

What is Driving China's Decline in Energy Intensity?*

Karen Fisher-Vanden**
Dartmouth College

Gary H. Jefferson
Brandeis University

LIU Hongmei and TAO Quan
National Bureau of Statistics, People's Republic of China

July 24, 2003

Published *Resource and Energy Economics*, 26, 2004

Abstract

While energy intensity in China has fallen almost continuously since the onset of economic reform in the late 1970s, beginning in 1996 the data show a striking decline in China's absolute level of energy use. Most of this decline can be accounted for by falling coal consumption in the industrial sector. In order to investigate this energy puzzle, this paper employs a unique set of panel data for approximately 2,500 of China's most energy intensive large and medium-sized industrial enterprises during 1997-99. Rising relative energy prices, research and development expenditures, and ownership reform in the enterprise sector, as well as shifts in China's industrial structure, emerge as the principal drivers of China's declining energy intensity and use.

JEL codes: Q4, P2

Keywords:

* We would like to thank Su Jian for excellent research assistance. We also thank Messers Xu Jianyi, Ma Jingkui, and Liu Fujiang for making the Dartmouth-Brandeis-NBS collaboration possible, and Jim Feyrer, Mun Ho, Adam Jaffe and participants at the Rockefeller Center's faculty seminar (February 2002) for helpful comments. This research was supported by the Rockefeller Center at Dartmouth College, the U.S. Department of Energy's Biological and Environmental Research Program (contract # DE-FG02-00ER63030), and the National Science Foundation (project/grant #450823). Finally, we appreciate the helpful comments of outside reviewers of earlier versions of this paper

**Corresponding author: Dartmouth College, 6182 Steele Hall, Hanover, NH 03755. Phone: 603-646-0213, fax: 603-646-1682, email: kfv@dartmouth.edu

1. Introduction

Contrasted with the three decades prior to 1978, the year in which China initiated its economic reforms, a significant proportion of China's robust industrial economic growth during the 25-year period 1978 to 2003 resulted from the growth of total factor productivity.¹ Notwithstanding rising energy efficiency that contributed to China's improved productivity performance during the 1980s, China's overall energy efficiency in 1990 continued to lag behind that of other countries with similar levels of per capita income. By 2000, the approximately 70 percent decline during the 1980s and 1990s in energy intensity, defined as the ratio of real energy consumption to real GDP, enabled China to close substantially the gap between its actual level of energy use and that predicted by cross-national data.² Notwithstanding these declines in energy intensity, at the turn of the century, China's energy intensity in 2000 was still three times larger than that in the U.S.

Although China's energy intensity has fallen since 1978, primary energy consumption and production have generally risen. Yet, beginning in 1996, the trend of rising consumption and production seems to have reversed itself. Between 1996 and 2000, total primary energy consumption fell by eight percent, driven mainly by a 17.4 percent decline in coal consumption. This downward trend in energy consumption parallels a similar trend in primary energy production. During 1996-2000, primary energy production fell by 17.8 percent, again driven by a 26.6 percent decline in coal production. Based on prior consumption and production trends from 1978 to 1996 and increasing household demand for automobiles and modern appliances, the fall in energy production and use is contrary to what most have forecast, causing some to question the accuracy of the reported energy statistics and/or Chinese GDP figures.

Explanations for China's decline in energy intensity – and perhaps as well the recent decline in overall consumption – fall into three categories. The first is gains in energy efficiency. At the firm level, energy productivity could be improving, thereby lowering the amount of energy required to produce a unit of output. The second possible explanation centers on structural change involving a decline in the relative weight of China's energy intensive sectors. Finally, China's statistical system may be systematically underreporting the growth of energy

¹ Kuan et al (1988), Table 5; Jefferson, Rawski, Wang, and Zheng (2000), Table 7.

² Author's calculations based on data obtained from World Development Indicators Online (World Bank, 2002).

consumption, and/or overestimating the growth of output. Although previous work has attempted to measure the relative contribution of each of these factors, we have the advantage of a firm-level data set that includes industry detail at the 3 and 4-digit levels, as well as firm-level data. Our data set includes approximately 2,500 large and medium-sized Chinese industrial enterprises for the years 1997-1999. We use these data to estimate a range of contributions, including changing relative prices, R&D expenditure, ownership and industry change, and regional effects, to changes in energy productivity at the firm level. This level of statistical and analytical detail has not been previously feasible.

Studies by Sinton and Levine (1994), Lin and Polenske (1995), and Garbaccio, Ho and Jorgenson (1999) have attempted to measure the relative contributions of sectoral shift and sub-sector productivity change. Each finds sub-sector productivity change to be the principal explanation of China's declining energy-output ratio.³ A shortcoming of these studies is their reliance on aggregations of data, usually at the 2-digit industry level. As acknowledged in these studies and confirmed by our analysis, the use of aggregations may cause the contribution of sub-sector energy productivity improvements to be overstated while assigning insufficient weight to the role of sectoral shift. An advantage of these studies may be their relatively comprehensive coverage. While our study is limited to large and medium-size industrial enterprises, the detail in our data set allows us to examine differences among forms of ownership and among industries, such as electric power generation, chemicals, and metal processing. Our reliance on data that are collected directly by the National Bureau of Statistics from the participating firms may also ensure greater statistical accuracy relative to aggregations that include the service and rural collective sectors.

A second advantage of our use of firm-level data is our ability to identify factors that drive sub-sector energy productivity improvements. Such factors include changes in energy prices, differences in energy efficiency across ownership types, and differences in R&D intensity that may have important policy implications. Lastly, while chronologically the studies cited above precede the late 1990s, our data set affords us the opportunity to study the apparent puzzle of robust economic growth and declining total energy consumption that emerges in the data in the latter half of the 1990s.

³ Sinton and Levine (1994) compare different years between 1980 and 1990, Lin and Polenske (1995) compare 1981 and 1987, and Garbaccio, Ho, and Jorgenson (1999) compare 1987 and 1995.

Not unexpectedly, we find that the importance of sectoral shift increases as we move from the one-digit SIC level of aggregation to the level of the firm. In explaining improvements in total energy consumption, we find that in addition to shifts in output across industries, changes in output associated with ownership types and regions also contribute to rising energy efficiency. Large contributions, however, also arise at the firm level due to research and development activity and rising energy prices. This latter result suggests that Chinese firms are reacting to changing energy prices, a strong indication of growing price responsiveness within China's enterprise sector.

The paper is organized as follows. Section 2 describes the data set used in the paper; this section situates our sample of firms within the context of China's overall industry. Section 3 compares trends in consumption and efficiency by energy type between our sample, total industry, and the Chinese economy as a whole; we identify possible explanations for these trends. In Section 4, by applying the Divisia decomposition method to our sample, we measure the relative contributions of sectoral shifts and productivity change. Section 5 employs regression analysis to investigate the sources of rising energy efficiency at the firm level. Lastly, we present the conclusions of our research in Section 6.

2. Data Description

Our data combine three firm-level data sets collected by China's National Bureau of Statistics (NBS). Two of the data sets – the first consisting of large numbers of economic and financial variables and the second including science and technology variables – span the full population of China's more than 20,000 large and medium-size industrial enterprises (LMEs).⁴ The third data set, which focuses on China's most energy-intensive firms, includes approximately 4,000 of the LME population. After combining and balancing (i.e., ensuring that only firms reporting in all years are included) these three data sets over the period 1997-1999, our operational sample includes 2,582 large and medium-size enterprises.⁵ Table 1 compares

⁴ In 1999, the formally measured industrial sector (i.e. enterprises reporting more than 5 million yuan in annual sales) comprised 7,864 (4.9%) large, 14,371 (8.9%) medium, and 139,798 (86.3%) small enterprises. In terms of gross industrial output value, the large, medium and small enterprises accounted for 43.4%, 13.6%, and 43%, respectively (NBS, 2001a).

⁵ The first of the two comprehensive data sets includes economic and financial data, collected by the Bureau's Department of Industrial and Transportation Statistics (NBS, 2001b); the second data set, which consists of science and technology measures, including innovation inputs and outputs, is maintained by the Bureau's Department of Population, Social, and Science and Technology Statistics (NBS, 2001c). These two data sets include the entire

levels of sales, employment, and fixed assets in our sample with the full population of large and medium-size enterprises and with total industry.

Table 1
Shares of LMEs and energy sample in aggregate industry
(% of total industry)

Measure	1999		
	All industry ¹	Of which: L&M Enterprises ²	Of which: energy sample ³
Sales (100 million yuan)	69,851 (100%)	41,166 (59%)	13,159 (19%)
Employment (10,000 persons)	4,428 (100%)	3,061 (69%)	1,031 (23%)
Assets ⁴ (100 million yuan)	71,847 (100%)	53,070 (74%)	21,810 (30%)
No. of enterprises	162,033 (100%)	22,000 (14%)	2,582 (1.6%)

¹ Industrial state owned and non-state owned enterprises with annual sales over 5 million Yuan. Source: China Statistical Yearbook, 2000 [NBS, 2000].

² Source: NBS (2001b).

³ Represents the largest number of enterprises reporting in each of three years. Source: NBS (2001b).

⁴ Original value fixed assets

The energy dataset includes 21 energy types and a measure of aggregate energy consumption. For our regression analysis, we combine the 21 energy types into three energy categories: coal and coal products, refined oil, and electricity. Crude oil is not included in this classification, since it is almost entirely used as an input to the production of refined oil. Coal gases and natural gas are not included due to their small relative share of total energy and the presence of relatively few observations in the data set. Because our focus is on combustible energy, other petroleum products, steam heat, and other energy types were not included.

The NBS data set classifies enterprises into 37 industrial classifications. For the purposes of our regression analysis, we group these 37 industrial classifications into 12 industry categories—mining; food and beverage; textile and leather products; timber, furniture and paper products; petroleum processing; chemicals; rubber and plastic products; non-metal products; metal products; machinery, equipment and instruments; electric power; and other industry. Relative to the distribution of total industry and LMEs, the energy sample includes a higher incidence of enterprises in the more energy-intensive industries. These over-represented

population of China's approximately 22,000 large and medium-size enterprises, far more than the number of enterprises that have been covered by the energy survey in recent years. The number of enterprises covered in the energy survey range from 3,746 enterprises in 1998 to 4,687 enterprises in 1999. A part of this variation reflects changes in energy consumption over the business cycle, when some enterprises fall below the critical levels of energy consumption required for inclusion in the annual energy survey.

industries, for example, include the chemical and electric power industries. The NBS data set also classifies enterprises into the seven ownership classifications—state-owned; collective-owned; Hong-Kong, Macao, and Taiwan; foreign; shareholding; private; and other. The data set comprises a comparatively high representation of state-owned enterprises, which reflects the tendency of China’s state-owned enterprises (SOEs) to be concentrated in the more energy-intensive raw materials and heavy industrial sectors. Lastly, the NBS dataset includes the six regional groupings—north; northeast; east; south; southwest; and northwest. The firms in our sample are largely concentrated in the north (e.g., Beijing), east (e.g., Shanghai), and south (e.g., Guangzhou).

3. Energy Consumption and Intensity, 1997-1999

Because our sample represents just 19 percent of total industry sales and 30 percent of total industrial assets, we examine whether the intensity and consumption trends in our sample mirror the intensity and consumption trends for the nation. We compare energy consumption and intensity for total primary energy, coal, and electricity in our sample with national statistics for the total economy and overall industry.⁶ The trends with our sample approximate those of the total economy and total industrial sector – for all three sets of statistics, the ratios of total energy, coal, and electricity to output decrease, implying a fall in the intensity of each energy type. The data also generally show absolute declines in the consumption of total energy and coal after 1997, while electricity consumption rises.⁷ Intensities for the sample are higher than for overall industry, reflecting a higher consumption of energy consumed per unit output in our sample. This fact is consistent with the sample selection criteria, i.e. the concentration on energy-intensive firms.⁸

⁶ Because comparable data are unavailable for refined oil, a comparison of our sample with national and overall industrial trends is not possible.

⁷ Intensities for each energy type are defined as the quantity of energy consumed of the specific energy type divided by constant GDP (in the case of “total economy”) or constant GVIO (in the case of “total industry” or “sample”).

⁸ Intensities for overall industry are lower than for the total economy because gross value industrial output (GVIO) is used rather than GDP. Although we also use GVIO to calculate intensities for our sample, our intensity numbers are still higher than those for the total economy, since the sample contains a higher concentration of energy intensive firms. No value added deflator exists in our sample, thus we are restricted to using GVIO (since we have access to GVIO in constant Yuan) for this comparison. Although to assess how representative our sample is, we are most interested in comparing intensities with overall industry (which also uses GVIO), it is still useful to compare trends in intensity with the total economy although we are unable to compare levels of intensity values.

Explanations for the declines in aggregate energy consumption and intensity fall into three general categories: (1) sectoral shift, (2) subsector energy productivity change, and (3) inaccurate statistics. We examine each of these candidate explanations below.

(1) Sectoral shift. The sectoral shift approach measures the impact on overall energy intensity of changes in industrial composition. For example, China's gradual move away from heavy industry, which is generally energy intensive, has contributed to China's declining energy intensity. Over the past 20 years, market reforms have affected China's industry mix through multiple channels. In particular, the opening to international trade and the phasing out of state-set prices and state-directed investment have altered the relative profitability of certain industries – in particular, heavy industry, which had been the principal beneficiary of trade protection and government subsidies. Rising incomes and changing relative prices have also spurred changes in patterns of consumer demand, notably increases in a wide range of consumer and electronic goods.

Most previous studies have found sectoral shift to be a relatively small contributor to the decline in China's energy intensity (e.g., Sinton and Levine, 1994; Lin and Polenske, 1995; and Garbaccio, Ho and Jorgenson, 1999). A World Bank study (1997), however, identifies sectoral shift as the largest contributor. As suggested by Garbaccio, Ho and Jorgenson (1999) and discussed later in this paper, the different results may result from the use of different levels of industry aggregation.

(2) Subsector productivity change. We measure subsector energy productivity change as change in the ratio of energy use to real output *within* an industrial classification. For instance, Hicks-neutral technical advance within an industry would result in lower energy intensity.

A number of factors can affect firm-level energy efficiency. The elimination of state-set prices, for example, has led to rising relative energy prices, which may be inducing energy saving innovations. In addition, enterprise reform has increased the incentives of managers to utilize innovation resources to implement cost-saving innovations (Jefferson, Bai, Guan, and Yu, forthcoming). Sinton and Levine (1994) also attribute improvements in subsector energy productivity to conservation policies imposed by the Chinese government. Government policies are targeting inefficient production, including closing down small generators in the power sector

so as to improve efficiency in electricity generation and the closing of small, inefficient mining operations (Sinton and Fridley, 2000).

(3) Inaccurate statistics. As discussed in the introduction, a striking decline in China's aggregate energy intensity has occurred since the introduction of market reforms in 1978. Additionally, aggregate energy consumption has fallen since 1996. Numerous observers argue that these results are based on reported data that are inaccurate. Some question whether the energy data may be underreported. On the consumption side, when household use of air conditioners and modern appliances has risen so rapidly, declining household energy consumption seems implausible. Indeed the data show that the industrial sector, which reported a decline in consumption of nearly 10,000 metric tons of standard coal during 1997-1999, more than accounted for the decline in China's total energy consumption. The phenomenon of declining consumption therefore appears to reflect a decline that is largely centered on the industrial sector. On the production side, Sinton and Fridley (2000) believe that energy statistics may be understated as a result of the omission of coal produced by small coal mines that have been officially shutdown and imported fuels, such as diesel, that have officially been banned. As explained in Sinton (2001), notwithstanding the order from the central government in 1999 to shutdown small coalmines, these mines have continued their operation. In addition, to protect domestic fuel producers that were being undercut by cheaper imported fuel, the Chinese central government ordered a ban on imported fuel (mainly diesel) in 1998. This ban has led to illegal smuggling of diesel fuel that does not show up in the import statistics. In both cases, this undercounting affects the reported production of fuels and not consumption.

Others argue that China's statistical authorities have over-reported output. Sinton and Fridley (2000) and Rawski (2001) have both suggested that measures of lower energy intensity might result from inflated GDP rather than real gains in energy efficiency. While many observers take two percent as an appropriate downward adjustment figure (e.g. see Sinton and Fridley, 2000), Rawski (2001) believes that in 1998, the downward adjustment should be closer to eight percent. As discussed in Sinton and Levine (1994) and Garbaccio, Ho and Jorgenson (1999), falsification of output figures is more prominent among non-state and rural firms.

Garbaccio, Ho and Jorgenson (1999) and Sinton and Levine (1994) raise the issue of deverticalization as another potential reporting problem that could overstate the decline in energy intensity. Deverticalization occurs when firms outsource certain parts of their production

process that were previously performed in-house. Deverticalization raises an industry's value of gross output (due to double counting), without increasing the level of energy consumed. The consequence of deverticalization is that energy intensity measured in terms of energy use per unit of GNP or value added should be unaffected, but when the denominator of the energy intensity measure is measured in terms of the gross output of firms or sectors, deverticalization will lead to the appearance of declining energy intensity.

Our sample avoids many of the reporting problems raised regarding the aggregate data. Output numbers are also more reliable in these survey data because they come from large established firms, which tend to provide more reliable numbers than smaller firms. Since we are concentrating on energy consumption figures in these survey data, the problems with production estimates are less relevant. These firms tend to buy from large established coalmines, and therefore largely avoid the problem of underreported purchases from small illegal mines.

4. Sectoral shift vs. subsector productivity change

As discussed in the previous section, energy use in our sample follows a similar decline to that seen in both the Chinese economy as a whole and in total industry. We use our sample to decompose the contributions of sectoral shift (i.e., changes in the sectoral composition of total industrial output) and subsector productivity change (i.e., changes in energy intensity within individual industrial sectors). We then compare our results with previous decomposition studies of China that have been conducted for years prior to 1995 (e.g. Sinton and Levine, 1994; Lin and Polenske, 1995; and Garbaccio, Ho, and Jorgenson, 1999).

Relative to these studies, our decomposition has two advantages. First, we are able to examine the years after 1996 when China experienced a dramatic fall in energy intensity and consumption. In addition, we can compare our results across multiple levels of decomposition – the one-, two-, three-, and four-digit SIC levels. We also include a 12-industry aggregation intermediate between the one- and two-digit aggregations. Although previous studies typically use industry classifications at the 2-digit aggregation level, Sinton and Levine (1994) present results from a highly disaggregated industry classification (i.e., 267 subsectors), but they are unable to adequately compare the results with their other datasets due to differences in coverage and the energy variable used (i.e., end-use energy versus gross energy consumption).

We apply to our sample the following multiplicative form of the Divisia decomposition method:⁹

$$\ln(E_t) = \ln(E_0) + \ln\left(\frac{Q_t}{Q_0}\right) + \frac{1}{2} \sum_{i=1}^N \left(\frac{E_{0,i}}{E_0} + \frac{E_{t,i}}{E_t}\right) \ln\left(\frac{I_{t,i}}{I_{0,i}}\right) + \frac{1}{2} \sum_{i=1}^N \left(\frac{E_{0,i}}{E_0} + \frac{E_{t,i}}{E_t}\right) \ln\left(\frac{s_{t,i}}{s_{0,i}}\right) + R \quad (1)$$

where

E_t \equiv total energy at time t;

Q_t \equiv total output at time t (constant GVIO);

$E_{t,i}$ \equiv total energy in sector i at time t;

I_t \equiv total energy intensity (E/Q) at time t;

$I_{t,i}$ \equiv total energy intensity of sector i at time t;

$s_{t,i}$ \equiv sector i's share of total output at time t; and

R \equiv residual.

The first two terms, which can be combined as $\ln\left(\frac{E_0}{Q_0} Q_t\right)$, represent energy use at time t, conditional on output at time t being produced at the same energy intensity as in period 0. The third term captures changes in total sample energy intensity between periods 0 and t due to changes in industrial subsector energy productivity. The fourth term represents changes in total sample energy intensity due to changes in the sectoral composition of total industrial output (i.e., sectoral shift). Since this decomposition method is an approximation, the last term captures the residual change.

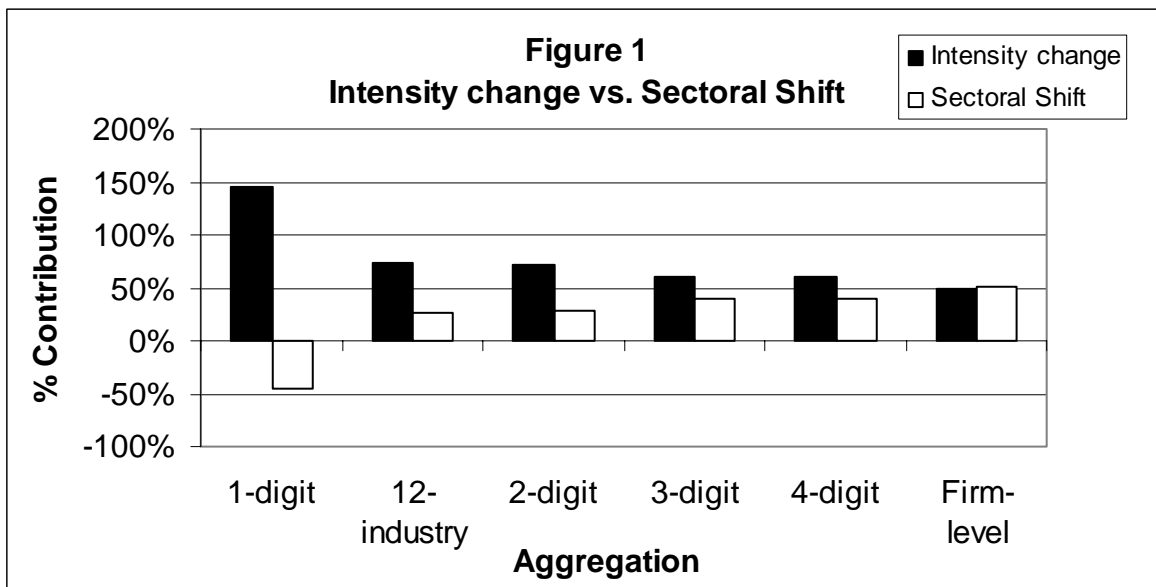
We apply the Divisia method to aggregate energy use in our sample for the period 1997-1999. In Table 2, we report six sets of results using different levels of industry aggregation. In addition to five levels of industry aggregation, we calculate the impact on total energy intensity resulting for shifts in firm-level shares of output. Figure 1 shows a pattern in which the explanatory power of sectoral shift rises as our decomposition moves from the 1-digit SIC to the firm level of aggregation. The largest increase in explanatory power comes from moving from the 1-digit to the 12-industry level of aggregation, although we also find a significant increase in our estimate of the contribution of sectoral shift when we move from the 4-digit to the firm level

⁹ A derivation of this equation can be found in Ang and Zhang (2000).

of analysis. At the firm level, we find that shifts in firm output shares account for more than half of measured reductions in energy intensity.

Table 2
Divisia Decomposition Results, 1997-1999
Total Energy

Terms in equation (1)	(a) 1-digit	(b) 12- industry	(c) 2-digit	(d) 3-digit	(e) 4-digit	(f) Firm-level
First term	10.9333	10.9333	10.9333	10.9333	10.9333	10.9333
Second term	0.0912	0.0912	0.0912	0.0912	0.0912	.0912
Third term (subsector energy productivity)	-0.1205	-0.0607	-0.0585	-0.0498	-0.0512	-0.0379
Fourth term (sectoral shift)	0.0376	-0.0222	-0.0244	-0.0340	-0.0335	-0.0426
Sum	10.9416	10.9416	10.9416	10.9407	10.9398	10.9439
Compare	10.9416	10.9416	10.9416	10.9416	10.9416	10.9416
Residual	0.0000	0.0000	0.0000	0.0008	0.0018	-.0023



Using the firm-level classification, Table 3 provides decomposition results for three types of energy – coal, refined oil, and electricity. While subsector productivity change emerges as the dominant factor driving the decline in the intensity of electricity, sectoral shift plays a near equal, albeit smaller, role in declining coal and refined oil intensities.

Table 3
Divisia Decomposition Results, 1997-1999
by Energy Type (Firm-level)

Terms in equation (1)	Coal	Refined Oil	Electricity
First term	10.7137	7.2182	7.5722
Second term	0.0912	0.0912	0.0912
Third term	-0.0998	-0.1343	-0.0702
Fourth term	-0.0785	-0.0998	-0.0103
Sum	10.6262	7.0753	7.5681
Compare	10.6367	7.0659	7.5559
Residual	0.0105	-0.0094	-0.0270
% Contribution			
Subsector productivity change	56%	57%	87%
Sectoral shift	44%	43%	13%

5. Factors affecting firm-level energy productivity

Although the magnitude of the contribution of intensity change depends on the sectoral aggregation used and type of energy examined, results from the Divisia exercise show that during the critical period 1997-1999, at the firm level, within firm productivity change accounted for nearly half of the decline in energy intensity. Given this result, we are interested in identifying the factors driving the decline in subsector energy intensity. Among the factors that may be contributing to rising firm-level energy efficiency are the following:

(1) Price reform. With the initiation of China’s “two-tiered pricing system” in 1984, prices set by the central plan have been gradually replaced with market-mediated prices. By 1990, the purchase and sale of most industrial goods included supplies that were priced by the market, causing firms to face market prices for factor inputs at the margin (Byrd, 1989, 1991). In 1990, approximately 46 percent of coal was plan allocated, leading to a ratio of market-plan price of 2.70; for crude oil, the respective figures were 80 percent and 5.92 (Garbaccio, 1995). By 1999, plan allocations had been virtually eliminated. As we will see, by 1999, there were no significant differences in prices faced by state-owned enterprises and foreign-invested firms. These rising prices for energy inputs, we anticipate, have induced firms to seek ways to improve energy efficiency.

(2) Ownership reform. China's enterprise reform has included a gradual clarification and decentralization of property rights. Property rights reform within China's enterprise sector has included both the strengthening of managerial control rights within firms that have maintained their SOE designation and a rapid expansion of various ownership classifications outside the state sector, both through new entry and through the conversion of SOEs. During the latter half of the 1990s, many of China's larger SOEs have been converted to shareholding companies (e.g. Li, 1997); Jefferson, Su, Jiang, and Yu, 2003).

(3) Deliberate innovation. Many firms maintain formal research and development operations whose scale can be measured by R&D expenditures or by R&D personnel. Whether these innovation activities lead to product or process innovation, they may have measurable effects on energy intensity. Jefferson, Bai, Guan, and Yu (forthcoming) find that R&D inputs – both personnel and expenditures – generate returns that substantially exceed the returns to production workers and investment in physical capital. With rising relative energy prices, we should expect that R&D would at least have a neutral, if not energy-saving, effect in promoting gains in energy efficiency.

(4) Changing industry composition. We anticipate that different industries use technologies that exhibit different levels of energy intensity. By their nature, electric power generation and petroleum processing and coking are likely to be significantly more energy intensive than the food processing or apparel industries. For the same reason that we used the Divisa approach to identify the contribution of changing industry composition to energy intensity, we wish to control for sectoral differences in energy intensity in our regression analysis.

(5) Changing regional composition. Across regions there may exist significant regional variation in energy pricing associated with differences in distribution and transportation costs. Also, provincial policies relating to pricing or regulation may vary across regions and result in differences in levels of energy intensity across regions. Change in the regional distribution of output may therefore lead to changes in overall energy intensity.

In order to investigate the sources of subsector productivity gains in energy consumption, we construct a balanced sample (that is, a sample that includes firms reporting in all three years) of 2,582 enterprises. Over three years the total sample size consists of 7,746 observations. Because our regression includes variables for prices, R&D expenditure, ownership, and location,

as well as industry classification, the number of observations for which data are available for all of the relevant variables shrinks to a total of 2,622 observations over the 3-year period. Due to this shrinkage, we test how closely our regression sub-sample tracks the changes in energy intensity for the full sample. We do this by regressing the log of the energy/GVIO ratio on the 1998 and 1999 time dummies. For each of the three energy categories, intensities decline by significant amounts in both 1997-98 and 1998-99. The pattern of declining intensity in the full sample is therefore apparent also in our regression subsample.

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

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

where

Q ≡ quantity of output;
P_K ≡ price of capital input;
P_L ≡ price of labor input;
P_E ≡ price of energy input;
P_M ≡ price of materials input; and
α_X ≡ elasticity of input X (X=K,L,E,M).
A ≡ productivity term defined as

$$A = \exp \left(\theta \ln(RDE) + \sum_{t=97}^{99} \delta_t T_t + \sum_{i=1}^{12} \gamma_i IND_i + \sum_{j=1}^7 \lambda_j OWN_j + \sum_{k=1}^6 \phi_k REG_k \right) \quad (2)$$

where

RDE ≡ R&D expenditure (a proxy for the stock of R&D capital);
T₉₇, T₉₈, T₉₉ ≡ time dummies;
IND_i ≡ industry dummies;
OWN_j ≡ ownership dummies; and
REG_k ≡ region dummies.

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:

$$E = \alpha_E A^{-1} P_K^{\alpha_K} P_L^{\alpha_L} P_E^{\alpha_E} P_M^{\alpha_M} Q / P_E. \quad (3)$$

Assuming,

$$P_Q = P_K^{\alpha_K} P_L^{\alpha_L} P_E^{\alpha_E} P_M^{\alpha_M} \quad (4)$$

where $\sum \alpha_i = 1$, we simplify equation (3) as:¹⁰

$$E = \alpha_E A^{-1} P_Q Q / P_E \text{ or } E / Q = \alpha_E A^{-1} P_Q / P_E \quad (5)$$

Substituting for A defined above and taking the log of both sides, we obtain the following estimation equation:

$$\ln\left(\frac{E}{Q}\right) = \alpha + \theta' \ln(RDE) + \sum_{t=97}^{99} \delta'_t T_t + \sum_{i=1}^{12} \gamma'_i IND_i + \sum_{j=1}^7 \lambda'_j OWN_j + \sum_{k=1}^6 \varphi'_k REG_k + \beta \ln\left(\frac{P_E}{P_Q}\right) + \varepsilon_i \quad (6)$$

Symmetrically, by decomposing total energy into our three energy components, the cost function in equation (1) is amended to include the three energy prices. Again, applying Shephard's lemma, say to the case of coal, we obtain the following:

$$E_{coal} / Q = \alpha_{coal} A^{-1} P_Q / P_{coal},$$

which can also be written as

$$E_{coal} / Q = \alpha_{coal} A^{-1} \left[\hat{P}_Q^{1-\alpha_{coal}-\alpha_{roil}-\alpha_{ele}} P_{coal}^{\alpha_{coal}} P_{roil}^{\alpha_{roil}} P_{ele}^{\alpha_{ele}} \right] / P_{coal} \quad (7)$$

where

$$\ln(\hat{P}_Q) = (\ln(P_Q) - \alpha_{coal} \ln(P_{coal}) - \alpha_{roil} \ln(P_{roil}) - \alpha_{ele} \ln(P_{ele})) / (1 - \alpha_{coal} - \alpha_{roil} - \alpha_{ele}) \quad (8)$$

Substituting (2) into (7), and converting to logs gives the following:

$$\begin{aligned} \ln\left(\frac{E_{coal}}{Q}\right) &= \alpha + \theta' \ln(RDE) + \sum_{t=97}^{99} \delta'_t T_t + \sum_{i=1}^{12} \gamma'_i IND_i + \sum_{j=1}^7 \lambda'_j OWN_j + \sum_{k=1}^6 \varphi'_k REG_k \\ &+ (\alpha_{coal} - 1) \ln(P_{coal} / \hat{P}_Q) + \alpha_{roil} \ln(P_{roil} / \hat{P}_Q) + \alpha_{ele} \ln(P_{ele} / \hat{P}_Q) + \varepsilon_{coal} \end{aligned} \quad (9)$$

¹⁰ In this formulation, we assume that prices are exogenous, i.e. factor prices are set in the relevant factor markets. As shown in equation (4), product prices are set by the exogenous factor prices and by industry technology summarized by the vector of factor output elasticities, i.e., the α_i s. Consistent with the process summarized in equation (2), a subset of firms enjoys productivity levels for which $A > 1$. With $A \geq 1$, the short-run industry supply curve is upward sloping. Given exogenous prices, this subset of firms with $A > 1$ exhibits positive profits, while the firms for which $A = 1$ exhibit zero profits.

Because the price elasticities in the cost equation represent long-run equilibrium conditions, which are unlikely to hold in panel data, we generalize Equation (9) as follows

$$\ln\left(\frac{E_{coal}}{Q}\right) = \alpha + \theta' \ln(RDE) + \sum_{t=97}^{99} \delta'_t T_t + \sum_{i=1}^{12} \gamma'_i IND_i + \sum_{j=1}^7 \lambda'_j OWN_j + \sum_{k=1}^6 \varphi'_k REG_k \quad (10a)$$

$$+ (\beta_{coal} - 1) \ln(P_{coal} / \hat{P}_Q) + \beta_{roil} \ln(P_{roil} / \hat{P}_Q) + \beta_{ele} \ln(P_{ele} / \hat{P}_Q) + \varepsilon_{coal}$$

Likewise, the regression equations for oil and electricity are:

$$\ln\left(\frac{E_{roil}}{Q}\right) = \alpha + \theta' \ln(RDE) + \sum_{t=97}^{99} \delta'_t T_t + \sum_{i=1}^{12} \gamma'_i IND_i + \sum_{j=1}^7 \lambda'_j OWN_j + \sum_{k=1}^6 \varphi'_k REG_k \quad (10b)$$

$$+ \beta_{coal} \ln(P_{coal} / \hat{P}_Q) + (\beta_{roil} - 1) \ln(P_{roil} / \hat{P}_Q) + \beta_{ele} \ln(P_{ele} / \hat{P}_Q) + \varepsilon_{roil}$$

$$\ln\left(\frac{E_{ele}}{Q}\right) = \alpha + \theta' \ln(RDE) + \sum_{t=97}^{99} \delta'_t T_t + \sum_{i=1}^{12} \gamma'_i IND_i + \sum_{j=1}^7 \lambda'_j OWN_j + \sum_{k=1}^6 \varphi'_k REG_k \quad (10c)$$

$$+ \beta_{coal} \ln(P_{coal} / \hat{P}_Q) + \beta_{roil} \ln(P_{roil} / \hat{P}_Q) + (\beta_{ele} - 1) \ln(P_{ele} / \hat{P}_Q) + \varepsilon_{ele}$$

We estimate the above three equations (10a-10c) with equation (6) as a system of four seemingly unrelated regressions (SUR). In each set of estimates, the reference intercept includes state-owned enterprises, the machinery industry, the Xibei (northwest) region, and the year 1997. The results from the SUR and aggregate energy estimations are shown in columns (a)-(d) of Table 4. In all four cases, the price elasticities are significant, and the sign of the coefficients are consistent with our prior expectations – own-price elasticities are negative implying that an increase in the relative price of the energy type leads to increased efficiency, and cross-prices are positive implying that the three energy types are substitutes – except for electricity in the coal equation, which enters as a complement. Expenditure on R&D is significant for coal, electricity, and aggregate energy. The negative sign on the coefficient implies that an increase in R&D activity decreases energy intensity (i.e., increases energy efficiency). The relative magnitudes of the R&D elasticities suggest a distinct coal-saving bias for China's industrial research and development expenditure.

Table 4
Determinants of intensity by energy type¹

Dependent variable = ln(Quantity of energy/constant GVIO)	Aggregate Energy (a)	Coal (b)	Refined Oil (c)	Electricity (d)
Constant²	-2.275*** (0.107)	-2.829*** (0.208)	-4.638*** (0.209)	-3.732*** (0.124)
ln(price of coal/ composite price of non- energy inputs)³	-	-0.397*** (0.041)	0.598*** (0.050)	0.076*** (0.024)
ln(price of refined oil/ composite price of non- energy inputs)³	-	0.463*** (0.042)	-0.909*** (0.050)	0.165*** (0.025)
ln(price of electricity/ composite price of non- energy inputs)³	-	-0.082** (0.034)	0.306*** (0.041)	-0.234*** (0.020)
ln(price of aggregate energy/price of output)⁴	-0.368*** (0.014)	-	-	-
ln(R&D expenditures)	-0.063*** (0.010)	-0.120*** (0.017)	0.013 (0.016)	-0.056*** (0.010)
Collectives	-0.502*** (0.108)	-0.627*** (0.185)	-0.125 (0.174)	-0.424*** (0.111)
Foreign	-0.353*** (0.117)	-0.485** (0.201)	-0.406** (0.188)	-0.317*** (0.120)
Hong Kong, Macao, Taiwan	-0.451*** (0.143)	-0.634*** (0.246)	-0.131 (0.230)	-0.250* (0.147)
Shareholding	-0.021 (0.053)	0.059 (0.091)	-0.037 (0.085)	-0.082 (0.054)
Private	0.541 (0.543)	0.577 (0.934)	0.206 (0.875)	0.997* (0.560)
Other	0.078 (0.236)	0.029 (0.406)	0.925** (0.380)	-0.097 (0.243)
Mining (06-10, 12)	1.525*** (0.075)	1.270*** (0.130)	1.539*** (0.122)	1.295*** (0.078)
Food and beverage (13-16)	-0.172** (0.084)	0.327** (0.144)	-1.037*** (0.135)	-0.496*** (0.086)
Textile, apparel, and leather products (17-19)	0.068 (0.083)	-0.434*** (0.143)	-1.553*** (0.133)	0.369*** (0.085)
Timber, furniture, and paper (20-24)	1.146*** (0.102)	1.573*** (0.174)	-0.502*** (0.163)	1.022*** (0.104)
Petroleum processing and coking (25)	3.372*** (0.173)	2.584*** (0.296)	1.830*** (0.277)	0.565*** (0.177)
Chemicals (26-28)	1.453*** (0.061)	1.626*** (0.105)	-0.317*** (0.098)	1.275*** (0.063)
Rubber and plastic products (29-30)	0.264** (0.107)	0.591*** (0.184)	-0.454*** (0.173)	0.017 (0.110)

Non-metal mineral products (31)	1.896*** (0.071)	2.158*** (0.120)	1.075*** (0.113)	1.313*** (0.072)
Metal processing and products (32-34)	1.398*** (0.071)	1.319*** (0.122)	0.836*** (0.115)	1.470*** (0.073)
Electric power (44)	2.968*** (0.143)	3.546*** (0.243)	1.345*** (0.227)	2.191*** (0.145)
Other (43,45,46)	2.046*** (0.138)	0.968*** (0.238)	0.818*** (0.223)	2.212*** (0.143)
Huabei—North	-0.044 (0.072)	-0.013 (0.123)	-0.353*** (0.115)	-0.211*** (0.074)
Dongbei—Northeast	-0.112 (0.075)	-0.021 (0.130)	0.057 (0.122)	-0.385*** (0.078)
Huadong—East	-0.168** (0.070)	-0.071 (0.123)	-0.829*** (0.117)	-0.130* (0.074)
Huanan—South	-0.150** (0.071)	-0.363*** (0.122)	-0.681*** (0.115)	-0.034 (0.073)
Xinan—Southwest	0.086 (0.092)	-0.241 (0.158)	-0.435*** (0.148)	0.004 (0.094)
1998	-0.042 (0.045)	-0.029 (0.077)	-0.199*** (0.072)	0.042 (0.046)
1999	-0.021 (0.046)	-0.086 (0.079)	-0.308*** (0.074)	-0.019 (0.047)
R sq. (obs.)	0.561 (2622)	0.290 (2622)	0.355 (2622)	0.398 (2622)

¹ The figures in parentheses are standard errors.

² The constant term include state-owned enterprises, the machinery, equipment and instrument industries (35-37, 39-42), the Xibei (Northwest) region, and the year 1997.

³ Defined in equation (8) above and as shown in equations 10a-10c.

⁴ As shown in equation (6).

* Significant at the 10% level, ** Significant at the 5% level, *** Significant at the 1% level.

Firm ownership matters only in certain cases. In particular, foreign-invested firms are consistently more energy efficient than their state-owned counterparts, as reflected in the set of four negative coefficients. Collectives and Hong-Kong-Macao-Taiwan (HKMT) firms all generally exhibit greater energy efficiency than the SOE firms. Industry-specific factors are also significant in explaining efficiency levels. Relative to the machinery sector, mining, non-metal mineral products, metal processing and products, electric power, and other industry all report relatively high levels of energy intensity across all four energy categories. Even after controlling for differences in prices, ownership, and industry mix, we find significant regional differences in the case of refined oil. Huadong (East) and Huanan (South) report lower levels of refined oil intensity and aggregate energy intensity than the rest of the country, while the South also reports lower coal intensity. Lastly, year-specific factors seem to matter principally for refined oil. This

result indicates that while the price and institutional factors are largely able to explain declining energy intensity for the coal, electricity, and aggregate energy sectors, these variables are less able to explain the decline in the intensity of use of refined oil during our sample period. We address this anomaly in our findings later.

In Table 5, we decompose the relative contribution of each of the factors shown in Table 4 to changes in the dependent variable (i.e., the log of energy intensity) from 1997 to 1999. Relative contributions are calculated by multiplying the change in the within sample mean for each of the independent variables by the relevant coefficient.¹¹

The results shown at the bottom of Table 5 suggest that our estimates of the overall declines for aggregate energy and electricity approximate the actual declines in intensity; the estimates for coal and refined oil, particularly the latter, underestimate the actual declines in intensity. For these two cases, we speculate on reasons for the disparities between our estimates and the actual outcomes

We first look at refined oil, the most inaccurate of our predictions. Relative to the other two energy types, the proportional decline in the intensity of use of refined oil is far larger than that of any other energy component – the 30 percent decline in refined oil intensity is twice the decline in coal, which registers the second largest decline among our three energy types. Underscoring our inability to identify economic factors that are associated with this decline in refined oil intensity, Table 4 show that 1999 year-dummy accounts for nearly three-quarters of the reported decline. As shown in Table 4, none of the 1999-year dummies for the other energy types is statistically significant.

We do not have a satisfactory economic explanation for this deviant behavior of refined oil; however, administered restrictions on imported fuel oil may explain the decline. Following the onset of the Asian financial crisis and the Chinese government's announcement that it intended effectively to link the Chinese currency to the U.S. dollar, the government proceeded to limit the import of refined oil, wishing instead to shift to domestic sources. These restrictions may have fallen heavily on firms within our sample, particularly the power-generating sector, which uses a substantial portion of the refined oil. Within the sample, in 1998, oil used for electric power generation fell by 21.5 percent, followed by a further decline of 5.8 percent during

¹¹ Because the firms in our sample do not change industry or region over time, we use coefficients from a regression that uses share of total output in each dummy category rather than zero or one.

1998-99. These restrictions on refined oil supplies may have prompted a substitution toward coal. During these same years, coal used in power generation rose by 3.4 and 6.7 percent respectively (Tao, 2003). Because the preponderance of enterprises in the power-generating sector are large and medium-size state-owned enterprises, they may have been most compliant with the restrictions. Our preliminary explanation, therefore, for our under-explanation of the large decline in refined oil intensity focuses on import restrictions on supplies that had been used by LMEs in our sample.

We now direct our attention to coal, for which we explain 55 percent of the price decline. This focus on coal is particularly important, since the recent declines in levels of energy consumption are driven principally by declines in reported coal consumption. In Table 5, we see that the price and R&D contributions stand out. The R&D contribution alone accounts for 37 percent of the decline in coal intensity.

While the overall price contribution for coal shown in Table 5 is near zero, the individual components are substantial. The own-price elasticity of coal is “well behaved” in the sense of being negative and of robust statistical and economic significance; by itself, it accounts for more than half of the decline in coal intensity. The cross price elasticities, in particular, warrant attention. As mentioned earlier, the cross price elasticity of coal with respect to refined oil prices is negative; electricity prices, which led to the rise in energy prices during the latter half of the 1990s, also led to rising coal efficiency. We interpret this result as a consequence of coal being a substantial input to the power-generating sector; a rise in electricity prices that motivates a shift away from electricity, also leads to a decline in the consumption of coal for power generation. Within our sample, 38 percent of coal consumption is consumed by the electric power sector.

Among the price elasticities that we estimate for the coal sector, the most curious is the cross-price elasticity for refined oil. While the positive sign is as expected, the estimate of 0.463 is strikingly large - greater than the (absolute value) of coal’s own price elasticity. The magnitude of this large cross-price elasticity, in combination, with the 30 percent rise in the relative price of refined oil, causes this increase in refined oil prices to contribute to a rise in coal intensity. The magnitude of the contribution more than compensates for the other coal-conserving price effects and accounts for more than twice the magnitude of our underestimate of the decline in coal intensity. We examine this curiosity in more depth.

Table 5
Decomposition of Relative Contributions

	Contribution to Change in Dependent Variable (ln(E/Q))			
	Total Energy	Coal	Refined Oil	Electricity
ln(price of coal/composite price of other inputs)	-	-.0850	.1277	.0161
ln(price of refined oil/ composite price of other inputs)	-	.1218	-.2380	.0431
ln(price of electricity/ composite price of other inputs)	-	-.0296	.1084	-.0827
ln(price of aggregate energy/price of output)	-.0923	-	-	-
Total price contribution	-.0923	.0073	-.0019	-.0234
ln(R&D expenditures)	-.0286	-.0541	.0062	-.0254
State-owned	-.0464	-.0720	.0143	-.0688
Collectives	-.0037	-.0041	-.0018	-.0021
Foreign-owned	.0003	.0004	.0007	.0001
Hong-Kong, Macao, Taiwan	-.0015	-.0020	-.0010	-.0001
Shareholding	.0282	.0635	-.0195	.0311
Private	.0013	.0013	.0002	.0020
Other	.0015	.0017	.0047	.0011
Total ownership contribution	-.0205	-.0113	-.0024	-.0368
Huabei—North	.0043	.0171	.0097	.0019
Dongbei—Northeast	.0055	.0182	.0047	.0044
Huadong—East	-.0153	-.0459	-.0411	-.0020
Huanan—South	-.0002	-.0008	-.0005	.0000
Xinan—Southwest	.0012	.0096	.0052	-.0005
Xibei—Northwest	-.0002	-.0011	-.0003	.0001
Total region contribution	-.0046	-.0028	-.0223	.0039
Mining	.0016	.0106	-.0006	-.0028
Food & beverage	.0078	.0116	.0096	.0049
Textiles	.0186	.0394	.0315	.0041
Timber, paper	.0062	.0158	.0177	-.0024
Refined oil	.0004	-.0002	.0001	-.0000
Chemicals	-.0034	-.0152	-.0160	.0047
Refined products	-.0015	-.0026	-.0018	-.0007
Non-metals	.0007	-.0117	-.0036	.0058
Metals	-.0007	-.0034	-.0010	.0012
Machinery	-.0447	-.0806	-.0349	-.0186
Electric power	-.0130	-.0027	.0009	-.0164
Other	-.0018	.0199	.00551	-.0124
Total Industry contribution	-.0299	-.0191	.0070	-.0327
Sum of contributions from each of the five factors above	-.1760	-.0800	-.0134	-.1144
1997-1999 (residual)	.0064	-.0665	-.2793	.0153
Total	-.1696	-.1465	-.2928	-.0991

Actual change in $\ln(E/Q)$ (dependent variable)	-.1696	-.1465	-.2928	-.0991
Residual (Total – Actual Change)	.0000	.0000	.0000	.0000
% explained by the five economic factors above	104%	55%	5%	115%

We suspect that the government’s restriction on refined oil imports and consumption created price and quantity distortions that may have magnified the impact of measured price increases in refined oil on coal consumption. Since it is most likely that the enterprises that were most directly affected by, and complied with, restrictions on refined oil were state-owned enterprises, we re-estimate our coal intensity equation by interacting a state-ownership dummy with the relative price of refined oil. The result is striking. Without the state sector observations, coal’s refined oil cross-price elasticity becomes statistically insignificant. Estimating the elasticity with observations from the state sector alone, relative to the whole sample estimate shown in Table 4 the estimate rises to a value of about 0.56. This result confirms that most of the action regarding the association between rising refined oil prices and rising coal intensity takes place in the state sector, which we believe was particularly vulnerable to quantity and price restrictions during 1998-99. If indeed these government interventions created an upward bias in our estimated cross-price elasticities involving refined oil, then the measured contributions of these factors shown in Table 5 may be too large and the extent of our under-explanation of the decline in refined oil and coal may be less than shown in Table 5.

6. Conclusions

In Section 3 of this paper, we identified three broad explanations for the declines in energy intensity and consumption during 1997-1999. These are (1) sectoral change, (2) subsector energy productivity gains, and (3) inaccurate statistics. Results from our Divisia calculations indicate that as we move from one-digit SIC aggregations to firm-level analysis, shifts in output shares account for increasingly large proportions of the decline. At the firm level, the sectoral shift analysis accounts for somewhat more than half of the decline. This result implies that nearly half of the change in energy consumption and intensity has resulted from gains in energy efficiency at the firm level.

Unlike previous studies, we are able to identify the factors behind improvements in firm-level energy productivity. Again, using the firm as the unit of observation, we find that changes

in relative prices and R&D activity are important contributors to the decline in firm-level energy intensity. We also find that in addition to shifts in output across industry, shifts in share of output by region and ownership type have contributed to changes in measured energy intensity.

Two of our estimated changes – those for declines in total energy and electricity – closely approximate the actual reported changes, while the estimated changes for coal and refined oil, particularly the latter, are not nearly so accurate. We first focus on overall energy, for which our analysis accounts for 104 percent of the decline. Figure 1 shows that at the firm level, sectoral shift accounts for barely more than half of the decline in overall energy intensity, whereas intensity change, that is change in energy intensity at the firm level, accounts for the balance. Viewing Table 5, we see that the price effects account for 54.4 percent of the decline in measured aggregate energy intensity (i.e. $-0.0923/-0.1696$), R&D for 16.9 percent, and ownership change for 12.1 percent. After accounting for these factors, using the regression analysis approach, the proportion of the total decline in aggregate energy intensity that we attribute to changes in 12-digit industry mix is just 17.6 percent – about the same as the R&D contribution. The difference between Figure 1 and Table 5 results from our reliance in the simple shift-share analysis on a dichotomous analytical framework, which omits important economic variables that are able to provide a robust story about the sources of increase in energy intensity. Apparently some of the gains in China's overall energy efficiency resulting from growing shares of relatively energy efficient industries arise from the economic sources that we analyze. Rising coal prices are causing shifts away from coal intensive industries; R&D likewise contributes to reallocations of economic activity away from China's more traditional industries. These factors considerably reduce the importance of unexplained sectoral shifts in explaining the decline in China's energy intensity and consumption during 1997-99.

This leaves us with the last of the three potential explanations for the reported decline in energy intensity and energy consumption – inaccurate statistics. Looking at total energy and electricity alone, because sectoral shifts and productivity factors more than fully explain the declines in intensity and consumption for these energy aggregations, we do not need to resort to flawed data – underreported energy or over-reported output – to explain the phenomenon of declining energy intensity and consumption in our data set. Yet, the substantial under-explanation of the declines in coal and refined oil may give credence to the flawed statistics hypothesis. Still, we hesitate to adopt this hypothesis, at least for our LME industry data set, for

the following reasons. First, we see from the discussion in the previous sections that the cross price elasticities involving refined oil, which account from much of this under-estimate may arise from quantity and/or price controls in the refined oil sector, particularly with state-owned enterprises. Even with the significant under-estimate for coal, the 1999 year-dummy variable remains insignificant. Only that for refined oil is significant, and the fact of administrative controls on refined oil import can plausibly explain the observed decline in the consumption of oil. A casual averaging of the over- and under-reporting across the three specific energy types – whether or not weighted by the share of each in total energy – suggests some incongruity among these results. However, since our aggregate energy measure includes crude oil and natural gas, we cannot view the aggregate energy calculations as a simple linear combination of the three components. Our “bottom line” is that we seem to have identified the factors that contributed to the decline in aggregate energy; we do not need to engage the explanation of flawed statistics. This conclusion, however, must be provisional on a somewhat longer data set that will allow for us to estimate a set of price elasticities that are more consistent with the duration of the time horizon of our analysis.

A few caveats are appropriate. First, we acknowledge two econometric issues. We have already acknowledged that, since our estimation results are based on cross section data, our price elasticities may not be consistent with the relatively short time two year time horizon over which we are analyzing change. Second, since we rely on cross section data, we have not controlled for possible fixed effects. For example, higher managerial quality in R&D intensive firms may partially correlate with higher energy productivity thus creating a spurious or overly robust association between R&D intensity and energy efficiency. As more year observations become available, the use of a fixed effects estimator, which will allow for the easing of firm-specific effects, will become possible. Beyond these econometric issues, a further caveat is that this analysis includes only the industrial sector. As a result, the effects of changes in final demand sectors such as consumer demand and imports cannot be directly measured. In addition, our analysis only includes large and medium-size enterprises and therefore omits small and rural enterprises. Although this omission allows us to avoid certain data problems that have affected previous studies, it also precludes our attention to the small-scale enterprise sector, where technology, pricing, and R&D may play different roles than they do in the LME sector.

Notwithstanding the limited scope of our sample, the patterns of energy consumption exhibited by our sample are consistent with those found in nationwide data. An important finding of our analysis is that China's large and medium-size enterprises exhibit substantial responsiveness to changes in relative prices and to R&D. Because measured energy intensities in 1999 reflected only the short-term impact of rising relative energy prices, barring sudden price reversals, in accord with our predictions we can anticipate that declining energy intensity will continue beyond 1999. Furthermore, with the on-going rise in industrial R&D intensity, firms should continue to explore and find energy conserving process and product innovations as they did during the latter half of the 1990s.

REFERENCES

- Ang, B.W. and F.W. Zhang. 2000. "A Survey of Index Decomposition Analysis in Energy and Environmental Studies." *Energy*, 25 (2000), 1149-1176.
- Byrd, W.A. 1989. "Plan and Market in the Chinese Economy: A Simple General Equilibrium Model." *Journal of Comparative Economics* 13(2), pp. 177-204.
- Byrd, W.A. 1991. *The Market Mechanism and Economic Reforms in China*. M.E. Sharpe, Inc.: Armonk, NY.
- Garbaccio, R.F. 1995. "Price Reform and Structural Change in the Chinese Economy: Policy Simulations using a CGE Model." *China Economic Review* 6(1), pp. 1-34.
- Garbaccio, R.F., M.S. Ho, and D.W. Jorgenson. 1999. "Why has the Energy-Output Ratio Fallen in China?" *Energy Journal*, 20 (3), 63-91.
- Jefferson, G.H., T.G. Rawski, L. Wang, and Y.X. Zheng, 2000. "Ownership, Productivity Change, and Financial Performance in Chinese Industry," *Journal of Comparative Economics*: 28,4: 786-813.
- Jefferson, G.H., Bai Huamao, Guan Xiaojing, and Yu Xiaoyun. "R and D Performance in Chinese Industry," (forthcoming) *Economics of Innovation and New Technology*.
- Jefferson, G.H, Su Jian, Jiang Yuan, and Yu Xinhua. 2003, "The Impact of Shareholding Reform on Chinese Enterprise Performance, 1995-2001," prepared for the conference "The Distributional Consequences of Privatization," Center for Global Development and The Inter-American Development Bank, Washington, D.C., February 24-25, 2003.
- Kuan, Chen, G.H. Jefferson, T.G. Rawski, and Zheng Y.X. 1988, "Productivity Change in Chinese Industry, 1953-85." *Journal of Comparative Economics*, 12,4: 570-591.
- Li, Wei. 1997. "The Impact of Economic Reform on the Performance of Chinese State Enterprises, 1980-1989." *Journal of Political Economy*, vol. 105, no. 5, pp. 1080-1106.
- Lin, X. and K.R. Polenske. 1995. "Input-Output Anatomy of China's Energy use Changes in the 1980's." *Economic Systems Research*, 7(1), 67-84.
- National Bureau of Statistics. 2000, 2001a. *China Statistical Yearbook* (2000, 2001 eds). Beijing: China Statistics Press.
- National Bureau of Statistics. 2001b. Department of Industrial and Transportation Statistics, annual LME economic and fiscal survey data and annual energy survey.
- National Bureau of Statistics. 2001c. Department of Population, Social, and Science and Technology Statistics, annual LME science and technology survey.

Rawski, T.G. 2001. "What's Happening to China's GDP Statistics?" *China Economic Review*, 12(4), 347-354.

Sinton, J.E. 2001. "Accuracy and Reliability of China's Energy Statistics," *China Economic Review*, 12 (2001), pp. 373-383.

Sinton, J.E. and D.G. Fridley. 2000. "What Goes Up: Recent Trends in China's Energy Consumption." *Energy Policy*, 28 (2000), 671-687.

Sinton, J.E. and M.D. Levine. 1994. "Changing Energy Intensity in Chinese Industry." *Energy Policy*. 17 (March 1994), 239-255.

Tao, Quan. 2003. Email communication (April 17, 2003), Department of Industrial and Transportation Statistics, National Bureau of Statistics.

World Bank. 1997. *Clear Water, Blue Skies: China's Environment in the new Century*. World Bank, Washington, DC.