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Abstract

China experienced a dramatic decline in energy intensity from the onset of economic reform in the late 1970s until 2000, but since then rate of decline slowed and energy intensity actually increased in 2003. Most previous studies found that most of the decline was due to technological change, but disagreed on the role of structural change. To the best of our knowledge, no decomposition study has investigated the role of inter-fuel substitution in the decline in energy intensity or the causes of the rise in energy intensity since 2000. In this paper, we use logarithmic mean Divisia index (LMDI) techniques to decompose changes in energy intensity in the period 1980-2003. We find that: (1) technological change is confirmed as the dominant contributor to the decline in energy intensity; (2) structural change at the industry and sector (sub-industry) level actually increased energy intensity over the period of 1980-2003, although the structural change at the industry level was very different in the 1980s and in the post 1990 period; (3) structural change involving shifts of production between sub-sectors, however, decreased overall energy intensity; (4) the increase in energy intensity since 2000 is explained by negative technological progress; (5) inter-fuel substitution is found to contribute little to the changes in energy intensity.

JEL classifications: Q43

Keywords: China, energy, decomposition analysis, inter-fuel substitution

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A Decomposition Analysis

Introduction

Since the start of economic reform in 1979, China has experienced spectacular economic growth. Its gross domestic product (GDP) has increased at 9.5% annually over the past quarter century. Industry and manufacturing grew by an even faster rate, more than 11% p.a. from 1980 to 1990 and more than 13% p.a. from 1990 to 2000 (World Development Indicators, 2002). But, over the same period, commercial energy consumption [1] increased by only 4.44% p.a. (China Energy Statistical Yearbook, CESY). By 2000, commercial energy intensity (energy/GDP) had decreased by 65% compared to 1980. Energy intensity declined in every year up till 2000 except for 1989. However since 2000 the decline in energy intensity slowed and energy intensity actually increased in 2003 (Figure 1 & 2). The aim of this paper is to investigate the causes of this reversal in the trend and to apply a more detailed decomposition analysis to a longer period than any previous study of China's energy intensity.

The causes of the significant decline in China's energy intensity have been investigated by a number of decomposition studies (Huang, 1993; Sinton and Levine, 1994; Lin and Polenske, 1995; Garbaccio *et al.*, 1999; Zhang, 2003; Fisher-Vanden *et al.*, 2003). While most studies find that the most important factor is technological change, there is disagreement on the role of structural change – a shift in the mix of industries. Many found that structural change has played a minor role in reducing energy intensity. However, Garbaccio *et al.* (1999) found that structural change actually increased energy intensity between 1987 and 1992. Fisher-Vanden *et al.* (2003) similarly found an intensity-increasing effect at the 1-digit SIC sectoral level

[1] Commercial energy consumption is equivalent to all non-traditional forms of energy. In other words, it does not include biomass, firewood, and other traditional fuels.

from 1997 to 1999.[2] We reach the same conclusion as the latter two research teams in our investigation of the entire 1980-2003 period.

Both Sinton and Levine (1994) and Fisher-Vanden *et al.* (2003) found that the explanatory power of structural change rises as the level of sectoral disaggregation becomes finer. In this paper we carry out a decomposition on a consistent[3] set of data at three levels of sectoral disaggregation: among industries – the highest level subdivisions of production[4], sectors within each industry, and sub-sectors within each sector. Structural change at each level will be exactly identified. To the best of our knowledge, no decomposition study of China's energy intensity has examined the role of inter-fuel substitution. This study will contribute to examining the substitution effect among coal, oil, natural gas, electricity and other fuels, on the overall energy intensity. Additionally, all previous studies focus on the continuous decline in energy intensity in the period until 2000, though mostly they examine short numbers of years within those two decades. This is the first study to look at the post-2000 period.

The paper is organized as follows. Section 2 briefly reviews the literature and conducts a exploratory analysis of the data. Section 3 describes the method used to decompose the inter-fuel substitution effects, the technological change effect, and the structural effects at three levels of sectoral disaggregation. Section 4 discusses the sectoral disaggregation and data used. Section 5 applies the decomposition method to two sets of data and presents and discusses the results. Lastly, Section 6 concludes.

Literature Review and Exploratory Analysis

There are two broad categories of decomposition techniques: input-output techniques – structural decomposition analysis (SDA) and disaggregation techniques – index decomposition analysis (IDA) (Hoekstra and Van der Bergh, 2003). The SDA approach is

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[2] This level is intermediate between the industry and sector levels of aggregation used by the Chinese government and in this paper.

[3] Consistency is defined in terms of aggregation. For example, a set of output data with various levels of sector al disaggregation is considered consistent if the output of an industry equals the sum of the output of all the sectors within that industry and the output of a sector equals the sum of the output of all the sub-sectors within that sector.

[4] China's economy is currently categorized into three industries: primary, secondary and tertiary industries.

based on input-output coefficients and final demands from input-output tables while the IDA framework uses aggregate input and output data that are typically at a higher level of aggregation than input-output tables. This basic difference also determines the advantages and disadvantages of the two methods. One advantage of SDA is that the input-output model includes indirect demand effects – demand for inputs from supplying sectors that can be attributed to the downstream sector's demand - so that SDA can differentiate between direct and indirect energy demands. The IDA model is incapable of capturing indirect demand effects. Thanks to the greater structural detail in the input-output table, SDA has another advantage of being able to distinguish between a range of technological effects and structural effects that are not possible in the IDA model. The advantage of the IDA framework is that it it can readily applied to any available data at any level of aggregation. While input-output tables may only be available sporadically, IDA can be applied to data available in time series form. In this paper, we use the IDA model and, therefore, energy consumption refers to direct energy consumption without considering indirect spillovers.

There are a variety of different indexing methods that can be used in IDA. Ang (2004) provides a useful summary of the various methods and their advantages and disadvantages. Several of these have been applied in analyses of China's energy intensity. Huang (1993) uses multiplicative arithmetic mean Divisia indices to decompose energy intensity changes in Chinese secondary industry and the six sectors into which he divided it in the period 1980-1988 into the effects of structural change and improvements in energy intensities. The six sectors are: paper, chemicals, building, metal, mechanical - electric – electronic (MEE), and other secondary industry. He found that the main contribution to declining intensity in each industry is from the improvements in sub-sector intensity during the period. Most studies assume that such changes are the result of technological change. Structural change due to shifts of production among subsectors contributed little to the total change in Huang's study. Sinton and Levine (1994) used a Laspeyres index method to determine the relative roles of structural change and real intensity change (i.e. the technological effect) in China's industrial sector between 1980 and 1990 with three different sets of data, and found similar results to Huang (1993). While the previous studies use IDA approaches, Lin and Polenske (1995) used SDA to study China's energy use between 1981 and 1987. The economy was disaggregated into seven sectors: agriculture, energy, heavy industry, light industry, construction, and transport and services. They found that China's reduction in energy use during this period came about primarily by "changes in how to produce" (production technology changes) rather than in what to consume (final demand shift)", which is consistent with other studies. Garbaccio *et al*. (1999) also applied SDA to study the decline in intensity between 1987 and 1992, disaggregating the economy into 29 sectors. Their main conclusion is that technical change within sectors accounted for most of the fall in the energy-output ratio. Structural change actually increased the use of energy, which is at variance to most of the other studies. An increase in the import of some energy-intensive products also contributed to the decline in energy intensity[5]. Zhang (2003) used an additive Laspeyres index to examine the energy use in China's industrial sector during 1990-1997. Industrial energy consumption was decomposed into scale, real intensity, and structural effects, and real intensity (i.e. technological effect) was found to be the dominant factor. The industrial sector was also disaggregated into 29 sectors. Fisher-Vanden *et al.* (2003) examined the absolute decline in energy consumption as well as intensity decline during 1997-1999. They applied the multiplicative arithmetic mean Divisia methods to a unique set of enterprise-level data. They decomposed both total energy intensity as well as intensities computed for each of the individual fuels and electricity. As expected, they found that proportion of the change in energy intensity explained by structural change rises as the level of disaggregation becomes finer. At the firm level, shifts in the shares of firms in industry output accounted for more than half of measured reductions in total energy intensity. While productivity change within firms still emerges as the dominant factor driving the decline in the intensity of electricity, shifts of output between firms plays a near equal, though smaller, role in declining coal and refined oil intensities. Consistent with the findings of Garbaccio *et al*., the results also showed that structural change at the 1-digit SIC level increased energy intensity.

[5] These two SDA studies also use index decomposition in their analyses. Lin and Polenske's study was actually an additive Laspeyres type decomposition that use fixed base-period shares, whereas Garbaccio *et al.*'s work used additive arithmetic mean Divisia type decomposition.

Figure 1 - Commercial Energy Intensity in Logarithms (1980-2003)

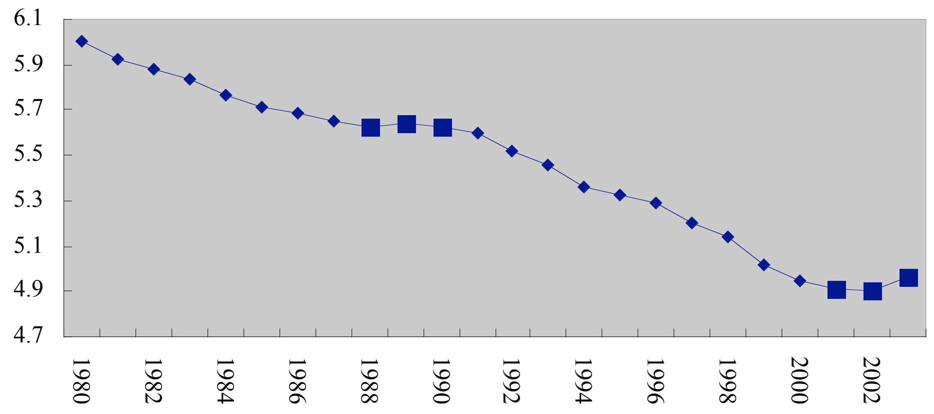
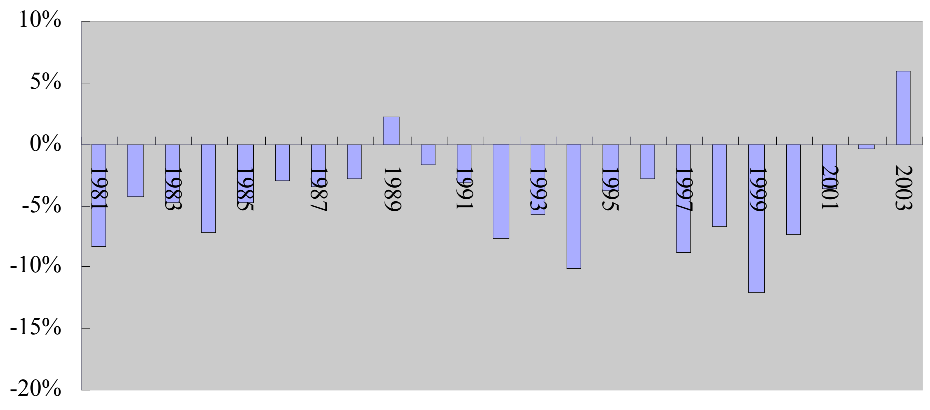


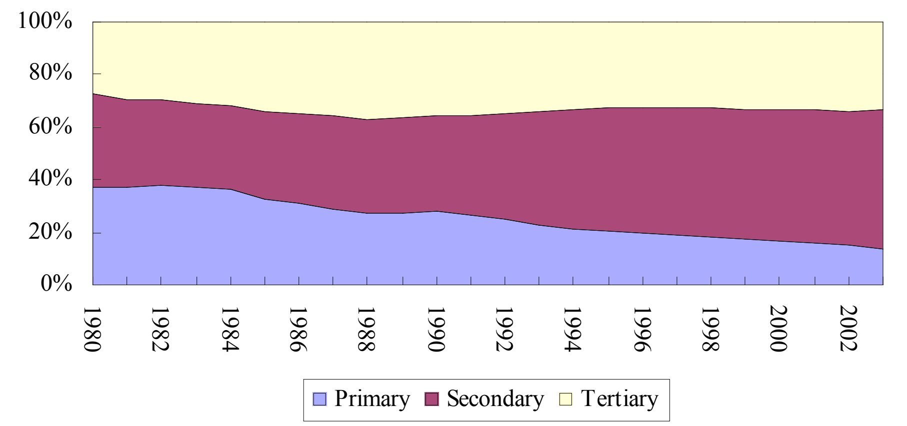
Figure 2 - Commercial Energy Intensity in Growth Rates (1980-2003)



1) Data Source: China Statistical Yearbook (CSY), China Energy Statistical Yearbook (CESY), various issues.
2) The raw energy data are in grams of standard coal equivalent (GSCE) and commercial energy consumption includes the consumption of coal, oil, natural gas, electricity, heat and others; the raw GDP data are at constant prices (RMB).

In conclusion, according to the studies discussed above, the technological effect has consistently contributed to decreasing energy intensity in China during most of the economic reform period but a clear picture does not emerge regarding the contribution of structural change. The actual changes in industrial structure are very different in the decade of the 1980s and the period following the 1980s. As shown in Figure 2, from 1980 to 1990, structural change occurred mainly from primary industry (agriculture) to services, with primary industry's share of GDP decreasing from 37% to 28% and services' share increasing from 28% to 36%. In this period the share of secondary industry was relatively constant, increasing slightly from 35% to 36%. However, from 1990 to 2003, a shift in output from primary industry to secondary industry dominated, with the share of primary industry decreasing from 28% to 14% and secondary industry increasing from 36% to 53%. Over the same period, the share of services declines slightly from 36% to 33%. Figure 3 shows the different energy intensities of primary, secondary and tertiary industry in China. Secondary industry has the highest intensity and primary industry the lowest. Considering the energy intensities in the three industries (Figure 4) and the patterns of structural change over time (Figure 3), the effect of structural change on energy intensity at the industry level should be an increase in energy intensity during the entire period of economic reform.

Figure 3 - Industry Composition



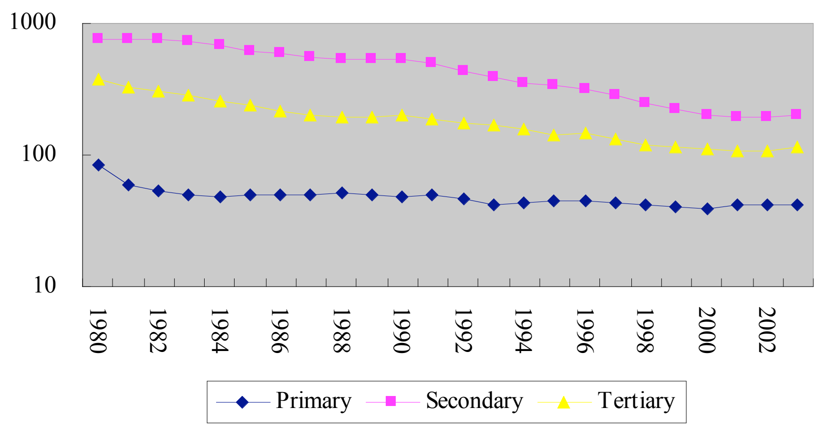
1) Primary industry includes one sector – "Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy"; secondary industry includes four sectors – "Mining", "Manufacturing", "Electric power, Gas and Water" and "Construction"; and tertiary industry includes three sectors - "Transportation, Storage, Post and Telecommunication Services", "Wholesale, Retail Trade and Catering Services", and "Residential Consumption and Others" (Households).
2) Data Source: CSY 2005; authors' calculation (constant prices).

While most studies attribute the decline to the effects of structure and technological change, none of the previous studies have examined the effect of inter-fuel substitution on overall energy intensity. Presumably, as the energy composition of an economy changes, the overall energy intensity would change as well due to the differences in quality of the various energy carriers,[6] given a constant level of technology and composition of output. In all previous

[6] The concept of energy quality refers to the differences in economic productivity of different fuels and electricity. There are different ways of defining and measuring energy quality. The relevant concept here is the different marginal productivities of the fuels (Cleveland et al., 2000). Typically electricity has a higher marginal product per joule than oil and natural gas, which in turn have higher marginal products than coal. Therefore, substituting a joule of electricity for a joule of oil, or a joule of oil for a joule of coal will reduce energy intensity.

studies of China's energy intensity inter-fuel substitution is subsumed into technological change.[7] The current study separates inter-fuel substitution - a move along a neoclassical production isoquant from technological change - a shift in the neoclassical isoquants.

Figure 4 - Industrial Energy Intensity (1980-2003)



1) Figure is in logarithmic scale; the raw energy data are in grams of standard coal equivalent (GSCE) and the raw GDP data are at constant prices (RMB).
2) Data Source: CSY 2005; CESY, various issues; authors' calculation.

Commercial energy intensity in China has fallen continuously in most years over the 1980 – 2003 period (Figure 1 & 2) but it also stagnated during two periods: 1988-1990 and 2001-2003. The decline in commercial energy intensity slowed down during both periods although stagnancy was more salient in the latter period. Moreover, energy intensity even increased in the years of 1989 and 2003. What are the differences between these two periods in terms of the causes of stagnancy? Is the change in the latter period temporary as in the late 1980s, or is it a sign of a reversal in trend? All previous studies focus on the dramatic decline. It's important to understand the substantial decrease in China's energy intensity; however, it also makes good sense to also examine the stagnant periods and answer these questions.

[7] The inter-fuel substitution effect has been studied in the carbon decomposition literature using the Kaya identity decomposition or its extended forms.

Methods

Several variants of the IDA approach have been developed. However, to a large extent, selection of method seems to be arbitrary and there is little consensus as to which one is the superior method. Ang (2001, 2004) and Ang *et al.* (1998) argued that the logarithmic mean divisia index (LMDI) method should be preferred to other decomposition methods with the advantages of path independency, ability to handle zero values and consistency in aggregation (See Appendix for more details). Therefore, we have adopted this method though it has not been used in previous studies of China's declining energy intensity.[8]

Each decomposition approach can be applied in a period-wise or time-series manner. A period-wise decomposition compares indices between a base year and the final year of a given period, showing the accumulated effects over the period. However, the results of a period-wise decomposition are very sensitive to the choice of base year and final year and it does not show how the effects of the decomposed factors have evolved over the studied period. A time-series analysis compares indices on a year-by-year basis and when annual data are available, time-series decomposition is, therefore, preferred and adopted in the current study. In any case, periodwise results can be derived from a time-series analysis, but not *vice versa*, of course.

The additive form[9] of the decomposition is as follows:

$$I = \sum_i \sum_j \sum_k \sum_m F_m \cdot I_k \cdot S_k \cdot S_j \cdot S_i \qquad (1)$$

I - Overall energy intensity;

F_m - Share of fuel m in total energy consumption of the *ijk*-th sub-sector;

I_k - Energy intensity in the *ijk*-th sub-sector;

S_k - Output share of the *ijk*-th sub-sector in the *ij*-th sector;

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8 However, this method has been used in decomposing China's carbon emissions (Wu *et al.*, 2005; in press; Wang *et al.*, 2005)

9 See Ang (2005) for definitions of additive and multiplicative forms of decompositions.

S_j - Output share of the *ij*-th sector in the *i*-th industry;

S_i - Output share of the *i*-th industry in the overall economy.

Manipulating equation (1) as described in the Appendix results in the decomposition of the annual changes in energy intensity:

$$\begin{aligned}\Delta I_{tot} &= \sum_i\sum_j\sum_k\sum_m L(w_{ijkm_{t-1}}, w_{ijkm_t})\ln(\frac{F_{m_t}}{F_{m_{t-1}}}) + \sum_i\sum_j\sum_k\sum_m L(w_{ijkm_{t-1}}, w_{ijkm_t})\ln(\frac{I_{k_t}}{I_{k_{t-1}}}) \\ &+ \sum_i\sum_j\sum_k\sum_m L(w_{ijkm_{t-1}}, w_{ijkm_t})\ln(\frac{S_{k_t}}{S_{k_{t-1}}}) + \sum_i\sum_j\sum_k\sum_m L(w_{ijkm_{t-1}}, w_{ijkm_t})\ln(\frac{S_{j_t}}{S_{j_{t-1}}}) \\ &+ \sum_i\sum_j\sum_k\sum_m L(w_{ijkm_{t-1}}, w_{ijkm_t})\ln(\frac{S_{i_t}}{S_{i_{t-1}}}) = \Delta I_{fls} + \Delta I_{tec} + \Delta I_{strss} + \Delta I_{strs} + \Delta I_{stri}\end{aligned} \quad (2)$$

Where $w_{ijkm} = F_m \cdot I_k \cdot S_k \cdot S_j \cdot S_i$, and $L(w_{ijkm_{t-1}}, w_{ijkm_t})$ is a weighting scheme called logarithmic mean weight: $L(w_{ijkm_{t-1}}, w_{ijkm_t}) = (w_{ijkm_t} - w_{ijkm_{t-1}})/\ln(w_{ijkm_t}/w_{ijkm_{t-1}})$. ΔI_{tot}, ΔI_{fls}, ΔI_{tec}, ΔI_{strss}, ΔI_{strs}, and ΔI_{stri} are aggregate intensity change, intensity changes due to fuel substitution, technological change, and structural shift at three levels (34 sub-sectors, 8 sectors and 3 industries) of sectoral disaggregation respectively. We apply this detailed model to a dataset covering the period of 1994-2003.

Because consistent data at the level of sub-sectors is not easily available for the period from 1980 to 1993 (See next section for more details) we conduct a separate decomposition in order to examine the patterns of the structural effects over the longer period from 1980 to 2003. This decomposition only uses two levels of sectoral disaggregation (3 industries and 6 sectors) and does not separately account for interfuel substitution. This simplified decomposition is given by:

$$\Delta I_{tot} = \sum_i \sum_j L(w_{ij_{t-1}}, w_{ij_t}) \ln(\frac{I_{j_t}}{I_{j_{t-1}}}) + \sum_i \sum_j L(w_{ij_{t-1}}, w_{ij_t}) \ln(\frac{S_{j_t}}{S_{j_{t-1}}})$$

$$+ \sum_i \sum_j L(w_{ij_{t-1}}, w_{ij_t}) \ln(\frac{S_{i_t}}{S_{i_{t-1}}}) = \Delta I_{tec} + \Delta I_{strs} + \Delta I_{stri} \quad (3)$$

Equation (2) and (3) are referred to as the complete decomposition and the simplified decomposition henceforward.

Data

We compiled data from various issues of the China Statistical Yearbook (CSY) and China Energy Statistical Yearbook (CESY). The energy data and GDP data are in grams of standard coal equivalent (GSCE) and RMB Yuan respectively. The whole economy is divided into three industries: the primary, secondary, and tertiary industries. The primary industry includes one sector – "Farming, Forestry, Animal Husbandry, Fishery and Water Conservancy" (FFAFW). Secondary industry is disaggregated into four sectors – "Mining", "Manufacturing", "Electric Power, Gas and Water" (EGW), and "Construction". Tertiary industry includes three sectors - "Transportation, Storage, Post and Telecommunication Services" (TSPTS), "Wholesale, Retail Trade and Catering Services" (WRTCS), and "Residential Consumption and Others" (Households). The third and finest level of disaggregation is within secondary industry sectors of "Mining", "Manufacturing", and EGW which are further divided into 6, 20, and 3 sub-sectors respectively. The dataset with three levels of disaggregation (3 industries, 8 sectors and 34 sub-sectors) covers the period of 1994-2003. The second set of data covers the longer period from 1980 to 2003; however, we only disaggregate the economy into two levels for this longer period analysis: three industries (primary, secondary and tertiary) and six sectors (FFAFW, Industry, Construction, TSPTS, WRTCS, and Households). This cruder disaggregation is used because we do not have energy consumption data at a finer level of disaggregation for the period 1980-1993.

Ideally, energy intensity should be measured by energy consumption per unit of gross output rather than value added. But, in order to have consistent aggregation at the various sectoral levels, summation of the output at a lower level of aggregation must equal the output at a higher level of aggregation. The double counting problem inherent in the gross output measure fails to satisfy this requirement. To make aggregation possible and consistent we use value added. Value added for the top two levels of aggregation (industry and sector) are available from various issues of CSY. However, measurement of value added at the level of the sub-sectors within secondary industry sectors needs some clarification. China's secondary industry was categorized into 40 sub-sectors in 1984 for the first time. Also village-run secondary industries were included in the FFAFW sector before 1984 and moved in 1984 into the totals for secondary industry. In 1994, amendments were made to the industrial categorization of 1984. Although the whole of secondary industry still has 40 sub-sectors,[10] there are some minor changes in the coverage of each sub-sector. Moreover, before 1998, value added in each sub-sector were collected and reported from all independent accounting units at or above the township level. From 1998 onwards, the data are reported from all state-owned industrial enterprises plus non-state-owned industrial enterprises with annual sales revenue of over 5 million RMB Yuan.[11] Because of these different sampling methods, changes between 1997 and 1998 are unreliable but the decomposition results within each of the 1994-1997 and 1998-2003 periods individually are totally valid.

Moreover, since value added at the sub-sector level is compiled and reported from a sample of enterprises that satisfy the criteria described previously, the sum of this value added does not equal the GDP reported for the MME sector[12] in the national accounts which, together with the "Construction" sector, constitute the secondary industry of our analysis. Between 1994 and 2003, the ratio of the sum of the value added in the sample enterprises to the GDP data of the MME sector in the national accounts varied from 58% (1998) to 79% (2003) as shown in Figure 5. To create a consistent sectoral aggregation, value added in each sub-sector was adjusted upwards using the assumption that the shares of total value added of the

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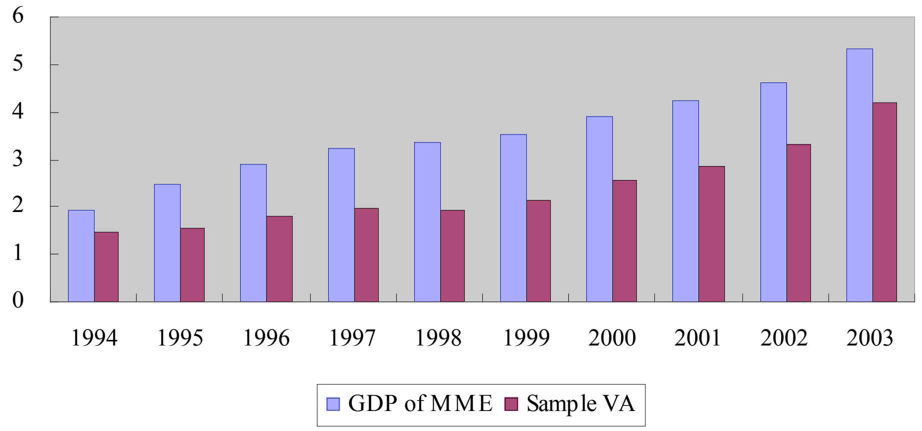
[10] Some sub-sectors are combined to make the 34-sub-sector disaggregation in this study.

[11] This change in sampling criteria does not result in a consistently larger or smaller percentage of economic activity being sampled.

[12] In the national account, the secondary industry is classified into two sectors: "Industry" and "Construction". The "Industry" sector is equivalent to "Mining", "Manufacturing" and "Electric Power, Gas and Water" (EGW). This sector is referred to as MME sector henceforward instead of "Industry" sector to avoid confusion with the classification at industry level. The finest classification is actually within this MME sector.

subsectors in the sample is equal to the shares of total value added of the subsectors in the entirety of the industry.

Figure 5 - GDP of MME and Sample VA (1994-2003)



1) Data Source: CSY 2005.
2) GDP and VA are in trillion RMB Yuan at current prices.
3) MME – Mining, Manufacturing, & Electric Power, Gas and Water, which is equivalent to the “Industry” sector in the national account.

GDP data are converted to constant prices in 2000. Since the price indices are only available at the levels of industries and sectors, value added at constant prices at the level of sub-sectors is derived using the price indices of the associated sectors, assuming that price indices of all the sub-sectors within each sector are the same as that of the sector.

Energy consumption in this study refers to commercial energy only[13]. Due to data limitations, final energy consumption is used in the full decomposition and total consumption (final consumption and losses in electricity generation) is used in the simplified decomposition. Electricity is converted to coal equivalent based on the quantity of coal needed to produce the electricity at the average coal input per kilowatt hour for thermal power generation in the relevant year, instead of the calorific value of the electricity itself.

[13] Biomass used to account for a substantial share of China’s total energy consumption, but its share reduced rapidly in recent years due to increases in other energy carriers. Biomass consumption data were only available at the economy wide level so that our study focuses on commercial energy only. The inter-fuel substitution results do not, therefore, include the effects of substitution between biomass and commercial energy.

Results and Discussion

In this section, we apply the proposed models (Equations (1) and (2)) to two sets of data and explore the contributions of the various effects to the changes in China's commercial energy intensity.

We first conduct the complete decomposition over the period from 1994 to 2003. Tables 1 and 2 and Figure 6 show the decomposition results. The change in the mix of industries ($\triangle Istri$) increases the energy intensity as we expected. The accumulated (period-wise) effect is an increase of 15.17 GSCE/constant RMB, which accounts for 21.86% of the total intensity change ($\triangle Itot$) in absolute value. The accumulated structural effect at the sub-sector level ($\triangle Istrss$) decreases energy intensity, accounting for 15.56% of the accumulated total energy intensity decrease ($\triangle Itot$). Most of the contribution occurred over the period of 1996-1998. This result is consistent with Fisher-Vanden *et al.* (2003)'s study in which they found that with finer sectoral disaggregation, the structural effect becomes very significant over these few years. But the structural shift among sectors ($\triangle Istrs$) plays a very minor role. This effect increases energy intensity in most years except 1995 and 1998, which results in an accumulated increase of 2.97 GSCE/constant RMB. Similarly, despite the major fluctuations in 1998 and 1999 the accumulated effect of the inter-fuel substitution ($\triangle Ifls$) is almost neutral over the period from 1994 to 2003.

Our results also show that technological change ($\triangle Itec$) plays the dominant role in decreasing energy intensity, which is consistent with the conclusions of previous empirical studies. It is noteworthy that the decrease in overall energy intensity ($\triangle Itot$) slowed down after 2000 and the decreasing trend was even reversed in 2003 (Table 1 & 2). Although structural effects explained a relatively larger share of the total changes after 2000 than previous years (Table 2 and Figure 5), they are not the main causal factor of the slowdown and the reversal. These structural effects are small and relatively stable over the entire period (Table 1). Thus, the increase in the explanatory power of the structural effects is not a result of an increase in the absolute value of the structural effects, but one of a decrease in the technological effects. It is

Table 1 - Complete Decomposition of Energy Intensity Change (GSCE/RMB) (1994-2003)

	△*Ifls*	△*Itec*	△*Istrss*	△*Istrs*	△*Istri*	△*Itot*
1994-1995	0.0435	-10.5178	0.5836	-1.6585	3.7077	-7.8415
1995-1996	0.0014	-4.9637	-5.6237	1.8380	2.6356	-6.1124
1996-1997	0.0331	-15.5602	-3.9465	1.2051	1.8057	-16.4627
1997-1998	2.4388	-11.2172	-3.5776	-0.6454	1.2626	-11.7389
1998-1999	-2.2774	-18.7917	0.3455	0.5093	0.9628	-19.2515
1999-2000	-0.6350	-11.7981	0.0838	0.5126	1.1751	-10.6617
2000-2001	0.3997	-6.8365	0.0137	0.4991	0.8250	-5.0991
2001-2002	0.0000	-0.8628	-0.9641	0.2623	1.0505	-0.5140
2002-2003	0.0054	3.8179	2.2913	0.4489	1.7429	8.3065
1994-2003	0.0094	-76.7301	-10.7939	2.9714	15.1680	-69.3752

1) Data Source: CSY 2005; CESY, various issues; authors' calculation (constant prices).

2) Negative values indicate decreasing energy intensity.

3) $\triangle I_{fl}$, $\triangle I_{tec}$, $\triangle I_{strss}$, $\triangle I_{strs}$, $\triangle I_{stri}$ and $\triangle I_{tot}$ are effects of the inter-fuel substitution, technological change, structural shift at the levels sub-sectors, sectors and industries, and aggregate intensity change respectively.

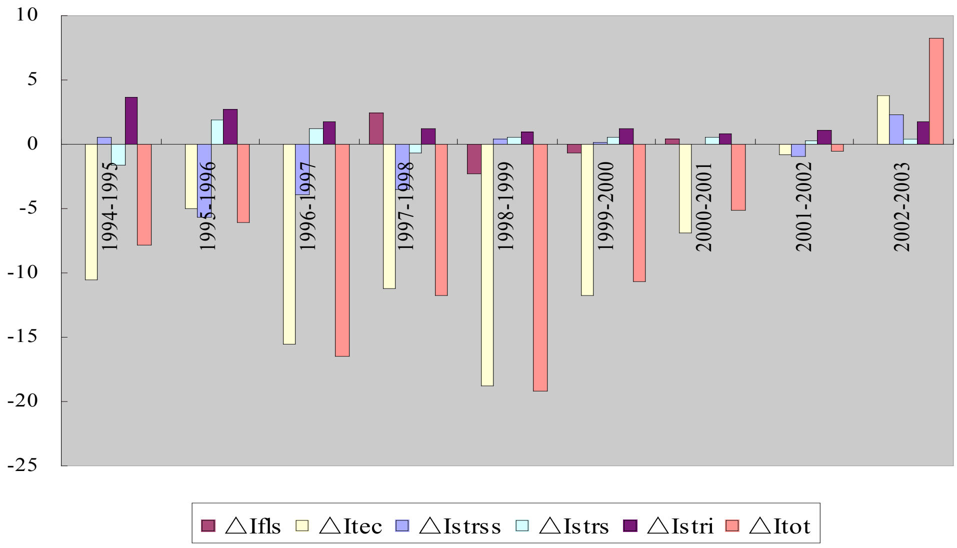
Table 2 - Decomposition of Energy Intensity Change in Percentage (% of △Itot) (1994-2003)

	△*Ifls*	△*Itec*	△*Istrss*	△*Istrs*	△*Istri*	△*Itot*
1995-1994	-0.55%	134.13%	-7.44%	21.15%	-47.28%	100.00%
1996-1995	-0.02%	81.21%	92.00%	-30.07%	-43.12%	100.00%
1997-1996	-0.20%	94.52%	23.97%	-7.32%	-10.97%	100.00%
1998-1997	-20.78%	95.56%	30.48%	5.50%	-10.76%	100.00%
1999-1998	11.83%	97.61%	-1.79%	-2.65%	-5.00%	100.00%
2000-1999	5.96%	110.66%	-0.79%	-4.81%	-11.02%	100.00%
2001-2000	-7.84%	134.07%	-0.27%	-9.79%	-16.18%	100.00%
2002-2001	0.00%	167.84%	187.54%	-51.03%	-204.36%	100.00%
2003-2002	0.07%	45.96%	27.58%	5.40%	20.98%	100.00%
2003-1994	-0.01%	110.60%	15.56%	-4.28%	-21.86%	100.00%

1) Negative numbers represent that the associated effect is in the opposite direction of the total intensity change. For example, if $\triangle I_{tot}$ in Table 1 is positive (increasing intensity), a negative number here indicates an effect that decreases the energy intensity.

2) Data Source: CSY 2005; CESY, various issues; authors' calculation.

Figure 6 - Complete Decomposition of Energy Intensity Change (GSCE/RMB) (1994-2003)



1) Data Source: CSY2005; CESY, various issues; authors' calculation (constant prices).

2) $\triangle I_{fl}$, $\triangle I_{tec}$, $\triangle I_{strss}$, $\triangle I_{strs}$, $\triangle I_{stri}$ and $\triangle I_{tot}$ are the effects of inter-fuel substitution, technological change, structural shift at the levels sub-sectors, sectors and industries, and aggregate intensity change respectively.

clearly shown in Table 1 that the shrinkage and reversal of the technological effect has been the major factor causing the slowdown of the intensity decrease and its reversal since 2000. In other words, the technological effect dominates all the changes in energy intensity: dramatic decrease, slow-down of the decrease, and reversal. Decomposed technological effects[14] for all sub-sectors also indicate that the two sub-sectors of "Raw Chemical Materials and Chemical Products" and "Households" made the most contribution to the accumulated technological effects during 1994-2000. Of the 72.85 (GSCE/constant RMB) accumulated reduction in real energy intensity for all sub-sectors, these two sub-sectors account for 37.85 (GSCE/current RMB), a contribution of 51.96%. Table 3 lists the top 10 contributing sub-sectors to the accumulated technological effect during 1994-2000. As the table shows, all of the ten sub-sectors have experienced a substantial decline in energy intensity and some of them are among the most energy intensive sub-sectors of the economy. These ten sub-sectors contributed 94.43% of the total accumulated technological effect over this period. It is noteworthy that China's households sector makes such a substantial

[14] More details are available on request.

contribution to the accumulated reduction in energy intensity due to the technological effect while Judson *et al*. (1999) found that the technological change in the U.S. households sector is energy using. Energy intensity in China's households sector has reduced from 196.31 GSCE/RMB in 1994 to 120.1 GSCE/RMB in 2000 - a very significant reduction. A deeper look at China's households sector reveals that the explanation may lie in the shift in fuel mix. In 1994, coal accounted for 53.74% of total energy consumption in this sector, while in 2000 it accounted for just 30.71%. The shares of other energy carriers (petroleum, natural gas, electricity etc) increase consequently, with electricity being the major substitute. The significant reduction in coal consumption may partially explain the substantial energy intensity decline in this sector given the low energy quality of coal. Additionally, other factors may also contribute to the decline in energy intensity, such as efficiency gains in cooking stoves, preference of energy-saving appliances, and a switch from individual heating system to group or district heating systems. However, such substantial decline in energy intensity will not last long for two reasons: 1) there is limited room for the households sector to further substitute coal with other fuels; 2) more and more energy-consuming gadgets will come to China's households as the living standard increases. Actually the reduction in energy intensity in household sector slowed down from 2000-2003, although the share of coal kept decreasing from 30.71% to 25.08%. Energy intensity in this sector only reduced from 120.1 GSCE/RMB to 119.53 GSCE/RMB.

The following sub-sectors experienced intensity increase during the period 2001 – 2003 and account for much of the slowdown in the overall technological effect: "Raw Chemical Materials and Chemical Products", "Chemical Fibers", "Electric Power, Steam, and Hot Water Production & Supply", TSPTS and WRTCS. Although we do not have data for more recent years, there are reports that the energy intensity of GDP continued to increase in 2004[15]. The increase has raised considerable concern in national policy circles. The newly approved Five-Year Plan (2006-2010)[16] for the first time makes reduction in energy intensity a national development objective. The objective states that energy intensity will be reduced

[15] http://house.focus.cn/news/2006-03-17/190621.html
[16] http://news.xinhuanet.com/politics/2005-10/18/content_3640318.htm

by 20% in 2010 compared with the 2005 level, which is equivalent to an annual 4.4% reduction. This seems reasonable compared with the annual 5.2% rate of decline in energy intensity over the period of 1980-2000; however, it is a rather difficult task given the recent trend of increasing intensity since 2000. Without innovative measures in technology, management, as well as engagement in legislation, policy and enforcement, it might be difficult to accomplish the task.

Table 3 - Top 10 Contributing Sub-sectors to Total Technological Effect

Top 10 Sub-sectors	Energy Intensity		Technological Effect	
	1994	2000	1994-2000	% of Total
Raw Chemical Materials & Chemical Products	1422.24	420.46	-23.35	32.05%
Residential Consumption & Others (Households)	196.31	120.10	-14.50	19.91%
Machinery, Electric Equipment, Electronic Manufacturing	139.34	64.11	-6.97	9.56%
Nonmetal Mineral Products	913.76	663.81	-5.47	7.51%
Food, Beverage, & Tobacco Processing	158.60	73.15	-4.24	5.82%
Electric Power, Steam, Hot Water Production & Supply	279.13	163.13	-4.20	5.77%
Petroleum & Natural Gas Extraction	245.66	101.54	-3.66	5.02%
Coal Mining and Dressing	703.12	313.02	-2.51	3.44%
Papermaking and Paper Products	525.17	364.35	-2.23	3.06%
Medical and Pharmaceutical Products	288.43	83.26	-1.67	2.29%

1) Data Source: CSY 2005; CESY, various issues; authors' calculation.
2) Energy intensity in GSCE/RMB at constant prices.

We conduct the simplified decomposition for the period 1980-2003 using constant prices. For ease of presentation, we summarize the decomposition results in 5-year periods in Table 4 & 5 and Figure 7 except for the periods 1985-1990 and 2000-2003 when energy intensity was stagnant or increasing which we look at in more detail. As discussed in Section 1 of this article, the pattern of structural change in the 1980s was different to that which followed it. In the 1980s the shift is mainly from primary industry to tertiary industry while from 1991 to 2003 the shift is mainly from primary industry to secondary industry. Despite this difference, the shifts are both from a less energy-intensive industry (primary) to a more energy-intensive industry (tertiary and secondary), which will tend to increase overall energy intensity. The decomposition results show that the structural effect at the industry level ($\triangle I_{stri}$) has consistently increased the energy intensity. Our finding of a structural effect at the industry level that increases overall energy intensity does not indicate inconsistency with previous

Table 4 - Simplified Decomposition of Energy Intensity Change (GSCE/RMB) (1980-2003)

	△*Itec*	△*Istrs*	△*Istri*	△*Itot*
1985-1980	-98.85	-8.49	4.42	-102.92
1988-1985	-44.74	-0.92	18.50	-27.16
1989-1988	-1.20	7.06	0.12	5.98
1990-1989	-4.49	2.04	-2.04	-4.48
1995-1990	-103.54	4.63	37.59	-61.32
2000-1995	-82.56	3.92	8.04	-70.60
2003-2000	-0.31	0.37	4.14	4.20
1980-2003	-336.06	8.96	70.78	-256.31

1) Data Source: CSY, CESY, various issues; authors' calculation (constant prices).

2) Negative values indicate decreasing energy intensity.

3) $\triangle I_{tec}$, $\triangle I_{strs}$, $\triangle I_{stri}$ and $\triangle I_{tot}$ are effects of the technological change, structural shift at the levels sectors and industries, and aggregate intensity change respectively.

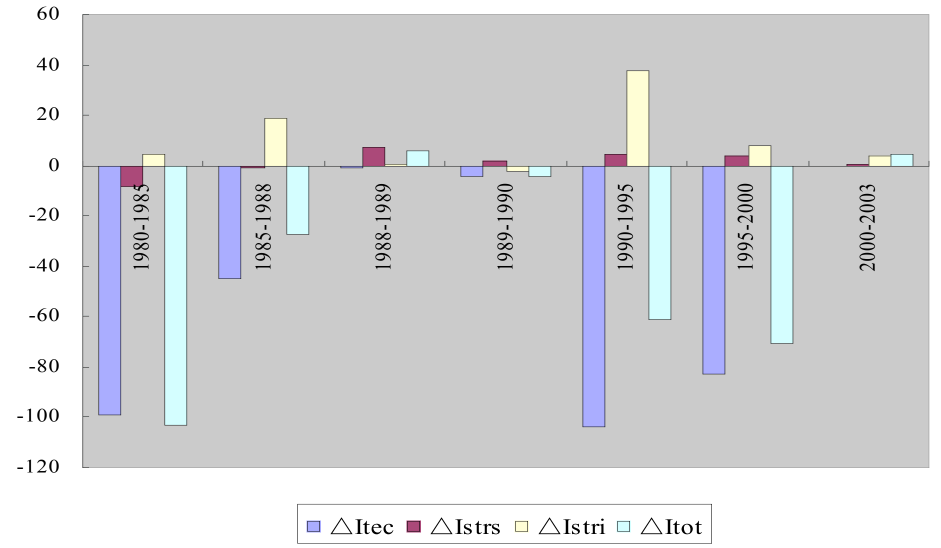
Table 5 - Simplified Decomposition of Energy Intensity Change (% of △Itot) (1980-2003)

	△*Itec*	△*Istrs*	△*Istri*	△*Itot*
1980-1985	96.04%	8.25%	-4.29%	100.00%
1985-1988	164.76%	3.38%	-68.14%	100.00%
1988-1989	-20.11%	118.10%	2.01%	100.00%
1989-1990	100.04%	-45.54%	45.50%	100.00%
1990-1995	168.84%	-7.54%	-61.30%	100.00%
1995-2000	116.93%	-5.55%	-11.38%	100.00%
2000-2003	-7.45%	8.91%	98.54%	100.00%
1980-2003	131.11%	-3.50%	-27.62%	100.00%

1) Data Sources: CSY, CESY, various issues; authors' calculation.

2) Negative numbers represent that the associated effect is in the opposite direction of the total intensity change. For example, if $\triangle I_{tot}$ in Table 4 is positive (increasing intensity), a negative number here indicates an effect that decreases the energy intensity.

Figure 7 - Simplified Decomposition of Energy Intensity Change (GSCE/RMB) (1980-2003)



1) Data Sources: CSY, CESY, various issues; authors' calculation (constant prices).

2) $\triangle I_{tec}$, $\triangle I_{strs}$, $\triangle I_{stri}$ and $\triangle I_{tot}$ are effects of the technological change, structural shift at the levels sectors and industries, and aggregate intensity change respectively.

empirical studies that found structural effects that decrease energy intensity. Those studies were conducted: either: 1) over a shorter period as periodwise analyses which are sensitive to the selection of the base year and ending year (A time series analysis may not find the structural effect consistently decreasing energy intensity); or 2) at a finer sector level that is similar to the finest sector level used in our complete decomposition in which we also found a structural effect that decreases the energy intensity. Actually, Fisher-Vanden *et al.* (2003) also found a structural effect that increases energy intensity when a sector level comparable to our industry level is used. The only exceptional study is Garbaccio *et al.* (1999) which found that structural change actually increased energy between 1987 and 1992 even if the economy is disaggregated into 29 sectors.

The structural effect at the sector level ($\triangle I_{strs}$) also increases the overall energy intensity (except for the first 5-year period) but to a lesser degree. Our results further confirm the dominant role of the technological effect in explaining the changes of overall energy intensity. It not only explains most of the decline in China's energy intensity over the entire period of economic reform, the slowdown and reversal of the technological effect also becomes the major reason for stagnancy in the two periods: 1988-1990 and 2000-2003. Decomposed technological effects at the sector level indicate that MME and Households make the greatest contribution to the reduction in real energy intensity at sectoral level during 1980-2000. These two sectors jointly explain 90.78% of the total accumulated technological effect. Our decomposition results show that stagnancy in these two sectors in terms of decreasing energy intensity is also the main reason for the slowdown and reversal during the two stagnant periods: 1988-1990 and 2001-2003.

Conclusions

Since the onset of economic reform in the late 1970s, China has experienced a dramatic decline in the energy intensity of economic output. Much research has been conducted to examine the causes of this decline. While most studies consider the decline of real energy intensity within sectors as the dominant contributor, there is disagreement on the role of structural effects as well as the effect of sectoral disaggregation on the measured contribution of structural change. Based on a consistent set of data (1994-2003), we examined the structural effects at three levels of sectoral disaggregation within one model using the LMDI method so that we could measure the contributions of structural change at different levels of aggregation. We also separated the inter-fuel substitution effect from the general technological effect, which has not been done in previous studies of energy intensity in China. Finally, we also investigated the slow down and reversal in the decline in energy intensity since 2000. With a second set of data (1980-2003), we conducted a simplified decomposition to identify the pattern of structural change over a longer period.

Our results confirm the dominant role of technological change over the entire period of 1980-2003. Continuous improvement in the real energy intensity within sub-sectors contributes the most to the overall energy intensity decline up till 2000. The reduction in the rate of improvement also becomes the major reason for the new trend of overall energy intensity since 2000. Although the pattern of structural change at the industry level is different in the 1980s and in the following period, the effects at both the industry and sector levels are similar contributing an increase the energy intensity, *ceteris paribus*. However, structural shift at the sub-sector level decreased energy intensity during the period 1994-2003. Inter-fuel substitution is found to contribute little to the changes in the energy intensity. As far as the technological effect and the structural effect are concerned, our results are consistent with previous empirical studies in that the technological effect plays a dominant role while the structural effect plays a minor role. In addition, we found that the technological effect not only explains most of the decline in China's energy intensity over the entire period of economic reform, the slowdown and reversal of the technological effect also becomes the major reason for stagnancy during 1988-1990 and the new trend since 2000. Moreover, our model identifies the direction and magnitude of the structural effect at different levels of sector disaggregation.

A couple of caveats are appropriate. First, to make sectoral aggregation consistent, we reconstructed the value added data for the sub-sectors of secondary industry from the sample statistics, assuming that the data structure of the sample statistics is representative of the population. Second, China's National Statistical Bureau has recently completed a comprehensive economic survey that includes all enterprises[17]. This is different from the current annual statistics derived from the sample survey. The new survey shows that the existing annual statistics omit a significant proportion of GDP and a majority of the ignored value-added is in tertiary industry. As a result, actual energy intensity is lower than previous estimates. This could affect decomposition results such as those presented in this paper. However, this new survey is only available for a single year and, therefore, cannot be used in a decomposition directly. Examination of these issues would provide topics for further research.

[17] http://www.stats.gov.cn/zgjjpc/, (Chinese)

Appendix- Index Decomposition Analysis (IDA)

There are two main classes of parametric decomposition methods based on the Laspeyres (or the Paasche) index, and the Divisia index. Methods of the first type[18] include basic Laspeyres index, Paasche index, Fisher ideal index, Shapley index and Marshall-Edgeworth index etc. They are all based on the basic Laspeyres and Paasche indices. For instance, the Fisher ideal index is actually a geometric average of the Laspeyres and the Paasche indices, while the Marshall-Edgeworth index is an arithmetic average of the two. The second type[19] includes the arithmetic mean Divisia index (AMDI) and the logarithmic mean Divisia index (LMDI). Ang (2004) provides a detailed classification of the various methods and proposed the LMDI method as the preferred method. LMDI has a few distinct advantages. Some other decomposition methods can result in large unexplained residuals, while LMDI is not path-dependent and leaves no unexplained residual, which makes for a perfect decomposition. LMDI can also handle zero values, which are common in real datasets.

Energy intensity is usually decomposed into the effects of industrial structural change and technological change. Since the technological effect is measured using sectoral energy intensity, as the level of sectoral disaggregation becomes finer, the share of total change accounted for by structural change will increase (Sinton and Levine, 1994; Fisher-Vanden *et al*., 2003). Our model is extended to consider the effects of multiple levels of disaggregation. Instead of examining the effects of different levels of disaggregation on the results of the decomposition separately, we study these effects in one model so that the contributions of the structural effects at each level can be identified. Also, the model includes the effect of inter-fuel substitution, which has not been examined before in the literature on China's energy intensity. Such a model can be specified as:

[18] Examples of empirical applications are Reitler *et al*. (1987) and Howarth *et al*. (1991).

[19] Empirical applications and developments of Divisia methods include Huang (1993), Choi *et al*. (1995), Wu *et al*. (in press), just to name a few.

$$E = \sum_i \sum_j \sum_k \sum_m \frac{E_{ijkm}}{E_{ijk}} \cdot \frac{E_{ijk}}{O_{ijk}} \cdot \frac{O_{ijk}}{O_{ij}} \cdot \frac{O_{ij}}{O_i} \cdot \frac{O_i}{O} \cdot O \tag{A1}$$

E - Total energy consumption;

E_{ijkm} - Consumption of fuel *m* in the *ijk*-th sub-sector;

E_{ijk} - Total energy consumption in the *ijk*-th sub-sector;

O_{ijk}, O_{ij}, O_i - Economic output in the *ijk*-th sub-sector, *ij*-th sector, and *i*-th industry;

O - Total economic output;

i, *j*, and *k* denote the industry, sector and sub-sector.

Dividing both sides of Equation (A1) *O* yields:

$$I = \sum_i \sum_j \sum_k \sum_m F_m \cdot I_k \cdot S_k \cdot S_j \cdot S_i \tag{A2}$$

I - Overall energy intensity;

F_m - Share of fuel *m* in total energy consumption of the *ijk*-th sub-sector;

I_k - Energy intensity in the *ijk*-th sub-sector;

S_k - Output share of the *ijk*-th sub-sector in the *ij*-th sector;

S_j - Output share of the *ij*-th sector in the *i*-th industry;

S_i - Output share of the *i*-th industry in the overall economy.

Differentiating Equation (A2) with respect to time yields:

$$\begin{aligned} \dot{I} = {} & \sum_i \sum_j \sum_k \sum_m \dot{F}_m \cdot I_k \cdot S_k \cdot S_j \cdot S_i + \sum_i \sum_j \sum_k \sum_m F_m \cdot \dot{I}_k \cdot S_k \cdot S_j \cdot S_i \\ & + \sum_i \sum_j \sum_k \sum_m F_m \cdot I_k \cdot \dot{S}_k \cdot S_j \cdot S_i + \sum_i \sum_j \sum_k \sum_m F_m \cdot I_k \cdot S_k \cdot \dot{S}_j \cdot S_i \\ & + \sum_i \sum_j \sum_k \sum_m F_m \cdot I_k \cdot S_k \cdot S_j \cdot \dot{S}_i \end{aligned} \tag{A3}$$

The right-hand side of Equation (A3) can be written in terms of growth rates:

$$\dot{I} = \sum_i \sum_j \sum_k \sum_m g_{Fm} \cdot w_{ijkm} + \sum_i \sum_j \sum_k \sum_m g_{Ik} \cdot w_{ijkm} + \sum_i \sum_j \sum_k \sum_m g_{Sk} \cdot w_{ijkm} + \sum_i \sum_j \sum_k \sum_m g_{Sj} \cdot w_{ijkm} + \sum_i \sum_j \sum_k \sum_m g_{Si} \cdot w_{ijkm} \quad \text{(A4)}$$

Where $g_{Fm}, g_{Ik}, g_{Sk}, g_{Sj}$ and g_{Si} are growth rates of the fuel share, sector energy intensity and sector output share at different levels of disaggregation, and, w_{ijkm} is the weight, with $w_{ijkm} = F_m \cdot I_k \cdot S_k \cdot S_j \cdot S_i$. The next step is to integrate both sides of Equation (A4) with respect to time:

$$\Delta I = \int_{t-1}^{t} \sum_i \sum_j \sum_k \sum_m g_{Fm} \cdot w_{ijkm} \cdot dt + \int_{t-1}^{t} \sum_i \sum_j \sum_k \sum_m g_{Ik} \cdot w_{ijkm} \cdot dt + \int_{t-1}^{t} \sum_i \sum_j \sum_k \sum_m g_{Sk} \cdot w_{ijkm} \cdot dt + \int_{t-1}^{t} \sum_i \sum_j \sum_k \sum_m g_{Sj} \cdot w_{ijkm} \cdot dt + \int_{t-1}^{t} \sum_i \sum_j \sum_k \sum_m g_{Si} \cdot w_{ijkm} \cdot dt \quad \text{(A5)}$$

To solve the integrals, some kind of weight function is needed. Sato (1976) proposed to use the logarithmic mean as the weight function based on its desirable properties which match those that weight functions are expected to have:

$$L(x, y) = (y - x) / \ln(y / x) \quad \text{(A6)}$$

Where both x and y are positive numbers and $x \neq y$, with L(x, x)=x which is the limit as $y \to x$. In our case with $w_{ijkm_{t-1}}$ and w_{ijkm_t}, we have:

$$L(w_{ijkm_{t-1}}, w_{ijkm_t}) = (w_{ijkm_t} - w_{ijkm_{t-1}}) / \ln(w_{ijkm_t} / w_{ijkm_{t-1}}) \quad \text{(A7)}$$

So, under the logarithmic mean weight scheme, Equation (A5) becomes:

$$\Delta I_{tot} = \sum_i \sum_j \sum_k \sum_m L(w_{ijkm_{t-1}}, w_{ijkm_t}) \ln(\frac{F_{m_t}}{F_{m_{t-1}}}) + \sum_i \sum_j \sum_k \sum_m L(w_{ijkm_{t-1}}, w_{ijkm_t}) \ln(\frac{I_{k_t}}{I_{k_{t-1}}})$$

$$+ \sum_i \sum_j \sum_k \sum_m L(w_{ijkm_{t-1}}, w_{ijkm_t}) \ln(\frac{S_{k_t}}{S_{k_{t-1}}}) + \sum_i \sum_j \sum_k \sum_m L(w_{ijkm_{t-1}}, w_{ijkm_t}) \ln(\frac{S_{j_t}}{S_{j_{t-1}}}) \quad \text{(A8)}$$

$$+ \sum_i \sum_j \sum_k \sum_m L(w_{ijkm_{t-1}}, w_{ijkm_t}) \ln(\frac{S_{i_t}}{S_{i_{t-1}}}) = \Delta I_{fls} + \Delta I_{tec} + \Delta I_{strss} + \Delta I_{strs} + \Delta I_{stri}$$

This is the LMDI decomposition in additive form[20], with ΔI_{tot}, ΔI_{fls}, ΔI_{tec}, ΔI_{strss}, ΔI_{strs} and ΔI_{stri} representing the aggregate intensity change, intensity changes due to the fuel substitution, technological change and structural change at the levels of sub-sector, sector and industry respectively.

[20] See Ang *et al*. (1998) for more details about the additive LMDI

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