. The potential for endogeneity bias is more likely to be apparent when using the contemporary measures of energy intensity and R&D intensity as compared with using the historical series for R&D spending as represented by the R&D stock.

VII. CONCLUSION AND DISCUSSION

Energy intensity in four Chinese industries—pulp and paper, cement, iron and steel, and aluminum—has decreased substantially over the last 30 years. Many factors, including rising energy prices, scale effects, increased research and development activity, market-oriented reforms, and imports of foreign capital and technology, are potential candidates for explaining this decline. In this paper, our empirical results show that several factors - rising energy prices, scale effects, R&D expenditure, several ownership categories, regional variation, and trade liberalization—seem to have most substantially and consistently enabled the decline in energy intensity over our period of study. While the effects of these factors have generally been consistent with the predicted contributions to greater energy intensity, the magnitudes of their impacts nevertheless vary considerably across the four energy-intensive industries included in this study.

Other factors on which we focus in this analysis—foreign capital intensity, the interaction of R&D with foreign capital intensity, and autonomous, time-driven energy productivity improvements—are relatively unimportant. Neither the incidence nor the magnitudes of these factors qualify them as key drivers of declining energy intensity. Foreign capital intensity appears to be a source of robust energy efficiency for state-owned enterprises, but not for the non-state sector. R&D-foreign capital interactions enable energy efficiency gains in the iron and steel non-state sector, but hardly elsewhere. Autonomous productivity improvements become significant for the unbalanced sample but only sporadically for the balanced sample.

We do find it curious that as much variation appears to exist across the four industries, such as the price elasticity estimates that show -0.13 and highly insignificant for aluminum vs.

10. The table is available from the authors.

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−0.73 with a p-value = 0 for iron and steel. Similarly, the R&D estimates exhibit very different outcomes. One possible explanation is the overlay of government regulation, subsidies, and oversight for many enterprises, particularly those in energy-intensive industries such as those comprising our sample. One example of such active, differentiating government policy is that which the central government and many local governments focused on China's 1,000 large energy-consuming enterprises during 2005–2010.[11] Highlighting special initiatives focused on the 1,000 Enterprise Energy Conservation Program enterprises, China's National Development and Reform Commission (NDRC) catalogued the following:

1. Focusing leadership on the energy efficiency objective;
2. Assigning clear responsibility, along with penalties and rewards;
3. Increasing investment in energy efficiency;
4. Strengthening management and the implementation of specific energy systems and programs within firms, including data management;
5. Increasing awareness among all employees.

These initiatives, including penalties and rewards for meeting certain targets focusing on leadership and management systems imply an extensive degree of government intervention, which may or may not act in concert with changing energy prices. Whether they do or do not, unless these initiatives are controlled for in our regression analysis they are likely to motivate energy conservation that is unwarranted by price increases or hinder adjustments to energy conservation that may otherwise result from a change in prices, either increases or decreases. The result is likely to downwardly bias the estimates of the relevant price elasticities. The energy-intensive industries covered in this paper were particularly subject to government intervention, such as the iron and steel industry to which the government focused large quantities of investment for expansion and energy conservation and the cement industry where the government shut down many of the smaller and least efficient enterprises.

The belief that government intervention is having an effect of weakening the power of the economic model in which prices, technology, and asset structure are key drivers of energy efficiency receives further support from an examination of the goodness of fit (i.e., the Rsq) comparisons of the various regressions. Comparing Tables 10 and 11, we see, for example, that the R-squared for the SOE pooled sample in Table 10 is somewhat less than that for the non-SOEs in Table 11. While in this table the pulp and paper industry SOEs show a surprisingly significant higher goodness of fit to our model than their non-state counterparts, for the other industries, the non-SOEs exhibit substantially higher R-sq's than their SOE counterparts in Table 10.

In conclusion, our study confirms one area of speculation set out in the introduction of this paper. That is that with respect to issues of energy conservation—both recent achievements and potential gains—Chinese industry is highly heterogeneous. The four energy-intensive industries on which this study has focused all exhibit significant differences in their responsiveness to prices, technology, and asset-ownership structure. Moreover, within industries, the responsiveness of SOEs and non-SOEs to these drivers varies significantly.

The central implication of these disparate findings is that policy makers in China need to analyze, understand, and address the responsiveness of each sector individually. A bundle of energy-

11. http://www.chinafaqs.org/blog-posts/chinas-1000-enterprise-energy-conservation-program-beats-target

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saving policies designed for all of Chinese industry may or may not work in all, most, or any of the four industries on which we have focused in this paper.

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