The World Economy

The World Economy (2011)
doi: 10.1111/j.1467-9701.2011.01370.x

The Abatement of Carbon Dioxide Intensity in China: Factors Decomposition and Policy Implications

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1. INTRODUCTION

TO control the emission of greenhouse gas, China decided to reduce the carbon dioxide (CO_2) emission per GDP (i.e. CO_2 intensity) by 40–45 per cent from 2005 to 2020. This is the first time that the Chinese government proposed the quantitative abatement target of CO_2 emission. Although it is only a relative target to reduce the emission per GDP rather the absolute emission level, some researchers still argue that it is too high to be achieved. This study aims to find out the factors driving the decline of CO_2 intensity in China between 1980 and 2008 using the decomposition technique. It will also derive corresponding policy suggestions from the decomposition that are necessary to complete the expected abatement of carbon intensity in 2020.

a. Absolute Carbon Dioxide Emission in China

Since China started the economic reform in 1978, shifting from central planning to market mechanism, its economic performance has been remarkable, with an average growth of GDP being 9.8 per cent per annum. However, it is well

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The author acknowledges the referees for their constructive comments. Thanks also go to Charlotte Chen who proofread the manuscript. The study is sponsored by Shanghai Leading Academic Disciplines Project (B101), Shanghai Philosophy and Social Science Project (2009BJB028), Project 985 at Fudan University, and MOE Projects of Humanities and Social Sciences at Universities (09YJA790046 and 2009JJD790011).

FIGURE 1
CO_2 Emission in China (1953–2008)

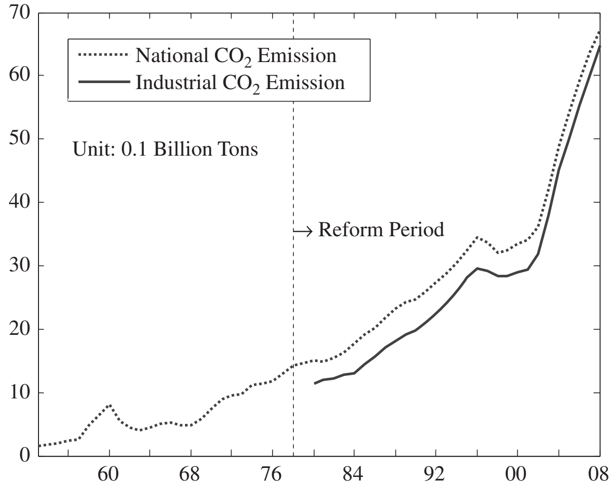
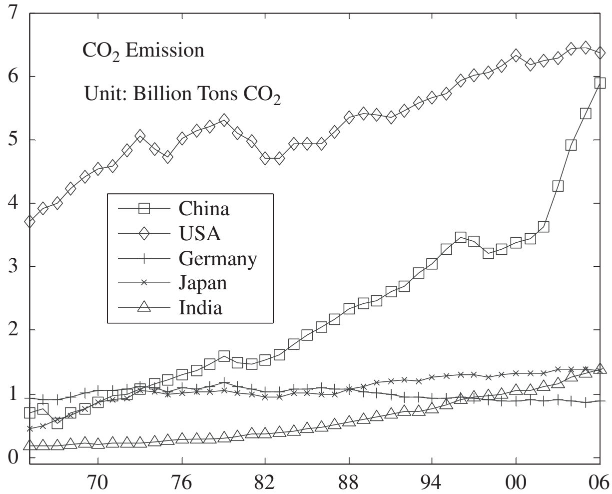


FIGURE 2
CO_2 Emission among Countries (1965–2006)



known that the economic growth in China is achieved through a high level of investment, energy consumption and waste emission, still extensive in nature. As shown in Figure 1, the national CO_2 emission in China has increased from 0.15 billion tons in 1953 to a peak of 3.5 billion tons in 1996. During the time, emission growth increases steadily with the only exception of the Great Leap Forward (1958–61). After 1996, CO_2 emission starts declining and, at some point, coming to a standstill, for 5–6 years. It then increases sharply to 6.7 billion tons in 2008.

By comparison with other countries, as shown in Figure 2, CO_2 emission in China is low in the 1960s and 1970s, similar to that in Germany and Japan, and then becomes higher and higher, exceeding Germany, Japan and India and approaching the same level of the USA. In fact, China has become the largest emitter of CO_2 in absolute terms in 2008 (CEACER, 2009).

Industrial CO_2 emission will be exemplified in the analysis of this research because industry is the main emitter, including the burning of fossil fuels and the manufacturing of cement, lime, iron and steel. As illustrated in Figure 1, during the reform period, industrial output accounts for only 40 per cent of national output but industrial CO_2 emission constitutes the majority of the total national CO_2 emission – the share being 84 per cent on average and over 90 per cent since the beginning of this century. It is clear that the industrialisation and urbanisation of China will carry on. As a result, energy- and emission-intensive industrial sectors such as chemicals products, cement, iron and steel will continue to play a fundamental role in the economy, both at present and in the foreseeable future. Therefore, a detailed analysis of carbon emission in industry is crucial for our understanding of emission abatement in China as a whole.

b. Carbon Dioxide Intensity in China

Although industrial CO_2 emission is growing in China (except for the period between 1997 and 2001), Figure 3 reveals that industrial CO_2 intensity basically keeps the decreasing trend during the whole reform period.[1] Industrial CO_2 intensity is defined as CO_2 emission per unit of industrial value-added, the reciprocal of which being carbon productivity. Thus, the decline of CO_2 intensity is equivalent to the improvement of carbon productivity, which implies that Chinese industrial CO_2 abatement is substantial and efficient during the reform period and the industrialisation produces low carbonisation in China.

Because CO_2 emission mainly results from the combustion of fossil fuels, the abatement of CO_2 is closely related to the consumption of fossil energy. In response to the shortage of energy, the Chinese government formulated an energy-saving policy in 1980, coupled with the fast development of light industry represented by TVEs, and an early decline in CO_2 intensity can be seen in Figure 3. The early reform of energy industry is implemented by encouraging the production of energy. The resulting rapid development of energy- and emission-intensive small enterprises such as the coal mines

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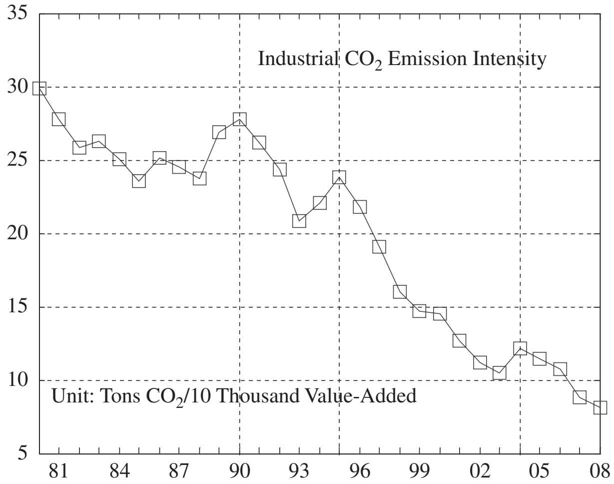
[1] Industrial CO_2 intensity in Figure 3 and industrial energy intensity in Figure 7 are weighted mean of respective intensity values of 38 sectors, the weight being the share of industrial gross output value of each sector.

FIGURE 3
Industrial CO_2 Intensity (1980–2008)



relieved the tight energy supply because of the long-term command economy but causes serious coal resources waste and environmental pollution. Thus, the CO_2 intensity begins to rise in the late 1980s, and the government has to clean up the coal market in 1989. It is not until the concept of sustainable development has become accepted worldwide in early 1990s that the consciousness of environmental protection takes root in China. The government once again emphasises the energy policy of 'saving and developing energy simultaneously' and turns to restrict the development of energy enterprises instead of encouragement of it in 1980s. This leads to the decline of CO_2 intensity again in 1990s, as shown in Figure 3, especially the largest reduction rate of CO_2 intensity (56 per cent) from 1995 to 2003, basically corresponding to state-owned enterprises' (SOEs) ownership reform by 'grasping the large and letting go of the small (Zhuada Fangxiao)'. The phenomenon of heavy industrialisation re-emerges after the turn of century. CO_2 intensity once rises to 12 tons per ten thousands value-added in 2004, but continues to decrease after 2004. This may be due to the implementation of new energy-saving and emission-abating policies such as the 'Outlines of China Medium and Long Term Energy Saving Plan 2004–20' enacted in 2004, the quantitative goal to save energy intensity by 20 per cent in the eleventh national Five-Year Plan proposed in 2006, the 'China National Plan for Coping with Climate Change' released in 2007 and so on. What is driving the decline of CO_2 intensity during the reform period? And what policy implications could be derived to conduct future abatement as scheduled?

2. LITERATURE REVIEW

a. Survey of Decomposition Techniques

The variables to be decomposed in the energy and environmental area are normally energy consumption, energy intensity, energy elasticity, carbon emission or carbon intensity in additive/multiplicative decomposing forms. The decomposition techniques normally include index decomposition, input and output structural decomposition, and nonparametric distance function–based decomposition. Ang and Zhang (2000) surveyed 124 articles published before 1999, in which 109 use index decomposition. The study by Ang et al. (2003) contains a complimentary survey of decomposition literature after 1999.

Index decomposition is represented by the Laspeyres index and Paasche index decomposition and extensively used in the 1970s and 1980s, see Doblin (1988), Park (1992) and Ang (1993), among others. The Laspeyres index approach is also extended to decompose the structural effect from the labour productivity, namely shift-share approach (Timmer and Szirmai, 2000). Boyd et al. (1987) propose another arithmetic mean Divisia index (AMDI) decomposition approach and use it to analyse the industrial energy consumption in the USA. Liu et al. (1992) further put forward the adaptive weighting Divisia index (AWDI) decomposition approach, which becomes popular in the 1990s, see Greening et al. (1998), Fisher-Vanden et al. (2004, 2006), Liu (2006) and Fan et al. (2007).

Before 1995, two imperfections of decomposition methods remained to be resolved are the existence of decomposition residual (largest residual term for Laspeyres index decomposition and lower residual for AWDI decomposition) and the calculation difficulty because of zero value. Then, Sun (1998) proposes a modified Laspeyres index decomposition approach to completely decompose the residual according to the principle of 'jointly created and equally distributed'. This approach is adopted to decompose the energy consumption in China by Zhang (2003) and Steenhof (2006), among others. Ang and Choi (1997) and Ang et al. (1998), respectively, put forward the modified Divisia decomposition approach in additive and multiplicative forms, namely logarithmic mean Divisia index (LMDI) decomposition method, and considerably improve two of the imperfections. As the Fisher index required, the ideal index should satisfy three tests (i.e. time-reversal, circular and factor reversal tests); and only modified Laspeyres decomposition method and LMDI method are able to pass these tests. That is because the modified Laspeyres method is normally used in additive decomposition to undertake incremental decomposition while the LMDI approach could take both the additive and the multiplicative decomposition forms, and the latter is more extensively used in application (Ang, 2004). Many studies choose LMDI approach to decompose the target variables (Wang et al., 2005; Wu et al., 2005; Liu et al., 2007). Other complete decomposition methods such as MRCI by Chung and Rhee (2001) and the Shapley method by Albrecht et al. (2002) are still new and hardly used in the literature.

Input and output structural decomposition makes use of comparative static technique to decompose the structural effect from energy consumption or carbon dioxide emission, which could be regarded as the detailed version of Laspeyres decomposition method (see surveys by Rose and Casler, 1996). Constrained by the availability of I-O tables, this approach can only undertake the periodwise analysis. Many studies use the structural decomposition methods, see Chang et al. (2008), Guan et al. (2008), Kahrl and Roland-Holst (2009), Weber (2009), Wood (2009) and Zhang (2010) for example. The third decomposing method in terms of nonparametric output distance function can decompose energy productivity into technical efficiency and technical progress, see Wang (2007).

b. Survey of Decomposition of CO_2 Emission or Intensity in China

The main literature on factors decomposition of Chinese CO_2 emission is reviewed as below. Wang et al. (2005) decompose Chinese CO_2 emission in 1957–2000 and find that the most important factor to reduce CO_2 emission is the reduction in energy intensity. The secondary factors are energy structure, investment to renewable energy and economic growth. Wu et al. (2005) completely decompose the CO_2 emission in China between 1985 and 1999 into structural effect, intensity effect and scale effect from three dimensions of industries, energy types and regions. They find that the decrease or stagnancy of Chinese CO_2 emission in 1996–99 is mainly because of the fall of energy intensity and the slowdown of labour productivity growth in industrial sectors, while the carbon abatement effect of structural adjustment is not obvious. Fan et al. (2007) analyse the influential factors of Chinese carbon intensity in 1980–2003 through decomposition and find that the decline of carbon intensity results mainly from the decline of energy intensity and then the change in energy structure. Chang et al. (2008) decompose the factors influencing Taiwan CO_2 emission in 1989–2004 and find the important factors are change in energy intensity and energy structure, export level and domestic final demand, among others. Zhang (2010) concludes that the structural variables in supply side measured by sectoral value-added share are important influential factors using structural decomposition. In 1992–2002, the rapid growth of manufacturing industry boosts the carbon emission, while in 2002–05, the share decline of carbon extensive sectors leads to the decrease in CO_2 emission.

3. METHODOLOGY AND DATA

a. LMDI Decomposition Technique

This study chooses the multiplicative logarithmic mean Divisia index (LMDI) method to decompose the overall industrial CO_2 intensity in China, symbolised by CI, from two dimensions of 38 industrial sectors and three types of primary energy (coal, oil and gas), represented by the subscripts i and j, respectively (that is, $i = 1, 2, \ldots, 38$; $j = 1, 2, 3$). The variables Y and C are defined to represent the overall industrial value-added and industrial CO_2 emission. The symbols of C_{ij}, E_{ij}, EC_{ij} and ES_{ij} represent CO_2 emission, energy consumption, CO_2 emission coefficient and consumption structure of energy types for ith industrial sector and jth energy type. The four variables, E_i, Y_i, EI_i and S_i, are energy consumption, industrial value-added, energy intensity and industrial structure (industrial value-added share) of ith sector. The overall industrial CO_2 intensity can be expressed equivalently as

$$\begin{aligned}\mathrm{CI} = \frac{C}{Y} = \frac{\sum_{i=1}^{38}\sum_{j=1}^{3} C_{ij}}{Y} &= \sum\sum\nolimits_{ij} \frac{C_{ij}}{E_{ij}} \cdot \frac{E_{ij}}{E_i} \cdot \frac{E_i}{Y_i} \cdot \frac{Y_i}{Y} \\ &= \sum\sum\nolimits_{ij} \mathrm{EC}_{ij} \cdot \mathrm{ES}_{ij} \cdot \mathrm{EI}_i \cdot S_i. \end{aligned} \tag{1}$$

Define the following symmetrical logarithmic weighting function:

$$L(a,b) = \begin{cases} \frac{a-b}{\ln a - \ln b} & a \neq b \\ a & a = b \end{cases}. \tag{2}$$

Therefore, the chain index of overall industrial CO_2 intensity can be decomposed into the following four influential terms using LMDI multiplicative approach,

$$\begin{aligned}\mathrm{RCI} = \mathrm{CI}^t/\mathrm{CI}^{t-1} &= \mathrm{RCI}_{\mathrm{ec}} \cdot \mathrm{RCI}_{\mathrm{es}} \cdot RCI_{\mathrm{s}} \cdot RCI_{\mathrm{ei}} \\ &= \exp\left[\sum\sum\nolimits_{ij} \frac{L\left(\mathrm{CI}_{ij}^t, \mathrm{CI}_{ij}^{t-1}\right)}{L\left(\mathrm{CI}^t, \mathrm{CI}^{t-1}\right)} \ln\left(\frac{\mathrm{ES}_{ij}^t}{\mathrm{ES}_{ij}^{t-1}}\right)\right] \\ &\cdot \exp\left[\sum\sum\nolimits_{ij} \frac{L\left(\mathrm{CI}_{ij}^t, \mathrm{CI}_{ij}^{t-1}\right)}{L\left(\mathrm{CI}^t, \mathrm{CI}^{t-1}\right)} \ln\left(\frac{S_i^t}{S_i^{t-1}}\right)\right] \\ &\cdot \exp\left[\sum\sum\nolimits_{ij} \frac{L\left(\mathrm{CI}_{ij}^t, \mathrm{CI}_{ij}^{t-1}\right)}{L\left(\mathrm{CI}^t, \mathrm{CI}^{t-1}\right)} \ln\left(\frac{\mathrm{EI}_i^t}{\mathrm{EI}_i^{t-1}}\right)\right], \end{aligned} \tag{3}$$

where t and $t-1$ are adjacent time points. RCI represents the overall development index of CO_2 intensity. $\mathrm{RCI}_{\mathrm{ec}}$, $\mathrm{RCI}_{\mathrm{es}}$, $\mathrm{RCI}_{\mathrm{s}}$ and $\mathrm{RCI}_{\mathrm{ei}}$ are decomposed four chain factor development indexes, that is, carbon emission coefficient index, energy structure index, industrial structure index and energy intensity index, respectively. Because carbon emission coefficient of three types of primary energy is assumed to be fixed when calculating CO_2 emission, the $\mathrm{RCI}_{\mathrm{ec}}$ term on the right side of equation (3) reduces to 1 in fact and the numbers of final decomposed terms are only three.

LMDI approach leads to perfect decomposition without the produce of residual term as proved by the following algebraic calculation and manipulation.

$$\begin{aligned}
&\mathrm{RCI}/(\mathrm{RCI}_{\mathrm{ec}} \cdot \mathrm{RCI}_{\mathrm{es}} \cdot \mathrm{RCI}_{\mathrm{s}} \cdot \mathrm{RCI}_{\mathrm{ei}}) \\
&= \frac{\mathrm{CI}^t}{\mathrm{CI}^{t-1}} / \exp\left[\sum\sum\nolimits_{ij} \frac{L\left(\mathrm{CI}_{ij}^t, \mathrm{CI}_{ij}^{t-1}\right)}{L\left(\mathrm{CI}^t, \mathrm{CI}^{t-1}\right)} \ln\left(\frac{\mathrm{EC}_{ij}^t \mathrm{ES}_{ij}^t S_i^t EI_i^t}{\mathrm{EC}_{ij}^{t-1} \mathrm{ES}_{ij}^{t-1} S_i^{t-1} \mathrm{EI}_i^{t-1}}\right)\right] \\
&= \frac{\mathrm{CI}^t}{\mathrm{CI}^{t-1}} / \exp\left[\sum\sum\nolimits_{ij} \frac{L\left(\mathrm{CI}_{ij}^t, \mathrm{CI}_{ij}^{t-1}\right)}{L\left(\mathrm{CI}^t, \mathrm{CI}^{t-1}\right)} \ln\left(\frac{\mathrm{CI}_{ij}^t}{\mathrm{CI}_{ij}^{t-1}}\right)\right] \\
&= \frac{\mathrm{CI}^t}{\mathrm{CI}^{t-1}} / \exp\left[\frac{\sum\sum_{ij}\left(\mathrm{CI}_{ij}^t - \mathrm{CI}_{ij}^{t-1}\right)}{L\left(\mathrm{CI}^t, \mathrm{CI}^{t-1}\right)}\right] \\
&= \frac{\mathrm{CI}^t}{\mathrm{CI}^{t-1}} / \exp\left[\frac{\mathrm{CI}^t - \mathrm{CI}^{t-1}}{L\left(\mathrm{CI}^t, \mathrm{CI}^{t-1}\right)}\right] = \frac{\mathrm{CI}^t}{\mathrm{CI}^{t-1}} / \exp\left[\ln\frac{\mathrm{CI}^t}{\mathrm{CI}^{t-1}}\right] = 1. \qquad (4)
\end{aligned}$$

b. Data

This study focuses on the two digital industrial sectors where we classify industrial sectors according to the new version of National Standard of Industrial Classification (GB/T4754) revised in 2002 in China. Data available for the period between 1980 and 2008 allow an analysis to be undertaken for 38 different industrial sectors, which belong to three categories: mining; manufacturing; and electric power, gas and water production and supply. The variables for the decomposition calculation are panel data of industrial value-added (100 million RMB at 1990 price levels), energy consumption (10,000 tons of coal equivalent, tce for short) and CO_2 emission (10,000 tons), in which the former two can be obtained directly from the corresponding statistical yearbooks but CO_2 emission cannot be obtained directly and needs to be estimated.[2]

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[2] All original data used in this study comes from publications of the National Bureau of Statistics of China – *China Statistical Yearbook*, *China Energy Statistical Yearbook*, *China Industry Economy Statistical Yearbook*, *China Compendium of Statistics 1949–2004*, *Statistical Review of World Energy*, and *China Urban Life and Price Yearbook*. See Chen (2011) for a detailed discussion of the estimation of input and output panel data for industrial sectors in China. All figures shown in this paper are drawn by the author based on the estimated data, if not stated otherwise.

Next, I will address the detailed estimating schedule of CO_2 emission. According to the definition of the World Bank, CO_2 emissions are those stemming from the burning of fossil fuels and the manufacture of cement, with the former accounting for at least 70 per cent of the total CO_2 emission. Therefore, CO_2 emission used in this study is only related to fossil energy combustion; that is to say, CO_2 emission is computed from the consumption of primary solid coal, liquid oil and gas fuels using the following expression.

$$C = \sum_{j=1}^{3} C_j = \sum_{j} E_j \times \mathrm{NCV}_j \times \mathrm{CEF}_j \times \mathrm{COF}_j \times (44/12). \tag{5}$$

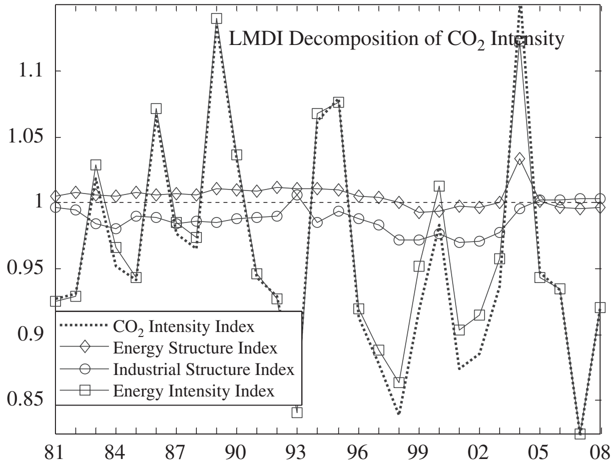
Except for the variables defined previously, C_j represents the flow of CO_2 emission corresponding to jth types of primary energy, and E_j is their respective energy consumption. NCV is net calorific value provided by *China Energy Statistical Yearbook* in 2007, CEF is carbon emission factor provided by IPCC (2006) and COF is carbon oxidisation factor set to be 1 for both oil and gas and 0.99 for coal in this study. Therefore, the calculated CO_2 emission coefficients for coal, oil and gas are 2.763, 2.145 and 1.642 tons of CO_2 per ton coal equivalent, respectively, in the case of China.

The choice of decomposition techniques depends on the features of database available. The panel data for 38 industrial sectors between 1980 and 2008, employed in this study, make the year-to-year decomposition possible using the index decomposition instead of input and output structural decomposition only suitable for the periodwise analysis. LMDI decomposition method in multiplicative form, as introduced previously in this section, is finally chosen to construct the chain development index, preferably analysed in this study, rather than any versions of Laspeyres index decomposition that could only undertake the incremental decomposition in additive form. As opposed to all literature reviewed in Section 2, the main contribution of this study is that it looks at the largest number of sectors (38 sectors) as one dimension to decompose CO_2 intensity in the longest sample period (29 years), making it possible to investigate the varying patterns of target variables over the whole reform period within the sector of Chinese industry. Unlike other studies, this study focuses on explaining the varying patterns of intensity and structural factors according to historical experience and economic policies, rather than just a description of various decomposed factors.

4. FACTORS DECOMPOSITION OF CO_2 INTENSITY IN INDUSTRY

Figure 4 depicts the trend of chain development index of CO_2 intensity and its influential factors by decomposition in Chinese industry (average over all sectors). Obviously, the index of CO_2 intensity fluctuates very much but

FIGURE 4
Industrial CO_2 Intensity Index and Its Influential Factors Through Decomposition (1981–2008)



exhibits the negative growth in many years (that is, exhibits the positive growth for only seven years among almost 30 years and only positive in 2004 since 1995). Figure 4 also reveals that the majority of the varying patterns of CO_2 intensity index could be explained by the index of energy intensity because there is much overlapping for the two index lines to reflect their much similar volatility. The indexes of energy structure and industrial structure have weaker correlation with and explanation to the variation of carbon intensity index than that of energy intensity. Seen from the year-to-year decomposition and its average over four sub-periods and the whole period reported in Table 1, the index value of CO_2 intensity and energy intensity is very close, but that of CO_2 intensity and energy/industrial structure is far from very other.[3] During the whole reform period, the development index of industrial CO_2 intensity reduces by 4.55 per cent on average, in which, energy intensity index reduces by 3.82 per cent, industrial structure index reduces by 1.23 per cent but energy structure index rises by 0.48 per cent. The detailed explanation of three influential factors on the variation of CO_2 intensity will be addressed next.

a. Energy Structure Effect

As illustrated by Figure 5, coal constitutes the main primary energy consumption in China, followed by oil and gas. In primary energy consumption in Chinese industry, coal accounts for 74.2 per cent on average, making China

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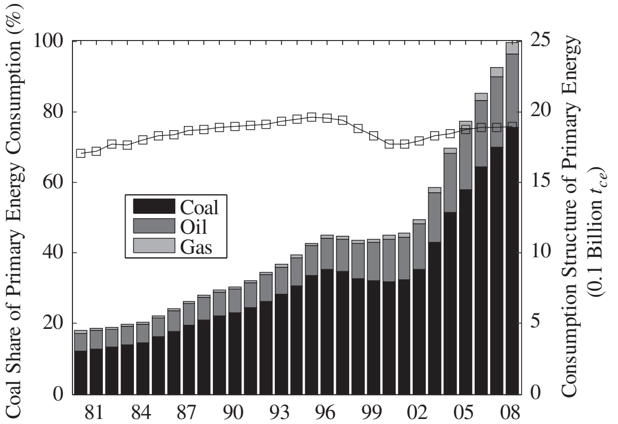
[3] The whole period is divided into four sub-periods in terms of the different pattern of industrial carbon intensity characterised in Figure 3.

TABLE 1
Industrial CO_2 Intensity Index and its LIMDI Decomposition in China (1980–2008)

Periods	*CO_2 Intensity Index*	*Factor Indexes through LMDI Decomposition*			*Periods*	*CO_2 Intensity Index*	*Factor Indexes through LMDI decomposition*		
		Energy Structure	*Industrial Structure*	*Energy Intensity*			*Energy Structure*	*Industrial Structure*	*Energy Intensity*
1981/80	0.9270	1.0052	0.9966	0.9254	1998/97	0.8388	0.99999	0.9719	0.8631
1982/81	0.9314	1.0079	0.9946	0.9292	1999/98	0.9186	0.9925	0.9722	0.9520
1983/82	1.0187	1.0060	0.9843	1.0288	2000/1999	0.9829	0.9939	0.9763	1.0130
1984/83	0.9518	1.0051	0.9804	0.9659	2001/00	0.8741	0.9976	0.9700	0.9033
1985/84	0.9414	1.0076	0.9900	0.9437	2002/01	0.8850	0.9963	0.9706	0.9153
1986/85	1.0663	1.0061	0.9887	1.0719	2003/02	0.9368	1.0003	0.9778	0.9578
1987/86	0.9764	1.0070	0.9843	0.9851	2004/03	1.1549	1.0332	0.9958	1.1226
1988/87	0.9656	1.0061	0.9859	0.9735	2005/04	0.9471	1.0016	1.0027	0.9431
1989/88	1.1352	1.0108	0.9848	1.1404	2006/05	0.9340	0.9966	1.0021	0.9352
1990/89	1.0333	1.0094	0.9881	1.0361	2007/06	0.8238	0.9957	1.0032	0.8247
1991/90	0.9433	1.0088	0.9887	0.9457	2008/07	0.9202	0.9962	1.0035	0.9205
1992/91	0.9286	1.0115	0.9897	0.9276	1980–90	0.9883	1.0069	0.9877	0.9938
1993/92	0.8545	1.0104	1.0062	0.8405	1990–95	0.9615	1.0101	0.9915	0.9600
1994/93	1.0624	1.0104	0.9852	1.0673	1995–2004	0.9206	0.99995	0.9781	0.9412
1995/94	1.0794	1.0096	0.9933	1.0764	2004–08	0.9502	1.0045	1.0015	0.9445
1996/95	0.9132	1.0051	0.9878	0.9198	1980–2008	0.9545	1.0048	0.9877	0.9618
1997/96	0.8775	1.0044	0.9834	0.8884					

FIGURE 5
The Structure of Primary Energy Consumption in Chinese Industry (1980–2008)



one of the few countries to rely on coal. That explains why the CO_2 intensity is so high in China when compared with other countries. Evidently, the CO_2 emission coefficient of coal is higher than that of oil and gas. It follows that the variation of energy structure has an impact on the carbon intensity.

As shown in Figure 5, the share of coal has gradually risen from 68 per cent at the early reform period to a peak of 78.4 per cent in 1995, corresponding to the energy policy of encouraging energy production implemented in the 1980s to solve the shortage problem arising from the long-run planned economy. Similar to the industrial reform to increase operating autonomy in urban area, energy-intensive industries such as coal mining, petrochemical and electric power enterprises have undertaken the reform of contract responsibility system in succession. Among them, the coal industry is one that has experienced the most thorough reforms, and where competition is fiercest because the State decentralises authority to local governments, which then relax the entry barriers of coal enterprises and encourage townships, commune and brigades (*Shedui*), individuals and foreign investors to mine coal. As a result, there is a surge in small coal mining all over the country for a time. In 1994, the dual-track price of coal is first phased out of the state plan and fully liberalised as opposed to that of product oil and electric power. It is then that the coal market is fully formed.

However, the production of coal has eventually gone out of control. The destructive exploitation and the lack of environmental protection measures cause serious damage and waste of coal resources and environmental pollution. As shown in the sub-periods of Table 1, from 1980 to 1995, energy structure is the only factor to drive CO_2 intensity reversely, the latter reducing by 1.17–3.85 per cent but the former rising by 0.69–1.01 per cent. From 1995 to this century, because the Chinese government closes down many small energy- and emission-intensive enterprises[4] and starts to restrict the development of energy enterprises instead of encouragement of it in the 1980s, the share of coal consumption decreases for the first time during the whole period – with the lowest being 70.89 per cent in 2000. Thus, this is the only phase (1995–2004) that energy structure has a positive effect on the reduction in CO_2 intensity and the indexes of three factors decrease simultaneously, although the value of the reduction rate of energy structure index is very small, as shown also in Table 1. As heavy industrialisation appears again in this century, coal share rises – attaining the highest 75.9 per cent in 2008 (see Figure 5). Accordingly, energy structure index increases by 0.45 per cent that leads to the final positive growth effect of energy structure during the whole period and hinders CO_2 reduction.

Of course, the overall influence of energy structure on CO_2 intensity is comparatively small because the adjustment of energy structure is restricted by the energy endowment in each country. For instance, China and USA are the top two coal consumers in the world, and the burning of coal makes the two countries the top two CO_2 emitters as well. Therefore, on account of the energy structure that coal reservation and consumption are the majority, it is difficult to abate CO_2 emission and its intensity by adjusting the energy structure in the short run.

b. *Industrial Structure Effect*

As shown in Figure 4 and Table 1, compared with the positive impact of energy structure on CO_2 intensity in only one sub-period, the effect of industrial structure on the reduction in CO_2 intensity is overall positive with the only exception at the last sub-period of heavy industrialisation. Industrial structure is the main component of the economic structure. Adjustment in industrial structural indicates that the production factors, such as capital, labour and energy, are re-flowed and reallocated among industrial sectors with different techniques, efficiency and profits. This leads to the changing of output share in different sectors. According to neoclassical growth theory, structural adjustment is an important source of sustainable growth and a radical way to transform the development model. Timmer and Szirmai (2000) refer to the positive effect of structural adjustment on economic growth as the structural bonus hypothesis.

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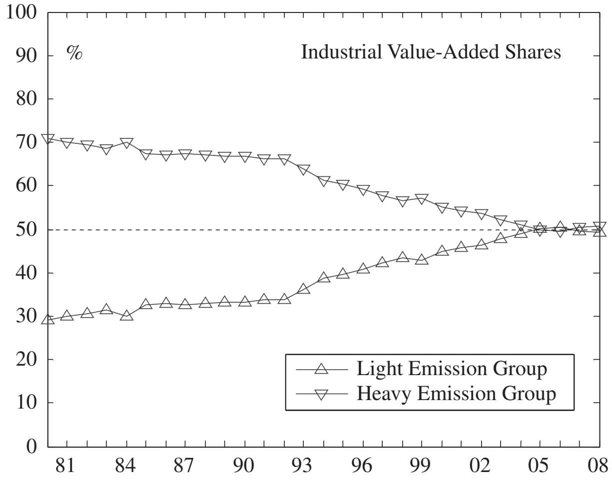
[4] According to the environmental protection programme of the10th and 11th national Five-Year Plan and the report of 'Environmental Protection in China (1996–2005)' released by State Council on 5 June 2006, for the first time, the Chinese government closes down about 84,000 small energy- and emission- intensive enterprises during the 9th Five-Year Plan (1996–2000). In the period of 10th Five-Year Plan (2001–05), the government continues to shut down 33,000 small enterprises that cause heavy pollution, but the environmental policy is not implemented as strictly as in the 9th Five-Year Plan, leading to the reappearance of heavy industrialisation at this phase.

FIGURE 6
Change in Output Structure between Low and High Emission Group (1980–2008)



In this study, industrial structural adjustment is characterised as the flow of production factors between light and heavy industries. Following Chen et al. (2011), all sectors are divided into light and heavy industrial groups according to the ranking of CO_2 emission in 2004 because heavy industry is normally assumed to cause more serious pollution and vice versa. That is, the light industrial group corresponds to the top half of sectors with the lower value and the heavy industry to the last half of sectors with the larger value of CO_2 emissions. Figure 6 describes the varying trends of value-added share for light and heavy industrial groups.

Since the advent of the economic reform, China has revised its economic strategy from focusing the heavy industry to catch up with the developed world to a more balanced approach to develop both the light and the heavy industries. This has led to the rapid growth of light industry in the following two decades, including town and village enterprises (TVEs), private enterprises and foreign funded enterprises. Thus, the value-added share of the light emission group increases continuously in the 1980s and 1990s and that of high groups decreases symmetrically, as illustrated in Figure 6. The same negative growth of both industrial structure index and CO_2 intensity index revealed by Figure 4 and Table 1 implies that factors reallocation to more efficient sectors drives the reduction in carbon intensity and that structural bonus exists.

Most importantly, since the SOEs' ownership reform encourages 'grasping the large and letting go of the small' (particularly closing tens of thousands of small-scale emission-intensive enterprises such as coal mines and power generation as stated in previous subsection) and the furlough policy (*Xiagang*) is implemented in the mid-1990s, the value-added share of heavy emission group falls faster, imposing the biggest positive effect on the reduction in carbon intensity.

In fact, at this phase, the development index of industrial structure reduces by 2.19 per cent. Heavy industrialisation reappears after the year of 2003. Figure 6 shows that value-added share in high emission group stops the downward trend for almost 20 years and stays parallel to that in low emission group. As shown in Figure 4 and Table 1, the index of industrial structure reveals a positive growth by 0.15 per cent for the first time and its effect on the reduction in CO_2 intensity turns to be negative.

In sum, the effect of energy structure and the industrial structure on CO_2 intensity reduction is not big but has reverse influence – the former being negative and the latter, positive. Thus, one approach to this new industrialisation is to adjust the industrial structure in which the important factors are continuously reallocated from energy- and emission-intensive groups to light industry with advanced technology, low energy consumption and CO_2 emission.

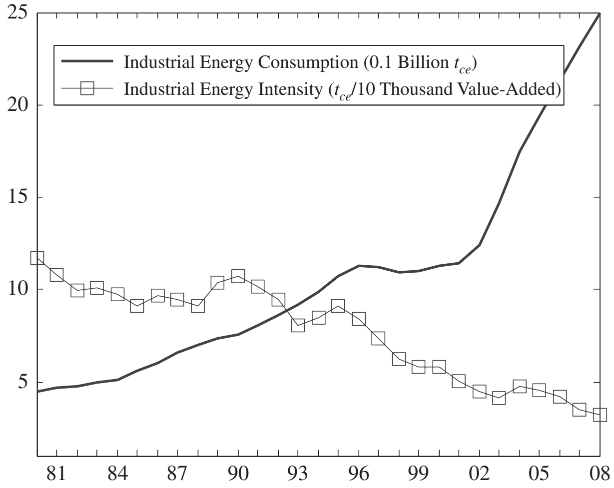
c. Energy Intensity Effect

Similar to the findings in most literature on decomposing the CO_2 emission or its intensity, this study also finds that the decline of energy intensity is the main force to drive the reduction in CO_2 intensity; the values of both energy and CO_2 intensity index are very close (see Table 1), and both index lines overlap in most periods (a significant gap is only visible in the mid and late 1990s as a result of a dramatic change in energy structure and industrial structure, see Figure 4). Since energy consumption causes CO_2 emission and the abatement of CO_2 intensity radically depends on the decline of energy intensity or the promotion of energy efficiency (defined as 'the reciprocal of energy intensity'), there is an intimate relationship between emission abatement and energy save.

In 1953, after three years of land reform, the national energy consumption is only 0.05 billion tons of coal equivalent (tce). In 1978, during the early reform period, it is 0.57 billion tce. In 2008, it has risen to 2.85 billion tce. Figure 7 depicts the trend of industrial energy consumption and its intensity. Industrial energy consumption is 0.45 and 2.5 billion tce in 1980 and 2008, respectively, accounting for 74 and 87 per cent of national consumption. This implies a sharp increase in the demand for energy in Chinese industry. Accordingly, the high shares of 76.1 and 96.3 per cent of industrial CO_2 emission to national emission in 1980 and 2008, revealed in Figure 1, do not seem strange. The higher coal share in primary energy consumption and higher CO_2 emission coefficient contribute mostly to this fact.

Figure 3 and Table 1 have divided the whole reform period into four subperiods according to the varying patterns of industrial CO_2 intensity. The

FIGURE 7
Change in Energy Consumption and its Intensity in Chinese Industry (1980–2008)



change in energy consumption and its intensity in Figure 7 displays the similar pattern. Before 1995, energy consumption rises steadily and energy intensity falls by 2.28 per cent on average with fluctuation. As stated in the previous two subsections, during the radical ownership reform period from 1996 to the advent of this century, industrial energy consumption reverses the previous increasing trend and is at a standstill, and industrial energy intensity shows the biggest decreasing process of the whole period (from 9.14 tce per ten thousand value-added in 1995 to 4.15 in 2003, with the reduce rate of 7.68 per cent on average), indicating a significant improvement of energy efficiency corresponding to the dramatic adjustment of energy and industrial structure. The re-emergence of heavy industrialisation after 2003 is also shown in the variation of energy consumption and intensity. It could be attributable to the fanatical expansion of housing and car industries, the rapid urbanisation, accelerated exports of energy- and emission-intensive products after the accession into WTO, the continuous and massive infrastructure investment, and the new entry of private capital into heavy industries because of the low price of natural resources. As shown in Figure 7, industrial energy consumption rises unprecedentedly, and industrial energy intensity temporarily rises, too, during the long-term decreasing process. Because of this, the eleventh national Five-Year Plan in 2006 puts forward the quantitative target to reduce energy consumption per GDP by 20 per cent from 2006 to 2010.

In other words, although fluctuated, industrial energy intensity experiences an overall decreasing trend, indicating the continuous improvement of utilisation efficiency of energy. Many studies find such factors historically driving the promotion of energy efficiency as the technology advances, including the adoption of new energy technologies and the energy-saving and emission-abating technologies, R&D expenditure, reform of energy prices, ownership reform and an industrial structural adjustment from high- to low-emission group (Garbaccio et al., 1999; Fisher-Vanden et al., 2004, 2006; Mukherjee and Zhang, 2007; Fisher-Vanden and Jefferson, 2008). Zhang et al. (2008) also note that the nature of the low carbon economic development model is to promote energy efficiency, and the core is technology innovation.

5. CONCLUSIONS AND POLICY IMPLICATIONS

Using the data behind Figure 3, the CO_2 intensity of Chinese industry in 2008 is 8.1 tons CO_2 per 10,000 industrial value-added, while the values in 1980, 1995 and 2004 are 29.9, 23.9 and 12.1, respectively. That means it has abated by 72.9 per cent over the past 28 years, 66 per cent over the past 13 years and 33 per cent over the past four years. Based on such historical abating speed in industry, it is highly possible for China to realise the abating target of national CO_2 intensity proposed in 2009, that is, 40–45 per cent from 2005 to 2020. As shown in Figure 7, industrial energy intensity, the driving force behind CO_2 intensity found in this study, is 4.5 tce in 2005 and decreases by 29 per cent to 3.2 tce in 2008, the shrinking magnitude of which also exceeds the required 20 per cent save of national energy intensity from 2006 to 2010 proposed in the 11th Five-Year Plan. Such intensity indexes reveal that the industrial sector saves energy and abates emission better than the whole state over the past years; though, it does consume energy and emit CO_2 mostly at the absolute level. Of course, such optimistic conclusions obtained previously may be due to the calculation of industrial CO_2 and energy intensity using the weighting average of nearly 40 industrial sectors, possibly different from the information behind the aggregation industry data directly provided by the official yearbooks.

As CEACER (2009) demonstrates, between 1980 and 2000, China quadruples its economy by only doubling its energy consumption, that is, the elasticity coefficients of energy consumption being about 0.5, contributing mostly to the reduction in CO_2 intensity. However, during the period of the 10th Five-Year Plan (2001–05), the re-emergence of heavy industrialisation results in the elasticity coefficients of energy consumption over 1 successively from 2003 to 2005, forcing the central government to put forward a quantitative energy-save target for the first time, that is, reducing energy intensity by 20 per cent during the period of the 11th Five-Year Plan (2006–10). If China can achieve the 20 per cent reduction in energy intensity during each of the Five-Year Plans before 2020, it can continue to quadruple the economy in 2020 by only doubling the energy consumption, as it did before the twenty-first century, leading to the successful achievement of the abating target of CO_2 intensity in the year 2020. Chen (2010) also says such an energy-saving and emission-abating policy not only reduces the CO_2 emission but also drives the growth of economy, leading to the win-win development in the long run.

In terms of the factors decomposition of CO_2 intensity for 38 industrial sectors between 1980 and 2008, some conclusions and corresponding policy implications could be obtained.

1. The most important driving force for the reduction in Chinese CO_2 intensity is energy intensity (or energy efficiency). According to the decomposing results, to the end of successful abatement of CO_2 intensity, it is necessary to substantially reduce energy intensity or improve energy efficiency from now on. Although energy efficiency in China keeps improving, it is still much lower than that in advanced countries and has much room for further improvement. For instance, in 2004, the Chinese energy intensity is 99,000 tons of oil equivalent per US$10,000 of GDP (price level of the year of 2000), much higher than that of the USA, Germany and Japan (respectively, 23,000, 19,000 and 11,000) and even higher than the value of 65,000 in India, a developing country. The following policies can contribute to the improvement of energy efficiency: to levy an environmental tax (such as 'carbon tax') and form the market mechanism of energy pricing to reflect the scarcity of resources and cost of environmental governance; to continuously increase R&D expenditure through multichannels on energy-saving technology and decarbonising technology; to establish technology markets and innovation locus devolved from a state-dominated system to firms, research institutes and universities; and to employ advanced technology to renovate traditional heavy industry and rapidly develop light industry, promoting this new industrialisation by green and information technological revolution.
2. Energy structure and industrial structure are also the factors to influence CO_2 intensity abatement in the future. Although the room for reducing carbon intensity by adjusting energy structure is not big because of the restrictions of resources endowment, in the long run, there is the possibility to change the current energy structure dominated by coal to cleaner energy structure by developing clean energy (hydro, nuclear, wind and solar), new energy and renewable energy. Structural adjustment represented by industrial structure is always the radical approach to transform the development model. China should develop the light and advanced industrial sectors faster than energy- and emission-intensive sectors to promote the abatement of carbon dioxide intensity in the future.

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