Why has the energy intensity fallen in China's industrial sector in the 1990s?

Zhang, Zhong Xiang

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The Relative Importance of Structural Change and Intensity Change

ZhongXiang Zhang

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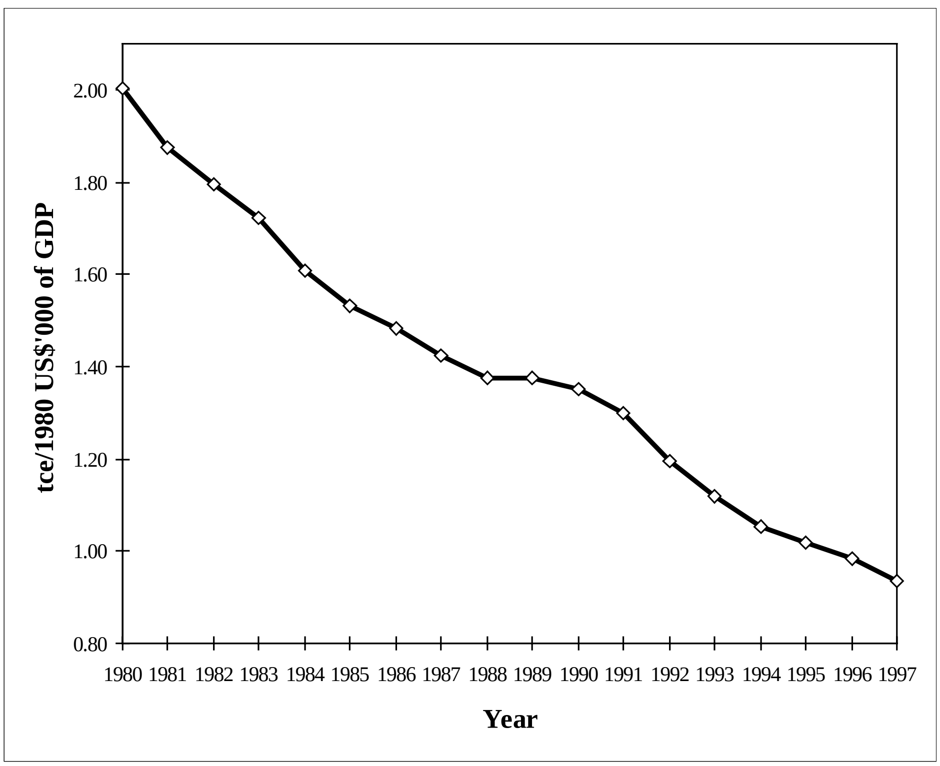
Abstract

There have been a variety of studies investigating the relative importance of structural change and real intensity change to the change in China's energy consumption in the 1980s. However, no detailed analysis to date has been done to examine whether or not the increased energy efficiency trend in the 1980s still prevailed in the 1990s. This article has filled this gap by investigating the change in energy consumption in China's industrial sector in the 1990s, based on the data sets of value added and end-use energy consumption for the 29 industrial subsectors. Our results clearly show that the overwhelming contributor to the decline in industrial energy use in the 1990s was the decline in real energy intensity, indicating that the trend of real energy intensity declines in the 1980s at the 2-digit level was still maintained in the 1990s. This conclusion still holds even if we lower the growth rate dramatically in line with the belief that the growth rate of China's GDP may be overestimated.

1. Introduction

Since launching its open-door policy and economic reform in late 1978, China has experienced spectacular economic growth, with its gross domestic product (GDP) growing at the average annual rate of about 10% over the period 1978-1997. In the meantime, by implementing a series of policies and measures towards energy conservation, China has cut its energy consumption per unit of GDP by half since 1980 (see Figure 1). This achievement corresponds to an income elasticity of energy consumption of 0.52 and to an annual saving rate of 4.37% (Zhang, 2000). As shown in Table 1, most developing countries at China's income level have an income elasticity of energy consumption well above one, suggesting that their energy consumption grows much faster than does the GDP. This clearly indicates that China's achievement is rarely accomplished in countries at this level of development.

Figure 1 Energy intensity of China's GDP measured in tons of coal equivalent (tce) per US$ 1000 in 1980 prices



Sources: Based on the data from State Statistical Bureau (1992, 1998b, 2000).

Table 1 Growth rates of GDP, energy consumption, and income elasticity of energy consumption among different economies 1980-1994

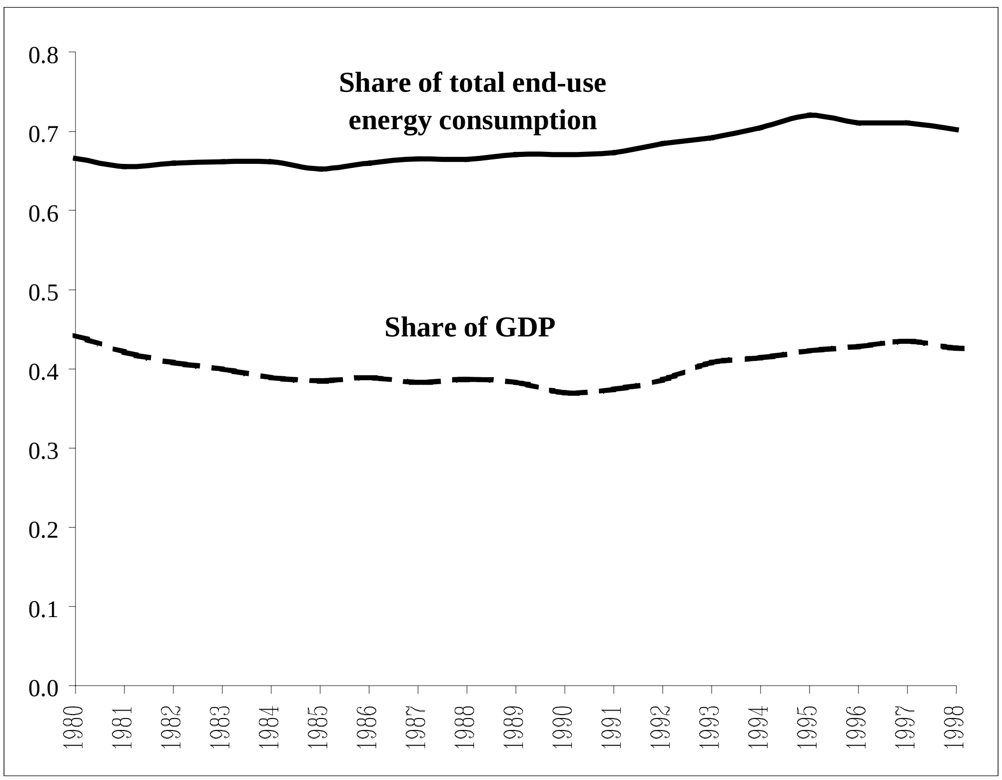
	Annual growth of GDP (%)	Annual growth of energy consumption (%)	Income elasticity of energy consumption
Low-income economies *	2.5	3.3	1.32
China	11.0	4.5	0.41
India	5.2	6.3	1.21
Upper-middle-income economies	2.5	3.9	1.56
High-income economies	2.8	1.1	0.39

* Excluding China and India.
Source: Zhang (2000).

The question then arises of what are the causes of this fall in energy use. Published work on this topic has expressed dissenting views. Based on the input-output tables in 1981 and 1987 for China, Lin and Polenske (1995) conducted a structural decomposition analysis to explain China's energy use changes between 1981 and 1987. They found that, relative to 1981, all the energy savings in China in 1987 can be attributed to energy efficiency improvements. Based on China's input-output tables in 1987 and 1992 and using the procedure similar to that used by Lin and Polenske, Garbaccio et al. (1999) concluded that the fall in energy use during 1987-92 was due mostly to a fall in real energy intensity. Using a Laspeyres decomposition method and based on three different sets of energy consumption and gross output value data, Sinton and Levine (1994) examined the relative roles of structural shift and real intensity change in China's industrial sector between 1980 and 1990. They found that real intensity change accounted for 85% of the country's overall industrial intensity change for the period 1980-90. In contrast to the above studies, suggesting that such a fall in energy use has been attributed mainly to the decline in real energy intensity, Smil (1990) and Kambara (1992) have argued that structural shifts away from more energy-intensive industrial subsectors to less energy-intensive industrial ones have been the major causal factor.

To ascertain the relative importance of structural change and intensity change is important not only because it provides policy makers with the energy impact of the policies that have been implemented, but also because a good understanding of this issue helps to improve the credibility of future projections for energy demand and energy-related emissions. This article aims to examine this disagreement by investigating the relative importance of structural change and real intensity change to the change in energy consumption in China's industrial sector. There are at least two reasons for choosing the industrial sector for the study. First, in China, industry is the dominant energy-consuming sector. As shown in Figure 2, although on average about 40% of China's GDP originated from the industrial sector from 1990 to 1998, it accounted for as high as 68% of the country's total end-use energy consumption. Because the industrial sector is critical for the past and future energy consumption, a deeper understanding of how energy consumption evolves in the sector is very important in formulating future policy. Second, the data at fine level of disaggregation are available for the sector. This makes it possible to calculate how much of the fall in the total industrial energy use is due to structural shifts within the subsectors and how much to changes in real energy intensity.

Figure 2



Sources: Data from State Statistical Bureau (1992, 1998b, 2000).

This study differs from previous analyses in two important aspects. First, previous work examined the relative contributions of structural change and real intensity change to energy savings in the 1980s or between 1987 and 1992, while our study examines their relative importance in the 1990s to see whether or not the increased energy efficiency trend in the 1980s still prevails in the 1990s. Second, we have proposed a decomposition method different from the Laspeyres method or Divisia method commonly used by previous work. This proposed method gives no residual so that all of the observed change in industrial energy consumption can be explained.

This paper is organised as follows. Section 2 describes the method to decompose the contributions of economic growth, structural change and real intensity change to the change in total energy consumption. Section 3 discusses the data used. Section 4 applies the decomposition method to analyse the changes in energy consumption in China’s industrial sector from 1990 to 1996 and presents the results from such a analysis. Section 5 tests the sensitivity of the results to the adjustment of the output data. Finally, Section 6 offers concluding remarks.

2. The decomposition method

Let E_o and E_t be total energy consumption in the industrial sector in year *o* and year *t*. The change in total industrial energy consumption between the two years, $\Delta E_{tot} = E_t - E_o$, is decomposed as follows:

$$\Delta E_{tot} = \Delta E_{out} + \Delta E_{str} + \Delta E_{\text{int}} + R$$

The first term ΔE_{out} on the right-hand side represents a change in energy consumption due to a change in aggregate production (output effect). The second term ΔE_{str} represents a change in energy consumption due to changes in composition of aggregate production (structural effect). If less energy-intensive industrial subsectors grow faster than do more energy-intensive industrial ones, such a structural change will put the downward pressure on energy demand, thus resulting in lower growth rate of energy consumption than would otherwise have been the case. The third term ΔE_{int} shows a change in energy consumption due to changes in subsectoral energy intensities (intensity effect). Real energy intensity may decline as a result of the adoption of more efficient production technologies and energy management techniques, changes in product mix within and between subsectors, changes in product value as well as changes in the quality and mix of material and fuel inputs. This is the reason why we refer this effect to the intensity effect rather than the technological effect because it contains more than purely technological changes. The last term is a residual.

In decomposing the change in overall energy consumption, the Laspeyres method has been used extensively.[1] Proposed by Park (1992), the method calculates changes in energy consumption with respect to a constant base year and has the following components:

$$\Delta E_{out} = \sum_i Q_t s_{i,o} I_{i,o} - E_o = (Q_t - Q_o) \sum_i s_{i,o} I_{i,o}$$
$$\Delta E_{str} = \sum_i Q_o s_{i,t} I_{i,t} - E_o = Q_o \sum_i (s_{i,t} - s_{i,o}) I_{i,o}$$
$$\Delta E_{\text{int}} = \sum_i Q_o s_{i,o} I_{i,t} - E_o = Q_o \sum_i s_{i,o} (I_{i,t} - I_{i,o})$$

[1] The Laspeyres method and Divisia method are the two most commonly used decomposition methods. Studies that employed either of the two methods include Ang and Lee (1994), Boyd et al. (1987), Boyd et al. (1988), Howarth et al. (1991), and Liu et al. (1992). Howarth et al. (1991) show that the two methods of decomposing manufacturing energy use in eight OECD countries yield very similar results in terms of the relative importance of the driving force of aggregate energy intensity declines.

where Q_o and Q_t are aggregate production in the industrial sector in year o and year t, $s_{i,o}$ and $s_{i,t}$ are the ith industrial subsector's share of aggregate production in year o and year t, and $I_{i,o}$ and $I_{i,t}$ are energy intensity in each industrial subsector i in year o and year t.

The Laspeyres method is more easily interpreted. But the disadvantage of the method is that there is a residual, which is not equal to zero and generally increases as t increases (Howarth et al., 1991). This leaves part of the observed change in industrial energy consumption unexplained. For this reason, we propose a different decomposition method. By keeping the definition of the first term unchanged but redefining the last two terms, this proposed method is as easily interpreted as the Laspeyres method, but gives no residual.

In what follows, we start describing the proposed method by defining ΔE_{str} to represent a difference between what energy consumption would have been if each subsectoral output at year t had been produced at the energy intensity of year o and that if the aggregate production at year t had been composed in the same way at year t as at year o and had been produced at the energy intensity of year o. Define ΔE_{int} to represent a difference between the observed energy consumption and what energy consumption would have been if each subsectoral output at year t had been produced at the energy intensity of year o. Thus, we have

$$\Delta E_{str} = \sum_i (Q_t s_{i,t} I_{i,o} - Q_t s_{i,o} I_{i,o}) = Q_t \sum_i (s_{i,t} - s_{i,o}) I_{i,o}$$

$$\Delta E_{\text{int}} = \sum_i (Q_t s_{i,t} I_{i,t} - Q_t s_{i,t} I_{i,o}) = Q_t \sum_i s_{i,t} (I_{i,t} - I_{i,o})$$

The proposed decomposition method gives no residual on the right-hand side. This can be illustrated as follows. Summing over the three terms, we have

$$\begin{aligned}
&\Delta E_{out} + \Delta E_{str} + \Delta E_{\text{int}} \\
&= (Q_t - Q_o) \sum_i s_{i,o} I_{i,o} + Q_t \sum_i (s_{i,t} - s_{i,o}) I_{i,o} + Q_t \sum_i s_{i,t} (I_{i,t} - I_{i,o}) \\
&= Q_t \sum_i s_{i,o} I_{i,o} - Q_o \sum_i s_{i,o} I_{i,o} + Q_t \sum_i s_{i,t} I_{i,o} - Q_t \sum_i s_{i,o} I_{i,o} + Q_t \sum_i s_{i,t} I_{i,t} - Q_t \sum_i s_{i,t} I_{i,o} \\
&= -Q_o \sum_i s_{i,o} I_{i,o} + Q_t \sum_i s_{i,t} I_{i,t} = -E_o + E_t = \Delta E_{tot}
\end{aligned}$$

3. Sector disaggregation and data

The choice for a level of sector disaggregation is mainly dictated by the aim of analysis and data availability. Ideally, the fine level of subsectoral detail is desirable in order to accurately disentangle the structural effect from the intensity effect. Sinton and Levine (1994) shows that as the level of subsectoral detail becomes finer, more intensity change becomes attributable to structural shift. Given that the effect of changes in product mix within and between subsectors is counted as the intensity effect, this should thus come as no surprise because a finer level of sector disaggregation is able to more accurately separate the effect from the intensity effect. In practice, however, the desire for a finer level of sector disaggregation is often restrained by data availability. This is certainly the case in China where the data for industrial value added and energy use are at roughly the 2-digit industry classification level.

Unlike Huang (1993) and Sinton and Levine (1994) where gross output value is used as the output indicator, value added is used as the output indicator for this present study in order to avoid double accounting the value of intermediate goods. The data for value added in the industrial sector are disaggregated into 40 subsectors for the period 1991-92 and into 37 subsectors in 1996 (State Statistical Bureau, 1993, 1998a), the latest year in which detailed end-use energy consumption data in a consistent manner are available. The data for end-use energy consumption are disaggregated into 31 subsectors. For each subsector, the total end-use energy consumption is the sum of the standard coal equivalents of coal, oil, natural gas, hydropower and nuclear power consumed. Because the energy consumption data are not compatible with such an industrial subsector classification, reconciling the differences between the two data sets obliges us to disaggregate the industrial sector into 29 subsectors. Value added at current prices and energy consumption in each subsector is taken from Chinese State Statistical Bureau (1993, 1994, 1995, 1996, 1998a, 1998b).

In this study, we use 1991 as the base year. Price indices from 1991 to 1996 are disaggregated into 14 subsectors and are derived from Chinese State Statistical Bureau (1998c). Because price indices are less disaggregated than the value added data, in converting 29-subsector value added at current prices into that in 1990 constant prices, the same price index is thus used for those subsectors that are further disaggregated from the same higher-level subsector.

4. The relative importance of structural change and intensity change

In this section, we will apply the above proposed decomposition method to analyse the changes in energy consumption in China's industrial sector from 1990 to 1996.

In the 1990s, the industrial sector experienced spectacular growth. Accompanying the growth, the cumulative energy consumption in the industrial sector between 1991 and 1996 would increase by 1615.95 million tons of coal equivalent (Mtce), as shown in Table 2, provided that the production structure and energy intensity had remained unchanged. But, the actual cumulative energy consumption in the industrial sector during the period increased only by 807.23 Mtce. Clearly, it is energy conservation that pushed the energy consumption during the period under review downward. Measured as the difference between the would-be and actual energy consumption, the accumulative energy savings between 1991 and 1996 amounted to 808.72 Mtce.

Table 2 Changes in the cumulative industrial energy consumption from 1990 to 1996 (Mtce)[a]

Due to change in aggregate production	Due to change in production structure	Due to change in energy intensity	Actual change in cumulative energy consumption
+1615.95	-54.71	-754.00	+807.23

[a] A positive sign indicates an increase in energy consumption; a negative sign indicates a decline.

With respect to the breakdown of the contributions, our results show that 754 Mtce or 93.2% of the cumulative industrial energy savings for the period 1990-96 were attributed to real intensity change. Because this study and the above cited studies for the 1980s all use data at roughly the 2-digit industry classification level, this dominant role of intensity change clearly indicates that the trend of real energy intensity declines in the 1980s at the 2-digit level was still maintained in the 1990s.

Figure 3 shows the results in more subsectoral detail. The lengths of the bars are in proportion to changes in cumulative energy consumption by each industrial subsector, with a positive sign indicating the contributions to energy savings and a negative sign indicating the increase in energy consumption. As shown in Table 3, within the industrial sector, the chief energy using subsectors are chemicals, ferrous metals, nonmental mineral products and machinery. Between 1991 to

1996, the four subsectors consumed 18.7%, 18.4%, 15.1% and 8.3% (60.5% in total) of the total end-use energy consumption in the industrial sector, respectively. From Figure 3, it can be seen that the machinery subsector exhibited the greatest reduction in energy consumption, accounting for 25.8% of the total reduction in industrial energy consumption due to decline in real energy intensity during the period 1991-96. Such a reduction is a result of the combined effects of decline in real energy intensity and the largest share (23% on average) of the subsector in the total industrial output (see Table 3). This is followed by the nonmental mineral products, ferrous metals, and chemicals subsectors. Real intensity declines in the last three subsectors contributed to 25.3%, 15.3% and 11.4% of the above total reduction. With 77.8% of the total occurring in the four subsectors, it is fair to say that real intensity declines in the four subsectors had kept industrial energy consumption from rising to 1615.95 Mtce as would otherwise have occurred.

Figure 3 Changes in cumulative end-use energy consumption by each industrial subsector from 1991 to 1996

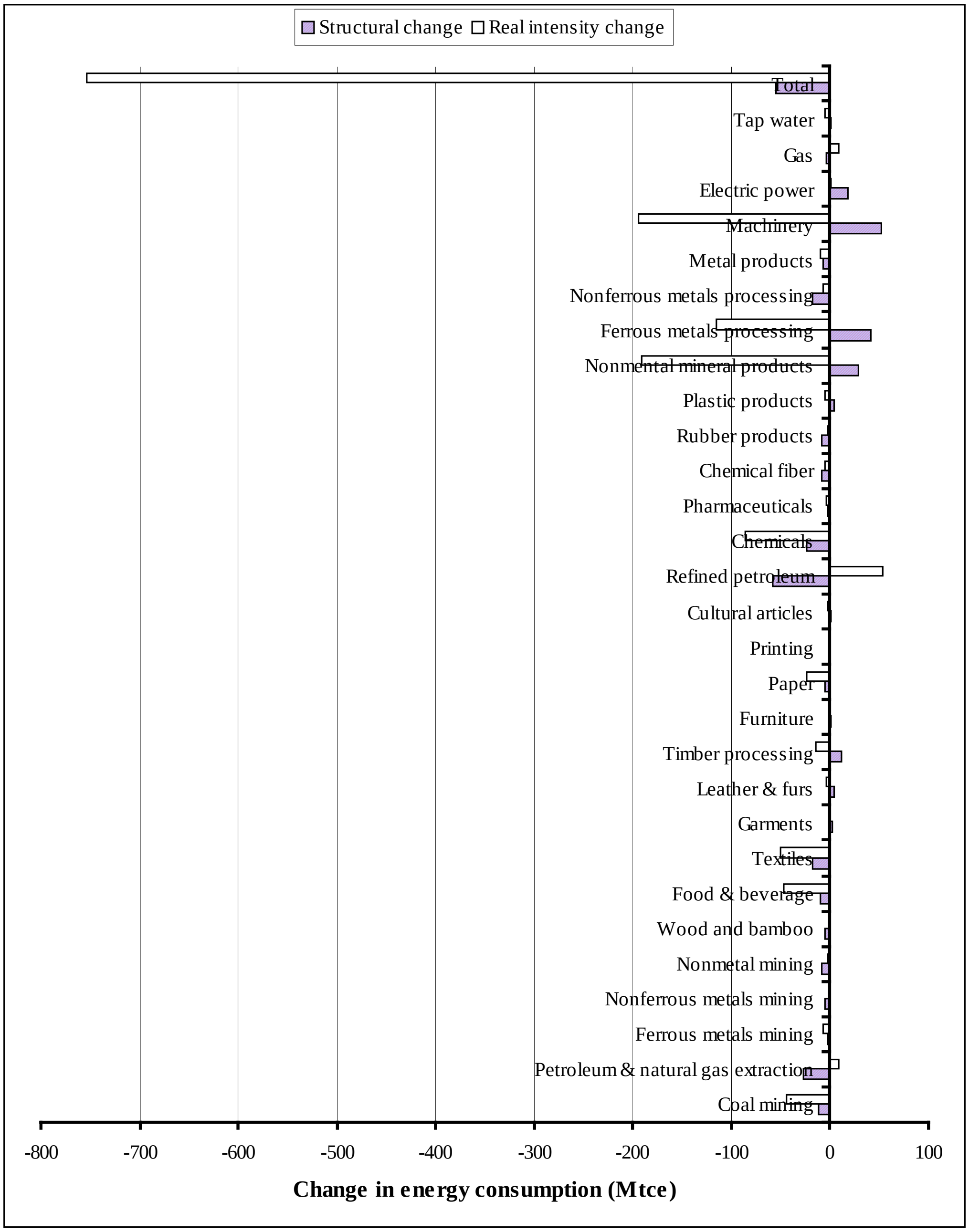


Table 3 Each industrial subsector's shares of total value added and cumulative end-use energy consumption from 1991 to 1996

	Average share of total industrial value added	Share of cumulative end-use energy consumption
Coal mining and dressing	3.40%	4.12%
Petroleum and natural gas extraction	4.95%	2.89%
Ferrous metals mining and dressing	0.29%	0.40%
Nonferrous metals mining and dressing	0.66%	0.61%
Nonmetal and other minerals mining and dressing	0.98%	0.73%
Logging and transport of wood and bamboo	0.69%	0.28%
Food, beverage and tobacco processing	11.35%	4.97%
Textile industry	7.04%	4.18%
Garments and other fiber products	2.28%	0.31%
Leather, furs, down and related products	1.19%	0.28%
Timber processing, bamboo, cane, palm & straw products	0.63%	0.43%
Furniture manufacturing	0.39%	0.13%
Papermaking and paper products	1.49%	2.49%
Printing and record medium reproduction	0.92%	0.21%
Cultural, educational and sports articles	0.56%	0.09%
Petroleum processing and coking	3.03%	3.88%
Raw chemical materials and chemical products	6.20%	18.71%
Medical and pharmaceutical products	1.92%	1.18%
Chemical fiber	1.30%	1.29%
Rubber products	1.12%	0.79%
Plastic products	1.61%	0.62%
Nonmetal mineral products	6.20%	15.06%
Smelting and pressing of ferrous metals	7.52%	18.43%
Smelting and pressing of nonferrous metals	1.86%	3.19%
Metal products	2.74%	1.20%
Machinery, electric equipment, electronic & other manufacturing	23.00%	8.30%
Electric power, steam and hot water production and supply	6.13%	4.49%
Gas production and supply	0.07%	0.23%
Tap water production and supply	0.48%	0.52%

Sources: Calculaion based on data from the State Statistical Bureau (1993, 1994, 1995, 1996, 1998a, 1998b, 1998c).

5. The effects of an alternative lower growth rate

It has been widely argued that China's statistical authorities underestimate China's GDP level and thus overestimate the GDP growth rate. Using a measurement technique closer to Western national accounting practice, Maddison (1997), for example, re-estimates China's GDP. He found that during the period 1952-1978 China's GDP grew at an average annual rate of 4.4%, in comparison with the official rate of 6%. For the period 1978-1994, his estimate for the GDP growth rate is 7.4%, whereas the official growth figure is 9.8%.

To test the sensitivity of the above results to the output value, we lower the annual growth rate of GDP by 2% from 1991 to 1996. Provided that its share in GDP remains unchanged, the annual growth rate of each industrial subsector accordingly reduces by 2%.[2] As would be expected from the assumed slow down of economic growth, the cumulative increases in energy consumption in the industrial sector between 1991 and 1996 would drop from 1615.95 Mtce in the above case of the high GDP growth rate to 1324.44 Mtce, as given in Table 4. Given the fact that the actual cumulative energy consumption in the industrial sector during the period remained unchanged, this implies that, in absolute terms, the cumulative contribution of energy conservation, which amounted to 517.20 Mtce, would be less than 808.72 Mtce in the above case of the high GDP growth rate. In percentage terms, however, 90.6% of the cumulative energy savings in the industrial sector for the period 1990-96 were attributed to real intensity change. This clearly indicates that our above finding on the relative importance of structural change and real intensity change to the change in energy consumption in China's industrial sector is fairly robust to the adjustment of the output data.

[2] There is a wide suspicion that the official rate of inflation for producer prices is understated because the official prices might not be the properly weighted average of plan and market prices, might have been misreported, or were not produced using a good sample of firms (Rawski, 1991; Garbaccio et al., 1999). Assuming that the official data for GDP and industrial subsector value added are correct, lowering the annual growth rate of each industrial subsector by 2% is equivalent to raising the annual rate of inflation of all industrial products by the same percentage in terms of the impacts on the energy consumption, although the reasons for the two adjustments are very different from each other.

Table 4 Changes in the cumulative industrial energy consumption associated with a lower GDP growth rate from 1990 to 1996 (Mtce)[a]

Due to change in aggregate production	Due to change in production structure	Due to change in energy intensity	Actual change in cumulative energy consumption
+1324.44	-48.70	-468.50	+807.23

[a] A positive sign indicates an increase in energy consumption; a negative sign indicates a decline.

6. Conclusions

By implementing a series of policies and measures towards energy conservation, China has cut its energy consumption per unit of GDP by half since 1980. In the literature that is examining the causes of this fall in energy use in the 1980s, however, there seem to be dissenting views. Some analysts believe that such a fall has been attributed mainly to the decline in real energy intensity, whereas others think that structural shifts away from more energy-intensive industrial subsectors to less energy-intensive industrial ones have been the major causal factor.

Based on the data sets of value added and end-use energy consumption for the 29 industrial subsectors and using the proposed decomposition method of giving no residual, we have examined this disagreement by investigating the relative importance of structural change and real intensity change to the change in energy consumption in China's industrial sector in the 1990s. Our results show that 93.2% of the cumulative energy savings in the industrial sector for the period 1990-96 were attributed to real intensity change, with about three quarters of such savings from the four chief energy using subsectors (i.e., chemicals, ferrous metals, nonmental mineral products and machinery). Because this study and the cited studies for the 1980s all use data at roughly the 2-digit industry classification level, this dominant role of intensity change clearly indicates that the trend of real energy intensity declines in the 1980s at the 2-digit level was still maintained in the 1990s.

Finally, to test the robustness of the above conclusion, we have lowered the annual growth rate of each industrial subsector by 2% in line with the belief that the growth rate of China's GDP may be overestimated. It is clear from this sensitivity analysis that our conclusion that the major contributor to the decline in industrial energy use in the 1990s was the decline in real energy intensity does not change even if the growth slows down dramatically.

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About the Author

Dr. ZhongXiang Zhang was trained at Tianjing University in Tianjan, China. He works as a professor at the East-West Center, Honolulu, U.S.A. and also as part-time Professor of Economics, Centre for Environment and Development, Chinese Academy of Social Sciences, Beijing, China and is visiting Professor of Economics, China Centre for Regional Economic Research, Peking University, Beijing, China.
Dr. Zhang is a former member of staff of the Faculty of Economics and Faculty of Law of the University of Groningen, the Netherlands.

His fields of Interest are:
- Energy economics and policy
- Environmental economics and policy
- Economics of regulation
- Public finance
- Trade and the environment
- Applied economic modelling
- Energy and environmental policy in China

Dr. Zhang has been involved in research and consulting assigments for a large number of institutions, such as: Asian Development Bank, China Wind Energy Development Centre, Beijing, several Chinese and Dutch ministeries and research centres, as well as several United Nations Programmes (UNCTAD, UNDP, ESCAP, UNEP and UNOPS)

Dr. Zhang is member of the editorial board of the following journals:

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