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An analysis of the driving forces behind pollutant emission reduction in Chinese industry

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ABSTRACT

The rapid economic development of China has been accompanied by the emission of a great number of pollutants, which in turn have caused severe environmental problems. To strengthen environmental management and to establish a pollution source information database covering all key pollution sources and activities, China carried out its first National Census of Pollution Sources (NCPS) in 2007. The survey contents include the basic environmental situation in 2007, the generation levels of the main pollutants at that time, and the amount of pollution actually discharged into the environment after end-of-pipe treatment at all kinds of pollution sources. Based on the first NCPS report for China released in 2011, and taking two typical industry pollutants, sulfur dioxide (SO_2), and chemical oxygen demand (COD) as examples, we first revised the historical data concerning environmental statistics based on the NCPS documents. Subsequently, we analyzed the overall industrial scale in the change of SO_2 and COD emissions using index decomposition analysis, and then studied the contributions and comparative significance of the "three pollution emission reduction measures" put forward by the Chinese government. The latter are: Engineering Emission Reduction (EER), Structure Emission Reduction (SrER) and Supervision Emission Reduction (SuER). From these analyses, we were able to identify the main driving forces for SO_2 and COD emission reduction in China's industrial system. The results indicate that, with continually increasing pollution pressure caused by rapid economic development, EER and SuER have made the greatest contributions to reducing SO_2 and COD emissions; but SrER has not had an obvious effect. In the future, EER and SuER will gradually have less and less potential and become more challenging, while SrER should be achievable through adjusting the economic structure.

1. Introduction

As the most populous country and now the second largest economy in the world, China has achieved an unprecedented economic rate of growth in the past 30 years. But it has also been confronted with extraordinary environmental problems and challenges (Kan, 2009; Liu et al., 2003) as result of this growth. At present, China has approximately 1.43 million sources of industrial pollution (National Pollution Census Compilation Committee, 2011). Meanwhile, industries with high resource consumption, high energy consumption, and high pollution emissions make up a large proportion of the total industrial sector domestically, while also being significant at the global level. For example, the steel, coal, cement and chemical fiber industries of China, respectively, accounted for 38.4%, 38%, 45% and 57% of total global capacity in 2010 (Chinese Academy of Engineering, 2010; Stern, 2002). Furthermore, many industries do not possess up-to-date production technologies, lack pollution control facilities, or only have facilities that cannot be operated reliably or stably (Ministry of Environmental Protection of China, 2010). It is also challenging for the government to have to supervise the millions of small- and middle-sized companies that also produce pollution. How China can solve these environmental problems has been a focus of the world's attention (Liu and Diamond, 2005; WWF, 2010).

According to Chinese environment statistics, only key enterprises are included in the annual environmental report; a large number of middle- and small-sized enterprises are not included within the scope of the statistics (Ministry of Environmental Protection of China, 2002–2007). In order to strengthen environmental supervision and management, and establish a pollution source information database covering all kinds of pollution sources activities, the Chinese government launched the National Census of

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Pollution Sources (NCPS) from 2007 to 2009. The survey contents include the basic situation of enterprises, main pollutants generated, and discharged after end-of-pipe treatment at all kinds of pollution sources. Overall, 5,925,600 targets were investigated and 1.1 billion data points relating to various pollution sources were obtained. Data on the emission levels and whereabouts of the main pollutants, and on the operating conditions of pollution control facilities, were comprehensively investigated. The NCPS report is the most complete information about pollution sources and pollution emissions available in China. Previous environmental statistics can be updated and made more accurate based on this NCPS data.

On the other hand, in order to reduce pollution emissions and prevent continual environmental deterioration, three key measures for pollution reduction—Engineering Emission Reduction (EER, or emission reduction by engineering measures), Structure Emission Reduction (SrER, emission reduction through economic structure change) and Supervision Emission Reduction (SuER, emission reduction through the strengthening of management measures)—were implemented in 1996 (Cao et al., 2009; Pasche, 2002; Qi et al., 2011). Through solid efforts, China successfully reduced the total amount of sulfur dioxide (SO_2) and chemical oxygen demand (COD) emitted from 2005 to 2010. Meanwhile, China maintained rapid economic growth; growth in gross domestic product (GDP) achieved an average increase of 11.4% from 2005 to 2010, a cumulative increase of 71.6%. This is a further indication that the amount of SO_2 and COD emitted per unit of GDP has decreased significantly (Cao et al., 2009).

Although China has achieved real progress in the reduction of pollutant emissions, the country has also been confronted with many severe challenges (Chinese Academy of Engineering, 2010; Richerzhagen and Scholz, 2008). Industry is the main source of the generation and emission of pollutants in China (Ma et al., 2014); industrial emissions of three key pollutants SO_2, COD and NO_x account for 91%, 42% and 66% of the total emissions, respectively (Wei et al., 2014). Industry is also the main emission source of dust and soot, heavy metals and toxic organic compounds (Ministry of Environmental Protection, 2010). Therefore, it is necessary to analyze the driving forces behind the generation and emission of industrial pollutants in China, discover the key factors for pollution control, and explore more effective emission reduction measures.

This paper analyzes the industrial system in China (mainland) and its key pollutants (SO_2 and COD), revises historical environmental statistical data with the more accurate data from the first NCPS, and analyzes the contributions and comparative significance of pollution reduction using the three measures (EER, SrER, and SuER) from 2001 to 2010, through using an index decomposition analysis method. This analysis thus recognizes the key driving forces behind pollution reduction in Chinese industry, and suggests more efficient and sustainable pollution reduction strategies.

2. Method and data

2.1. Index decomposition analysis

Index decomposition analysis is frequently used to analyze the impact of factors such as economic growth, economic structure transformation, and technical progress, on the transformation of economic or environmental indicators (Ang, 2004, 2005; Sun, 2001). This method can, for example, directly decompose the variation in pollutant emissions and make a quantitative analysis of the influencing factors (Chen et al., 2004; Fujii et al., 2013). Furthermore, the decomposition method separates the contributions and relative importance of the various mechanisms available for changes in pollution emission, and this provides an empirical basis for establishing and examining the pollution reduction measures used (Selden et al., 1999; Shao et al., 2014). Here a specific index decomposition analysis model is developed. First, the amount of pollution emissions can be expressed as the product of four different factors:

$$Q = E \cdot I \cdot S \cdot T \tag{1}$$

where Q refers to the total emission of pollutants; E = (e1, e2, ..., ek, ..., e39)T is a 1 × 39 vector and indicates the impact of the EER measure, specifically the pollutant emission rate in 39 industries in the national economy of China, with element ek referring to the emission rate of pollutants in the kth industry after the end-of-pipe treatment; I is a 39 × 39 diagonal matrix and refers to the factor of SuER measure, with its diagonal vector (i1, i2, ..., ik, ..., i39)T indicating the pollutants produced per unit output of each industry; S is also a 39 × 39 diagonal matrix and refers to the factor of SrER measure, with its diagonal vector (s1, s2, ..., sk, ..., s39)T indicating the proportion of the industrial output of each industry to the total industrial output value; and T refers to the total amount of the industrial economy, indicating the scale effect of economic growth.

Equation (1) indicates that the three measures of pollution reduction (EER, SuER, and SrER) and economic growth all lead to variations in the amount of pollutants emitted. Following these assumptions, during a certain period t0 to t1, the total emission amount of pollutants changes from Q0 to Q1, and the variation can be described as follows:

$$\Delta Q = Q_1 - Q_0 = \Delta Q_E + \Delta Q_I + \Delta Q_S + \Delta Q_T \tag{2}$$

where $\varDelta Q$ refers to the variation in the total amount; and $\varDelta Q_E, \varDelta Q_I, \varDelta Q_S, \varDelta Q_T$ respectively refer to the driving effects of the four factors EER, SuER, SrER, and economic growth, namely the contribution to$\varDelta Q$. Briefly, the change in pollutant emission amount is the sum of the driving effects of the four factors during a certain period.

The residual produced by the coupling effect of the variation of factors will be modified in order to completely include the variation of pollution emissions into different effects. The residual decomposition is as follows:

$$\begin{aligned} Q_1 - Q_0 &= E_1 \cdot I_1 \cdot S_1 \cdot T_1 - E_0 \cdot I_0 \cdot S_0 \cdot T_0 \\ &= (E_0 + \Delta E)(I_0 + \Delta I)(S_0 + \Delta S)(T_0 + \Delta T) - E_0 \cdot I_0 \cdot S_0 \cdot T_0 \\ &= \cdots + \Delta E \cdot \Delta I \cdot S_0 \cdot \Delta T + \cdots + \Delta E \cdot \Delta I \cdot \Delta S \cdot \Delta T \end{aligned} \tag{3}$$

Here, Q0 and Q1 respectively refer to the total emissions in the time of t0 and t1; E0, I0, S0, T0 and E1, I1, S1, T1 respectively refer to the four driving factors of t0 and t1; and $\varDelta E, \varDelta I, \varDelta S, \varDelta T$ refer to the variation value of the four driving factors during t0–t1.

At present, the residual decomposition methods that are extensively applied include fixed weight, applicable weight, and equal distribution of residuals methods (Ang and Zhang, 2000; Sun, 1998). This study adopts the equal distribution of residuals suggested by Sun (1998), to achieve the complete decomposition of the factors. This method distributes the residual item between relevant factors under the principles of equal distribution based on the Laspeyres decomposition. For instance, the residual item $\varDelta E \cdot \varDelta I \cdot S_0 \cdot \varDelta T$ can be deemed to be driven by changes in the three factors E, I, and T. Therefore this residual item decomposes into three equal portions ($\frac{1}{3} \varDelta E \cdot \varDelta I \cdot S_0 \cdot \varDelta T$), which are then added respectively to$\varDelta Q_E, \varDelta Q_I, \varDelta Q_T$. For instance:

$$\begin{aligned} \Delta Q_E = {} & \Delta E \cdot I_0 \cdot S_0 \cdot T_0 + \frac{1}{2}\Delta E \cdot \Delta I \cdot S_0 \cdot T_0 + \frac{1}{2}\Delta E \cdot I_0 \cdot S_0 \cdot \Delta T \\ & + \frac{1}{3}\Delta E \cdot \Delta I \cdot S_0 \cdot \Delta T + \frac{1}{4}\Delta E \cdot \Delta I \cdot \Delta S \cdot \Delta T \end{aligned} \tag{4}$$