

Reconciliation of Use of Coal and the Environment: Evidence of Declining Emission Intensity from China[†]

Xunpeng SHI*

Economic Research Institute for ASEAN and East Asia, Jakarta

Abstract:

This paper argues that the use of coal can be reconciled with the environment. In the empirical work, three environmental pollutants are considered, using two alternative methods with two sets of Chinese data. CO₂ emissions could not be studied because of data limitations. The hypothesis that the use of coal can be reconciled with the environment through declined emission intensity is confirmed by the empirical tests. The falls in emission intensity are driven by the application of clean coal technologies, which can be encouraged by appropriate regulations and incentives and have both environmental and economic benefits. Therefore it is critical that appropriate legal and fiscal regimes be formulated and that the development and utilisation of high-efficiency and clean coal technologies be promoted. The paper also suggests that the use of coal could continue to be reconciled with concern for the environment, even while considering CO₂ emissions.

Key Words: Air Pollution; China; Coal; Environment; Emission intensity

JEL Classification: Q32; Q48; Q56

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* Present address: ERIA Annex Office, 6th floor Sentral Senayan II, Jl. Asia Afrika no.8, Senayan, Jakarta Pusat 10270, Indonesia. Tel: +62 21 5797 4460, Fax: +62 2 5797 4464. Email: xunpeng.shi@eria.org; xunpeng.shi@gmail.com.

1 Introduction

Coal plays an important role in social and economic development worldwide. Arguably, as a fuel for steam engines, it was at the heart of the industrial revolution and has driven industrialisation in the past several centuries, although its production in 1900 was only 250 million tonnes (Church, 1986), in contrast to a production of 6.94 billion tonnes in 2009 (BP2010). Other examples are that 70 per cent of global steel was produced by technologies that require coal as a necessary input and that many countries, such as China, Poland, South Africa and Australia, get more than 80 per cent of their electricity from coal (WCI2008).

Coal, however, is one of the primary environmental polluters, particularly in China. It has been reported that 85 per cent of the SO_2 , 70 per cent of soot and 60 per cent of the NO_2 emitted into the atmosphere in China came from the use of coal (Wang & Feng, 2003). The correlation between increased SO_2 levels and coal consumption in China is above 95 per cent (He et al., 2002).

With the emergence of more environmental regulations, concerns are often raised that coal cannot reconcile with the environment, and thus the future for coal is gloomy. In contrast, many people argue that coal is promising, at least in the foreseeable future, because coal can be clean, and has in fact become cleaner (McGinley, 1992; Wang, 1999; Shi, 2006; MIT, 2007; 2008). However, most of these arguments were presented using qualitative analysis, and lacked quantitative evidence, except the MIT report (MIT, 2007) and Shi (2008). The issues of whether and by how much coal has become cleaner, and the implications of this trend remain to be further explored. These issues are important to countries that rely heavily on coal, such as China, India and Australia, in terms of energy supply, energy security, jobs, and economic development. They are also important to the global community in terms of environmental protection and climate change.

This paper demonstrates that the use of coal can be reconciled with the environment by examining changes in the emission intensity of coal using China's empirical data. The paper updates a recent quantitative study (Shi, 2008) using the latest data and more robust

estimation techniques. The proposal and demonstration of the common trend of emission intensity of coal and the differentiated trend of emission intensities between two kinds of coal, and the use of variables measuring regulatory enforcement, are also new to the literature.

The rest of the paper is organised as follows. The next section introduces the hypothesis of declining emission intensity, and the models and data that will be used to test it. The third section presents results about the environmental performance of coal in China from the two quantitative models. The fourth section discusses China's environmental protection efforts in terms of emission control with a brief international comparison, the role of clean coal technologies (CCTs), improvement of energy efficiency, and policy implications. The last section concludes the paper.

2 Hypothesis, modeling and the data

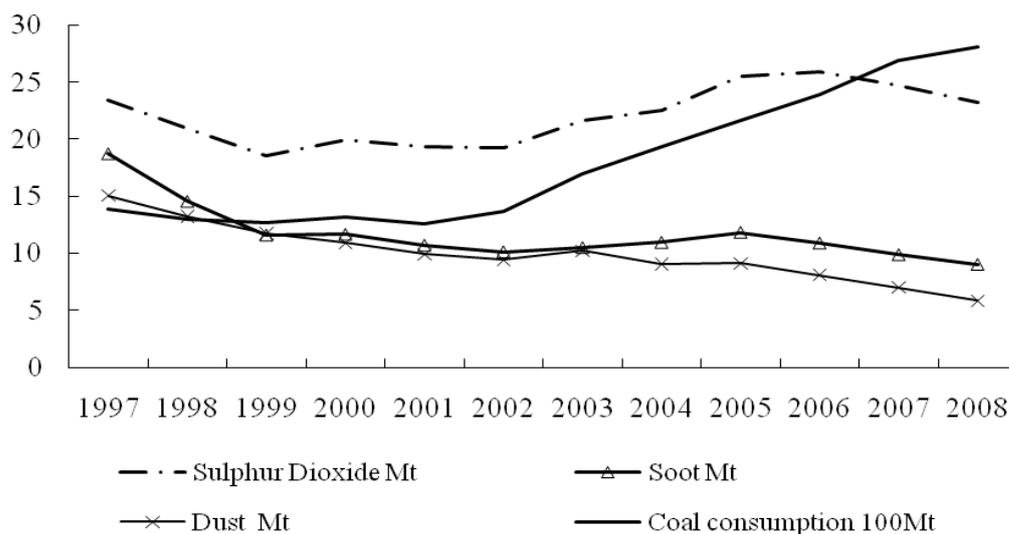
2.1 The Hypothesis of Declining Emission Intensity

Globally, the coal industry grew despite increasing environmental regulations, and consequent reductions of emissions. Despite the increasing number of environmental regulations relating to coal since the 1970s, global demand for coal has increased steadily in the past three decades (EIA, 2010). In 2009 coal accounted for 29.4 per cent of the world's energy consumption (BP, 2010). Coal consumption is expected to continue to increase in the next two decades. Total world consumption of coal is projected to increase 73 per cent and its share of energy will increase from 25 per cent to 28 per cent during the period 2005-2030 (IEA, 2007).

As the world's largest producer and consumer of coal, the Chinese coal industry has also managed to develop despite increased environmental protection measures. Since environmental protection was entrenched as one of China's basic national policies in the 1980s, a considerable degree of control of air pollutions has been achieved. For example, the amount of industrial SO₂, industrial soot and dust discharged in the generation of one unit of GDP in China in 2004 dropped by 42 per cent, 55 per cent and 39 per cent, respectively, from

the levels recorded in 1995 (State News Office, 2006). As shown in Figure 1, although coal consumption has been soaring in recent years, industrial dust and soot emissions were declining. There has been a slight increase in SO₂ emissions from around 2005, but the speed of the increase is far slower than that of coal consumption.

Figure 1 Coal consumption and air pollution emissions in China, 1997–2008



Sources: China Environment Yearbook Press (various years), NBS (various years) .

One hypothesis to explain this reconciliation of coal and the environment is that emissions per unit of coal, that is, emission intensity, has been declining, and continues to decline, mainly due to the application of clean coal technologies, driven by social, economic and technical factors such as innovation, costs, environmental regulation and other policies (Shi, 2003; 2006; 2008). According to this hypothesis, capping the amount of pollution emissions does not necessarily lead to a decline in coal consumption and that a reconciliation between coal use and the environment is possible.

Carbon dioxide emissions are not studied in this paper because of the way in which CO₂ emissions are inferred, even though coal emits the largest amount of CO₂ due to its dominance in China’s energy mix. There are no official data of CO₂ emissions in China published in a time serious and thus CO₂ emissions are often inferred by assuming constant

emission intensity for each fossil fuel (Ang & Pandiyan, 1997; Ang *et al.*, 1998; Wang *et al.*, 2005; IPCC, 2006; Wu *et al.*, 2006). This is understandable given that CO₂ emissions have seldom been the subject of environmental regulation. Therefore, the current data for CO₂ emissions are not suitable for this analysis to demonstrate non-constant emission intensity. However, since technically CO₂ emissions from coal combustion can be reduced, findings from the study of non-CO₂ emission may be able to be applied to the case of CO₂ and we will slightly extend the discussion to touch the case of CO₂.

2.2 Two Empirical Models

To test the hypothesis of declining emission intensity over time, two alternative methods are employed. Econometric techniques are used to examine changes in the emission intensity of coal, with a focus on long-term dynamics. The index decomposition (ID) approach is used to qualify the individual contributions of various factors that determine the final emissions.

The first method to be used is a fixed-effects panel data model, which will test the trend of emission intensity. That is, at time t , in province i , the j^{th} waste gas emissions (WGEs) are decided by the following equation:

$$WGE_{ij} = \beta_0 + \beta_1 FuelC_{it} + \beta_2 FeedC_{it} + (\beta_3 FuelC_{it} + \beta_4 FeedC_{it})T + \beta_5 T^2 + \beta_6 FuelC_{it}^2 + \beta_7 MatC_{it}^2 + \delta X_{it} + \alpha_{ij} + u_{ij} \quad (1)$$

in which $j = 1, 2, 3$ denotes SO₂, soot and industrial dust, respectively; FuelC and FeedC denote consumption of fuel coal and feed coal¹, respectively; their quadratic terms were assumed to test for misspecification of function form (Wooldridge, 2003). T is a general time trend; α_{ij} is the province-specific effect in the case of the j^{th} pollutant in the i^{th} province; u_{ij} is a normally distributed error term; X is a vector of exogenous variables representing factors

¹ According to how it is used, coal use in an industrial sector could be classified as fuel coal or feed coal. Fuel coal is the coal that will be combusted, primarily by power plants. This coal often has low carbon content. Examples are brown coal and bitumite. Feed coal is the coal that will be used as a feedstock, mainly in chemical factories. It often has high carbon content. An example is anthracite.

such as GDP per capita and enforcement of environmental regulation.

The variables of coal consumption will be in level form because here the coefficients, β_1 to β_4 , represent emission intensity, which is the ratio of emissions to coal consumed. The pattern of emission intensity over time is modelled by β_3 and β_4 . If β_3 or β_4 is significantly negative, it means that there is a declining emission intensity in that kind of coal. Due to differences in characteristics between fuel coal and feed coal in different cases of WGEs, β_3 and β_4 are likely to be different in different WGEs. If we aggregate both fuel coal and feed coal, the coefficient of the interaction term between time trend and the total coal variable will give the weighted-average trend of emission intensity, or a common trend of emission intensity.

The more stringent the enforcement of environmental regulation, the lower the WGEs would be because emissions are more likely to be deterred. The rates of removed WGEs are used as proxy variables for the enforcement. To avoid potential endogeneity in the equation of one emission, we use the closest correlated removal rate in the other two emissions as an instrument. We also use other instrumental variables to check the robustness of these estimations.

The second model uses index decomposition, which has been a popular tool used in the past 40 years for the quantitative assessment of various factors affecting WGEs and energy demand. Since there are many factors shaping WGEs, such as economic development and population growth, increased WGEs do not mean coal has not become cleaner. Therefore, it is necessary to assess the impact of reduced emission intensity on WGEs through decomposition. In terms of the decomposition method, the Laspeyres index and the Divisia index are the most frequently used and preferred decomposition methods in energy-induced gas emission studies (Ang & Zhang, 2000).

The Logarithmic Mean Divisia Index (LMDI) approach is applied in this study because it has the time-reversal property of an ideal index and can perform a perfect decomposition and

accommodate zero values in the data set, which is preferable to the refined Laspeyres method (Ang & Zhang, 2000). A detailed survey of this literature can be found in Shi (2008). Similar to Wang et al. (2005), the total WGE is expressed as an extended Kaya Identity (Kaya, 1990; IPCC2001)—that is:

$$WGE_j = \frac{WGE}{TC} \times \frac{TC}{FE} \times \frac{FE}{TE} \times \frac{TE}{Y} \times \frac{Y}{P} \times P = E \cdot C \cdot F \cdot I \cdot G \cdot P \quad (2)$$

in which j is the type of emission, including SO₂, Soot and Dust; TC is total consumption of coal; FE is fossil-fuel energy consumption and TE is total energy consumption; Y is GDP; and P is population.

In this method, the change of WGEs is decomposed into six effects: emission intensity effect (E), fossil fuel composition effect (C), energy composition effect (F), energy intensity effect (I), growth effect (G) and population effect (P). The explicit introduction of coal into the emissions function makes it possible to decompose the impact of the emission intensity of coal on final emissions.

As shown by Wang et al. (2005), using the LMDI approach (Ang et al., 1998), the difference in WGEs between two periods, t and T , can be expressed as:

$$\begin{aligned} \Delta WGE_{iT} &= WGE_{iT} - WGE_{it} = E_{iT} \cdot C_{iT} \cdot F_{iT} \cdot I_{iT} \cdot G_{iT} \cdot P_{iT} - E_{it} \cdot C_{it} \cdot F_{it} \cdot I_{it} \cdot G_{it} \cdot P_{it} \\ &= \sum_K \Delta WGE_{K-effect}, K = E, C, F, I, G, P \end{aligned} \quad (3)$$

In which, the K^{th} -effect on emission reduction is:

$$\Delta WGE_{K-effect} = L(WGE_{it}, WGE_{iT}) \ln(K_T / K_t) \quad (4)$$

in which:

$$L(y, x) = (y - x) / \ln(y / x). \quad (5)$$

The case without change in emission intensity (Non-CEI) is also defined as the basis for comparison with the current status. The Non-CEI of WGEs can be derived by dropping the emission intensity effect as:

$$Non - CEI = \sum_K \Delta WGE_{K-effect}, K = C, F, I, G, P \quad (6)$$

2.3 The Data

This hypothesis of declining emission intensity is tested using empirical data from China's industrial sector. The empirical study will focus on three WGEs: sulphur dioxide emissions (SO₂), industrial soot emissions (soot) and dust emissions (dust). The focus on industrial WGEs only is appropriate because industrial pollution plays a dominant role in total emissions. For example, in the period 1997-2008, more than 80 per cent of SO₂ emissions and soot emissions came from industrial sources (CEYP, various years).

China's provincial panel data from 1996–2008 for the three WGEs, consumption of two kinds of coal and various environmental variables were drawn from various issues of the *China Environmental Yearbook* (CEYP, various years). Thirty out of the 31 provinces are included in the panel data with Tibet excluded because of missing data. 1996 was chosen as the starting point because data for coal consumption broken down to fuel coal and feed coal were available only from that year. The following table presents a brief summary of the panel dataset which will be used in the econometric model (Table 1).

Table 1 Summary statistics of the panel dataset

Variables	Obs. number	Mean	Std. Dev.	Min	Max
Emitted SO ₂ , 103 tonnes	388	579.68	390.66	16.89	1760.06
Emitted Soot, 103 tonnes	388	286.85	218.43	8.00	1432.74
Emitted Dust, 103 tonnes	388	282.52	223.68	7.00	1005.81
Fuel coal, 106 tonnes	388	40.31	37.02	0.87	248.00
Feed coal, 106 tonnes	388	16.18	22.12	0.32	184.15
GDP per capita, 103 Yuan	388	11.26	8.31	2.01	57.15

Note: GDP are converted to 1996 constant prices.

The data for national total coal production (in physical quantity and in standard coal equivalent), energy consumption and its mix, GDP and population are drawn from the relevant issues of the *China Statistical Yearbook* (NBS, various years). Total consumption of coal, fossil energy and energy are evaluated at standard coal equivalent, which will avoid problems with heterogeneity of coal qualities. The national GDP data are deflated to 1996 constant prices by GDP deflator.

3 Model Results

3.1 The evidence for declining emission intensity

To accompany both the fixed effects and Seemingly Unrelated Regressions (SUR), a dummy variable fixed effects SUR model is used. A dummy variable is created for each province and all but one of them are included in the regression functions to capture fixed effects from unobserved provincial heterogeneity. Since unobserved factors such as new environmental legislation and policy will affect the outcomes for all WGEs simultaneously, as noted in the literature (Bao & Peng, 2006; Shadbegian & Gray, 2006; Shi, 2008), the SUR model is also employed, to allow for correlations in the residuals across equations for the three WGEs.

To test the endogeneity of coal consumption variables, both past and next year consumptions were used as instrumental variables for the current year consumption. However, the Hausman test rejects the assumption of endogeneity.

Several variations of Equation (1) are examined using Stata 9.1 as shown in Table 2: Specification I is the original form, which will be the basis for discussion; Specification II keeps only coal and time variables to test the robustness of the estimation of emission intensity; Specification III excludes the coal variables to test the relationship between emissions and economic development. Two additional cases are also estimated to check the sensitivity and robustness of the estimations: the first case employs a fixed effects estimation, which will be used as a comparison with the SUR estimation (Table 2); the second case

combines the two kinds of coal as one, and thus tests the common trend of emission intensity of coal (Table 3).

Table 2 Estimated results of differentiated emissions intensity

	Specification I-SUR			Specification II-SUR			Fixed Effects Estimation		
	so2 coef/se	soot coef/se	dust coef/se	so2 coef/se	soot coef/se	dust coef/se	so2 coef/se	soot coef/se	dust coef/se
Fuelcoal	14.00*** (1.59)	5.57*** (1.23)	-2.81* (1.49)	10.88*** (1.69)	3.08** (1.25)	-3.54** (1.57)	16.63*** (1.44)	7.48*** (1.02)	3.32*** (1.25)
T*	-0.27** (0.12)	-0.18** (0.09)	0.01 (0.11)	-0.62*** (0.11)	-0.23*** (0.08)	0.07 (0.11)	-0.42*** (0.11)	-0.26*** (0.08)	-0.32*** (0.11)
Feedcoal	4.79*** (1.52)	12.85*** (1.18)	12.87*** (1.47)	5.66*** (1.62)	14.92*** (1.20)	16.59*** (1.51)	4.66*** (1.58)	12.28*** (1.18)	11.01*** (1.54)
T*	-0.38** (0.15)	-1.14*** (0.12)	-0.62*** (0.15)	-0.31** (0.12)	-1.01*** (0.09)	-1.00*** (0.11)	-0.32** (0.16)	-1.09*** (0.12)	-0.44*** (0.16)
T	14.88*** (3.97)	7.95*** (3.07)	15.74*** (3.77)	21.86*** (2.16)	3.92** (1.59)	6.70*** (2.01)	15.13*** (3.73)	9.93*** (2.72)	15.65*** (3.44)
Fuelcoal ²	-0.03*** (0.00)	-0.01*** (0.00)	-0.00 (0.00)				-0.03*** (0.00)	-0.01*** (0.00)	-0.00 (0.00)
Feedcoal ²	0.00 (0.01)	0.02*** (0.01)	-0.01 (0.01)				-0.00 (0.01)	0.02*** (0.01)	-0.01 (0.01)
Average GDP	-8.42 (6.25)	-6.05 (4.84)	-4.88 (5.98)				-8.63* (5.24)	-9.55*** (3.61)	-3.98 (4.49)
Average GDP ²	-0.01 (0.08)	0.08 (0.06)	0.02 (0.08)				0.01 (0.07)	0.12** (0.05)	0.01 (0.07)
Enforce ment ^(S)	-2.11*** (0.78)	-3.22*** (0.60)	-12.78*** (1.79)				-2.58*** (0.83)	-4.00*** (0.62)	-16.15*** (1.96)
Constant	348*** (82.00)	542*** (63.24)	1818*** (174.00)	278*** (71.10)	358*** (52.42)	644*** (65.98)	323*** (73.18)	401*** (52.27)	1610*** (178)

Note: \$-Enforcement was proximate by the ration of removed pollutions: dust in cases of SO2 and Soot, and Soot in the case of dust; Number of observations is 388 in all estimations; Standard errors are in parentheses. ***, **, * show 1%, 5% and 10% significant, respectively.

The results demonstrate that there is a significant decline in emission intensity in the case of feed coal. For fuel coal, there is also a significant decline in emission intensity, except in the case of dust (Table 2). Such different patterns demonstrate the differentiated trend of emission intensity between fuel coal and feed coal. The different trends, which imply that emissions from feed coal are more likely to have fallen than those from fuel coal, could have arisen because users of fuel coal did not install necessary equipment or did not keep the equipment operating efficiently.

The findings about the emission intensity are robust across these various estimations. In Specification II, where square terms and economic variables are dropped, the conclusion is unchanged. With fixed effects estimation, the dust emission intensity of fuel coal becomes significant but the SO₂ emission intensity of feed coal becomes insignificant (Table 2). However, the findings about significant and differentiated emission intensity in these two kinds of coal still hold. Since the SUR regression can accommodate more unobservable factors, the estimated results of fixed effects are presented as a check of robustness only.

A further estimation without differentiation of fuel coal and feed coal shows that there is a significant common declining trend in the emission intensity of coal, which is consistent with the econometric estimations (Table 3).

Table 3 Estimated results of common emissions intensities and EKC

	Total coal consumption			Test of EKC		
	so2 coef/se	soot coef/se	dust coef/se	so2 coef/se	soot coef/se	dust coef/se
Totalcoal	9.49*** (0.95)	9.28*** (0.74)	4.79*** (1.00)			
T*Totalcoal	-0.21*** (0.07)	-0.56*** (0.05)	-0.33*** (0.07)			
T	10.74*** (3.73)	9.34*** (2.92)	27.00*** (3.86)	16.52*** (4.21)	8.58*** (3.31)	26.85*** (3.81)
Totalcoal ²	-0.01*** (0.00)	-0.00** (0.00)	-0.00 (0.00)			
Average GDP	-1.04 (5.71)	-4.13 (4.48)	-21.01*** (5.88)	21.89*** (5.71)	-7.64* (4.49)	-27.61*** (5.11)
Average GDP ²	-0.09 (0.08)	0.06 (0.06)	0.19** (0.08)	-0.41*** (0.08)	0.05 (0.06)	0.25*** (0.07)
Enforcement ^(S)	-1.65** (0.75)	-4.23*** (0.59)	-15.79*** (1.88)	-1.61* (0.89)	-4.29*** (0.69)	-16.75*** (1.86)
Constant	418.74*** (82.13)	510.95*** (64.21)	1882*** (189.69)	847*** (74.94)	989*** (58.35)	2219*** (170.33)

Note: \$-Enforcement was proximate by the ration of removed pollutions: dust in cases of SO₂ and Soot, and Soot in the case of dust; Number of observations is 388 in all estimations; Standard errors are in parentheses; ***, **, . ** show 1%, 5% and 10% significant, respectively.

In both estimations, the significant and positive time trend may capture factor such as shifting away from coal to other alternatives such as fuel oil and gas, which were often in relatively small scale.

The findings about the pollution–income relationship are mixed. There is no significant relationship in Specification I (Table 2 and Table 3). The reason could be that energy consumption serves as an intermediate between pollutions and economic development and thus its inclusion will isolate the relationship between these two factors. Actually, none of the previous studies, such as Bao and Peng (2006), Shen (2006), Kaufmann *et al.* (1998) and Markandya *et al.* (2006), included energy consumption variables. This assumption is supported by the estimation, which excluded coal consumption variables (Table 3). In that estimation, only one of the six economic variables in the three pollution cases is insignificant at the 10 per cent level. However, the Environmental Kuznets Curve (EKC) is only demonstrated in the case of SO₂—a finding reported also by Bao and Peng (2006), Kaufmann *et al.* (1998) and Markandya *et al.* (2006). In the case of dust, a U shaped pollution–income relationship is found, which is different from the findings of Bao and Peng (2006).

Enforcement of environmental regulations, approximated by the rates of removed emissions, is significantly negative and robust for all three WGEs (Table 2 and Table 3). This means that a tightener enforcement of environmental regulation will reduce the emissions of coal when all other factors are held constant, which is desirable. As a robust check, two other instrumental variables--the cumulative number of environmental standards as in Bao and Peng (2006) and operating costs of WGE-treatment equipment as in Shi (2008) -- were used to proximate the enforcement and the conclusion remains unchanged.

3.2 Decomposition of the total emissions

These decomposition results show that economic and population growths have led to more emissions, while the other four factors boosted emission reduction during the period 1996–2008. In terms of scale, the emission intensity and economic growth are major players,

but in opposite directions; and they are followed by the effect of energy intensity. The role of economic growth in the change of emissions is consistent with the theory and the literature (Lin & Chang, 1996; Shalizi, 2007). The decrease in soot and dust emissions was due primarily to the decrease in emission intensity. In the case of SO₂ emissions, even though overall emissions increased on occasion, emission intensity and energy intensity always have negative effects (Table 4). The significant effect of lowered emission intensity in reducing the total emissions echoes the finding of reduced emission intensity in the econometric estimations.

Table 4 Decomposed effects of the changes in emissions (Δ WGE), 1997–2008

	Δ WGE	E-effect	C-effect	F-effect	I-effect	G-effect	P-effect
SO ₂	55.20	-1512.45	-32.55	-66.48	-639.36	2136.15	164.21
Soot	-671.40	-1495.95	-17.12	-34.97	-336.29	1123.56	86.37
Dust	-920.10	-1585.54	-13.82	-28.22	-271.40	906.75	69.70

This study shows that energy intensity has played a less important role than the emission intensity. In contrast to the literature, where decreases in the emissions are explained mainly by declines in energy intensity (Torvanger, 1991; Lin & Chang, 1996; Ang & Zhang, 2000; Shalizi, 2007), this study finds that changes in industrial WGEs are to a large extent the result of the decline in the emission intensity of coal.

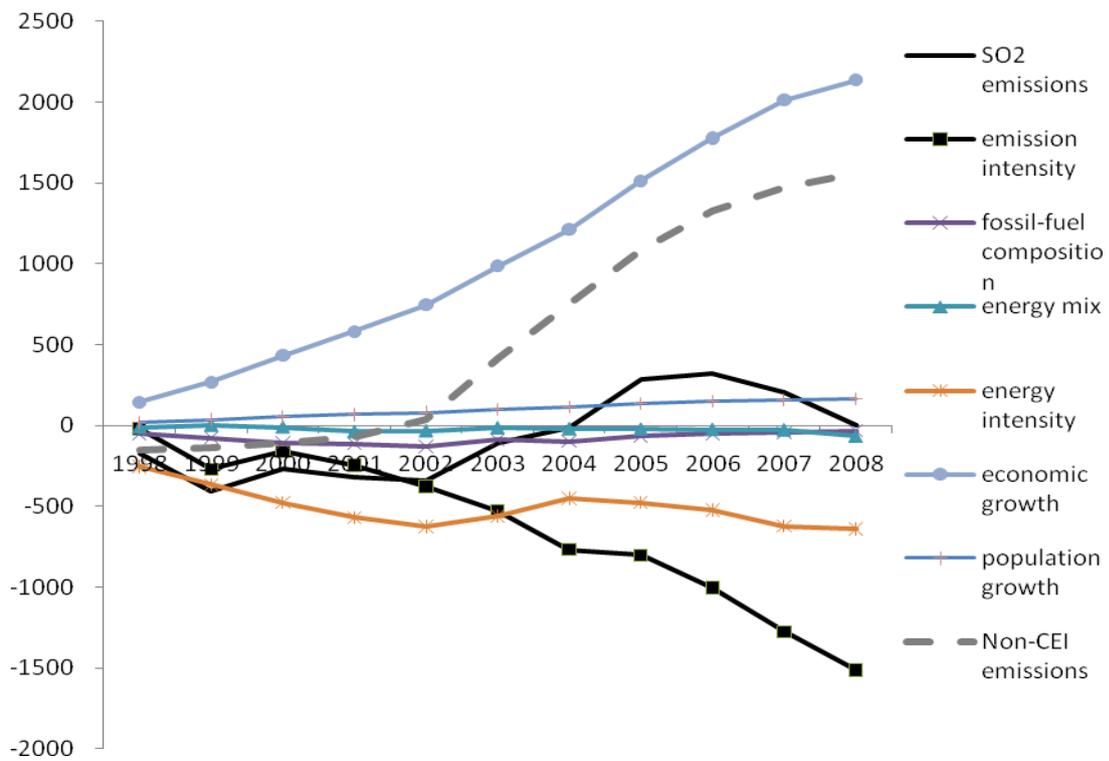
The changing structure of coal among fossil-fuel energy and the change of energy mix also contribute to the decreases in WGEs. However, the small value reveals they have a weak impact on final WGE reductions. The reason is that fossil fuel composition and share of non-fossil energy in the energy mix changed little over the sample period.

For easy understanding, the decomposed effects for the three WGEs are normalised to the year 1997. That is, the cumulative changes of emissions between 1997 and 2008 are decomposed to the cumulative changes of the six effects over time (Figure 2, Figure 3, and

Figure 4).

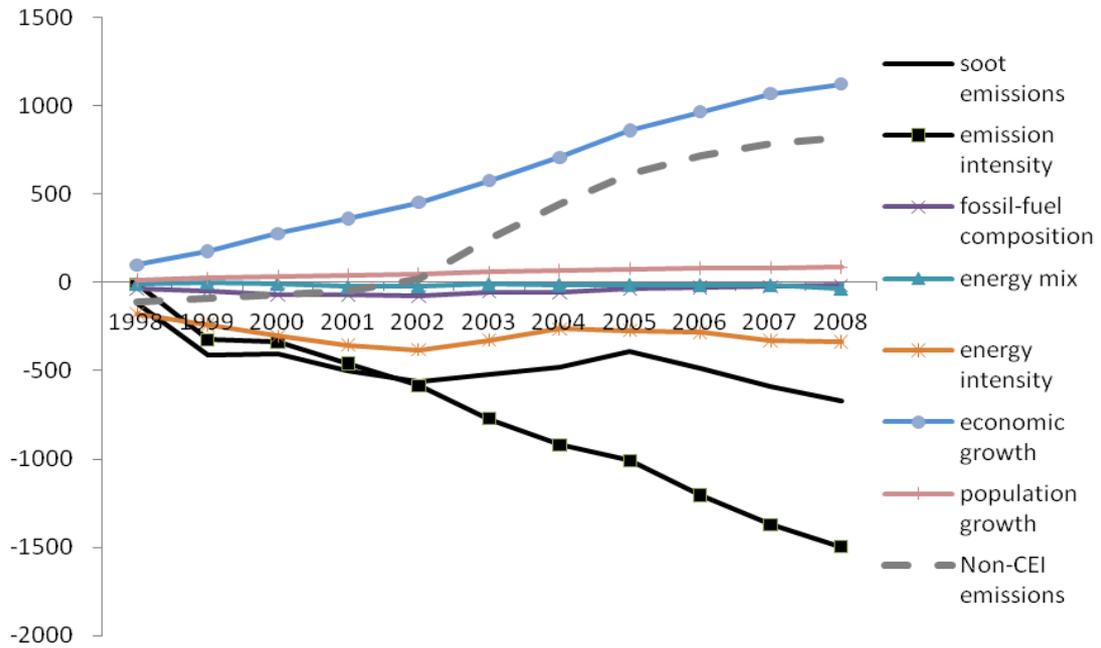
In all three cases, it is clearly demonstrated that without the factor of a decline in emission intensity (non-CEI), the emissions would be much higher than they were. This demonstrates that the decreasing emission intensity is the most significant contributor to emissions reductions.

Figure 2 Decomposed effects of SO2 emissions changes, 1997–2008



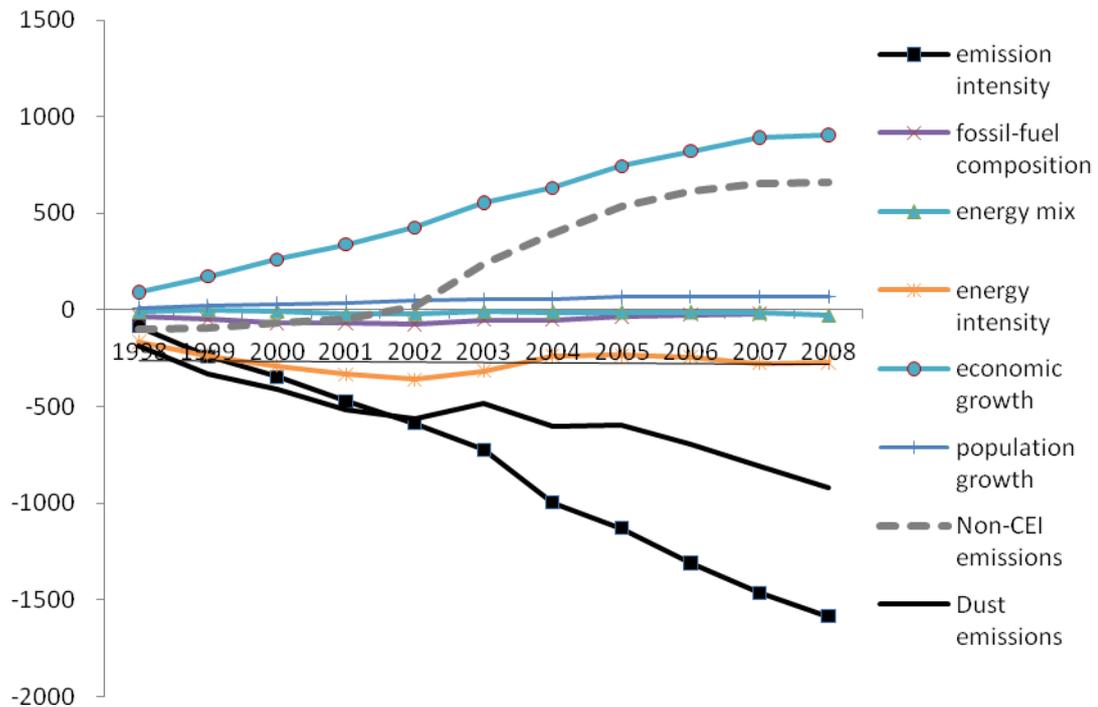
Note: Cumulated impacts on changes of SO2 emissions compared with 1997.

Figure 3 Decomposed effects of soot emissions changes, 1997–2008



Note: Cumulated impacts on changes of Soot emissions compared with 1997.

Figure 4 Decomposed effects of dust emissions changes, 1997–2008



Note: Cumulated impacts on changes of Dust emissions compared with 1997.

4 Discussion and policy implications

4.1 The future of coal

As the world's second largest coal consumer, accounting for 15.2 per cent of the world's total coal consumption in 2009 (BP, 2010), the USA has also demonstrated a reconciliation of coal with the environment. In the US, environmental regulations began to affect the coal industry in 1977 when the Clean Air Act (CAA) amendment established for the first time "ceilings" for different amounts of air pollutants, including particulate matter, CO, SO₂, and NO_x (Shi, 2006). Although experiencing growing environmental regulations from the early 1970s, US coal production continued to increase, its price continued to decline (EIA, 2007) and emissions consistently reduced. For example, the national average SO₂ concentrations decreased 71% between 1980 and 2008 and 59% between 1990 and 2008 (US EPA, 2010).

India, the world's third largest coal consumer, which consumed 7.5 per cent of the world's total coal usage in 2009 (BP2010), is unfortunately an exception to the reconciliation. The emissions from coal in India have not been effectively controlled. The compounded growth rate of CO₂ and SO₂ emissions in India was above 5 per cent per annum about the year 2000, and was projected to continue to grow due to the continued dependence on coal in its industrial sector (Menon-Choudhary et al., 2005). The Indian case may be a result of insufficient policy interventions in favor of clean coal uses, at least in the case of SO₂. For example, the flue-gas clean-up systems that are currently available commercially and that have long been used in power plants can remove 99.9 per cent of particulates, 95 per cent of SO₂ and 90 per cent of nitrogen oxides (The ASME Council on Engineering, 2005).

Complete phasing out of coal worldwide is not practical in the near future because of reasons such as the dominance of coal in the energy mix in many countries, affordability, and vested interests in coal and related industries. Beyond the investment and employment in the

coal mining industry, coal is also entrenched in the economy of many coal producing and consuming countries on a large scale in terms of investment, employment and revenue. There are also large numbers of coal-fired power plants, which often last several decades and thus cannot be reasonably changed in the short term. Coal is also a cheap and affordable energy source in many developing countries.

Coal is very likely to continue its dominance in the Chinese energy mix in the future. China is extremely abundant in coal reserves but poor in gas and oil reserves and thus more than half of its oil consumption is supplied by imports at this stage, which has led to tensions in the world oil markets. Despite an increasing share of non-fossil energies, together they provided only 8.9 per cent of China's national energy consumption in 2008 (NBS, various years). Even allowing for the planned building of 41 nuclear power stations before 2020, it is estimated that China's nuclear capacity will power only 4 per cent of the national total installed electricity capacity in 2020 (NDRC, 2007a). Since coal is still expected to be the major energy source in the future, it is important for China to find ways to reconcile the continuous use of coal and the protection of the environment.

Given that China is the world's largest coal consumer, using 46.9 per cent of the world's total coal consumption in 2009 (BP2010), the clean use of coal is of great concern both to China and to the global community. The cleaning of coal is important to the Chinese people and the Chinese economy, as SO₂ and other non-CO₂ pollutions are by-products of China's economic growth, but with significant costs. Local ambient air pollution is predicted to cost 13% of China's GDP by 2020, as a result of health damage (OECD, 2007). The attempts to clean up the use of coal are also important to the global community if it wants to mitigate the climate change impact of coal use.

4.2 Policy implications

The development and utilization of CCTs should be promoted to make coal use more environmentally acceptable. The application of CCTs, which is often induced by environmental regulation and policy, is a major instrument in converting the goals of

environmental regulation into reality. It is necessary to create an institutional environment with appropriate penalties and incentives that stimulates and forces coal users—particularly large-scale users such as steel makers and power generators—to develop and employ appropriate technology. International cooperation and making use of the international cooperation system, such as the Clean Development Mechanism, are important to applying new CCTs and funding environmental protection projects.

It should be understood that many CCTs have both environmental and economic benefits and a push for CCTs' adoption does not always result in negative impact on economic growth. IGCC technology could increase generating efficiencies by 20 to 30 per cent, with reference to conventional coal-fired power plants, and reduce emission levels (especially of CO₂ and SO₂) more effectively than present pollution-control technologies (EIA, 2001).

Improvement of energy efficiency is another practical way to ease the tension between coal uses and the environment. The energy intensity per unit of GDP in China is 20 per cent higher than the OECD average (OECD, 2007), which implies a huge potential for improvement. One per cent increase of efficiency by Chinese coal-fired plants could lead to more than 35 million tons annual reduction of carbon emissions, and such a one per cent increase worldwide would reduce atmospheric carbon concentration by 10-20 ppm (Wells, 2009). The improvement of energy efficiency can be delivered through commercial methods with the assistance of governments and non-government organisations (Shi, 2010).

Appropriate legal regimes such as government policy and environmental regulations in areas such as environmental and energy efficiency should be in place to force or encourage coal users to reduce their emission, because many emissions were produced due to lack of application of, rather than a shortage of, available CCTs. The empirical estimations demonstrate that enforcement of environmental regulations plays a significant role in reducing non-CO₂ emissions. This simple comparison across countries implies that technology availability is necessary but not sufficient to lead a reconciliation of coal use with the environment. Regulation and affiliated enforcement are also necessary to push or induce

coal users to apply CCTs and thus reduce the emission intensity of coal.

Fiscal regimes that create incentives should be established, together with tightening of regulations. Public funding for R&D and fiscal instruments such as tax holidays and tax credits should be employed. Economic instruments, in particular pricing, could be used to facilitate the reconciliation of coal and the environment. Pollution and carbon prices can also accelerate the pace of technical application by making new technologies more attractive (MIT2007).

4.3 Climate change

In the case of climate change, although the Chinese government has not committed to, and is unlikely to commit to, a cap on CO₂ emissions, it has promised a 40-45 percent reduction of carbon intensity in 2020 with reference to 2005 levels (Xinhua, 2010). Attempts to mitigate CO₂ emissions are underway. For example, China's first Integrated Gasification Combined Cycle (IGCC) power station, a 250,000 kWh power station that will reduce annual coal consumption by 70,000 tons and CO₂ emissions by 90 per cent compared with a standard power plant, is scheduled to go online in Tianjin in 2011 (China Daily, 2010).

When facing a future in which coal will continue to dominate the energy mix and the environment will be strictly protected, high efficiency and clean technology will be crucial for China. Zero or near-zero emissions from coal-fired power plants are technologically feasible. However, in general, the problem in China is not a shortage of feasible CCTs, but the lack of their application—the result of insufficient incentives and external pressures (Shi, 2008). For example, most of China's electricity is produced from coal and most coal-fired plants are far dirtier than those found in OECD countries (IEA, 2007); only 10 per cent of power plants had installed Flue Gas Desulphurisation (FGD) equipment in 2005 (IEA, 2007); and as a cheaper alternative to the use of FGD, coal-washing has not been used widely. Washed coal accounted for only 32 per cent of total coal consumption in 2005 (NDRC, 2007b).

This experience in reducing non-CO₂ emissions and applying CCTs might imply that

reduction of the CO₂ emissions of coal could be possible in future, since zero or near-zero emissions from coal-fired power plants through carbon capture and storage (CCS) are technologically feasible (Sachs, 2008). Their economic viability can be improved through technical progress and a carbon cap or carbon taxes. Another positive factor is that the economic feasibility of CCT will increase over time, because people are willing to pay more when they are richer (Shi, 2008).

CCS may be first implemented in the case where other benefits can be generated. Captured CO₂ can be injected into oil fields to increase the oil-recovery rate by 4-18 per cent (Tzimas *et al.*, 2006). Other carbon storage technologies, such as the creation of charcoal by the pyrolysis of biomass (“biochar”), can not only reduce atmospheric greenhouse gas levels, but can also improve soil fertility, increase agricultural productivity and improve water quality (Lehmann *et al.*, 2006). For example, China’s Shenhua Group, who has a coal to liquid factor, is cooperating with the China National Petroleum Company (CNPC) to capture carbon dioxide and inject it into oil fields to increase the oil-recovery rate.

5 Conclusion

This paper tests the relationship between coal use and WGEs over time with two sets of Chinese data. The efforts China has made to achieve these results were briefly discussed and a simple comparison with the other two major coal users, the US and India, was presented. The paper also discusses the role of CCTs, energy efficiency, and legal and fiscal regimes related to environmental protection in reconciling coal and the environment.

The hypothesis that coal has experienced declining emission intensity is demonstrated by China’s empirical data relating to three major non-CO₂ emissions from coal. The econometric study finds a common declining trend of emission intensity in the three pollutions and differentiated declining trend of emission intensities between the two kinds of coal. The decomposition approach quantifies the individual effects of the six decomposed factors in changing total WGE and finds that declining emission intensity had the largest effect on emission reduction.

The decline in emission intensity provides a possible means of resolving the tension between the use of coal and the environment, which can ease the tension between the continuous use of coal to power economic development and increasing demand for environmental protection. Based on these quantitative and qualitative findings, the paper argues that coal has been, and is likely to be, reconciled with the environment in the case of non-CO₂ emissions. Since CO₂ is technically removable, such declining emission intensity could be applied to the case of CO₂ in a carbon-constrained future.

The development and application of CCTs are important for the reconciliation of coal and the environment. The improvement of energy efficiency is another method for harmonizing the use of coal with the environment, and can be implemented through commercial methods. The application of CCTs and energy efficiency has both environmental and economic benefits. However, policy interventions are necessary and crucial to support the adoption of CCTs and improvement of energy efficiency. Legal and fiscal regimes, including environmental regulations and economic instruments, should be established to push or encourage the adoption and development of CCTs. Enforcement of environmental regulations is also effective in facilitating the emission reduction and thus reconciliation.

This paper may be subject to criticism with regard to data quality, as it has been observed that environmental monitoring systems in China are being gradually improved, leaving a scope for recording more accurate data in future. However, this observation will strengthen, rather than weaken, the empirical findings because even with a more accurate statistics record later on, there is an evidence of significant estimated improvement of environmental performance over time.

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