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Economic evaluation of environmental externalities in China's coal-fired power generation

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ABSTRACT

Serious environmental externalities exist in China's power industry. Environmental economics theory suggests that the evaluation of environmental externality is the basis of designing an efficient regulation. The purposes of this study are: (1) to identify Chinese respondents' preferences for green development of electric power industry and the socio-economic characteristics behind them; (2) to investigate the different attitudes of the respondents towards pollution and CO_2 reduction; (3) to quantitatively evaluate the environmental cost of China's coal-fired power generation. Based on the method of choice experiments (CE) and the 411 questionnaires with 2466 data points, we found that Chinese respondents prefer PM2.5, SO_2 and NO_x reduction to CO_2 reduction and that the environment cost of coal-fired power plants in China is 0.30 yuan per kWh. In addition, we found that the socio-economic characteristics of income, education, gender, and environmental awareness have significant impacts on respondents' choices. These findings indicate that the environmental cost of coal-fired power generation is a significant factor that requires great consideration in the formulation of electric power development policies. In addition, importance should also be attached to the implementation of green power price policy and enhancement of environmental protection awareness.

1. Introduction

Along with its dramatic economic development over the past decades, China has become the largest country energy consumption and CO_2 emission in the world, and is facing increasingly challenges of energy and environment in its path towards sustainable development. Numerous cities have witnessed frequent weather events of heavy fog and haze that linger over large areas of land, resulting in damages to people's mental and physical health. The appearance of China's "cancer villages", one of the serious consequences of the environment deterioration, is the result of countrywide pollution of air, land, and water (Zhao et al., 2014). The mortality of lung cancer patients in China has increased by 465% over the past 30 years,[1] and China's annual newly added cancer cases account for more than 20% of the total new cases in the world.[2]

Balancing environmental protection and economic development is a key step to realize sustainable development in China. Xepapadeas (1992) noted that the dischargers will always choose higher than socially desirable emission levels if by doing so they can increase their profits. As such, in the absence of environmental regulation, the external environmental cost is not the decision-making factor that producers consider, i.e., the cost of emission is zero (Tang, 2011). The objective of environmental regulation then is to motivate dischargers to internalize their external environmental cost. However, a serious challenge that policy makers are faced with is the lack of quantitative information on external environmental cost; there is no conventional market or price for pollutants to provide quantifiable measures of the environmental externality. Therefore, quantitative assessment of external costs to the environment is an important foundation for building stringent environmental regulations.

Along with China's dramatic economic growth over the past decades, the external environmental cost resulted from the coal-

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[1] Data source: the 3rd national investigation on death causes conducted by National Health and Family Planning Commission of PRC.
[2] Data source: the 22nd Asia Pacific Cancer Conference.

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dominated energy mix in the country is significant. In China, the coal-based power generation industry accounts for approximately 50% of the total coal consumption, and produces 40% of the CO_2 emission, 60% of the SO_2 emission and 60% of the NO_x emission of the whole country (SO_2 and NO_x emissions are the primary drivers in acid rain creation). To control the pollutant and greenhouse gas (GHG) emissions in electric sector, China's government has published a series of environmental regulations (Zhao et al., 2015). However, the implementation effects of these regulations are limited. One important reason is that the formulation of these regulations lacks strict reasoning and is subjective and arbitrary. According to the environmental economics regulation theory, an efficient environmental policy should be designed based on the cost caused by pollutant emissions. Hence, the quantitative analysis of the environmental cost of China's coal-based industry will provide a scientific basis for the environmental regulation in China's power industry.

Based on the method of choice experiments (CE) (also called choice model), we found that respondents have a preference to an electricity premium for promoting cleaner production of coal-fired power plants, which is consistent with our expectation that greater environmental awareness translates into a higher premium paid. It is also concluded that Chinese correspondents have higher preferences to the reduction of PM2.5, SO_2 and NO_x than CO_2. This result implies that China's government should pay more attention to educating the public about the importance of emission reduction of CO_2 and other kinds of GHG. Moreover, it is concluded that each household has the willingness to pay 40 yuan per month or 0.30 yuan per kWh for the best situation of environmental improvement.

The rest of this paper is organized as follows: Section 2 goes through main studies and results applying the methods of CE. Section 3 is about the background of coal-fired power in China and its environmental externalities. Sections 4 and 5 describe our choice experiment design and methodology respectively; and Section 6 discusses the results. Conclusion and policy implications are provided in Section 7.

2. Literature review

Study of the environmental externalities of the power industry has recently become a hot research topic. Most studies have focused on the value of renewable energy by evaluating respondents' preference to it. While Susaeta et al. (2011) assessed preferences for woody biomass-based electricity in the United States, which amounted to US $40.5 per capita annually, Longo et al. (2008) assessed the preferences of respondents for a policy to promote renewable energy in England and found that the willingness to pay (WTP) every year for reducing carbon emissions by one ton of CO_2 is US $967 in UK. Ek and Persson (2014) explored public preferences for characteristics of wind farm establishments in Sweden. Their results indicated that respondents are willing to pay a higher electricity fee corresponding to approximately 0.6 Euro per kWh to avoid wind farms located in mountainous areas and private ownership regions. Kosenius and Ollikainen (2013) elicited people's collective monetary preferences for four renewable energy sources: wind, hydro, crops, and wood, and considered the impacts of biodiversity, local jobs, carbon emissions, and the household's electricity bill. They concluded that the national aggregate WTP, for a combination of renewable energy technologies, is over 500 million Euros in Finland.

A few studies compared the environmental value of different renewable energy. For example, Borchers et al. (2007) estimated consumer preferences and the WTP for voluntary participation in green energy electricity programs, including wind, biomass, solar, and farm methane. Their results showed that individuals have a preference for solar over a generic green and wind; biomass and farm methane were found to be the least preferred sources. All of the above studies are based on the method of CE. The merits of CE comparing with other methods used for evaluating environmental cost will be discussed in Section 4.

Although the current studies have found numerous significant conclusions in environmental cost evaluation of power sector, the following issues remain to be addressed: (1) There is a lack of evaluation of cleaner production preference in coal-fired power industry, especially in China's coal-fired power industry based on CE. (2) The impact of environmental conscious on respondent preference has attracted limited concerned. Ellis et al. (2007) pointed out that respondents value and feeling have significant influence on their preference to renewable energy. However, the empirical studies of integrating environmental consciousness into the analysis of environmental cost of power sector are lack. (3) The different preference to GHG (such as CO_2), PM2.5, SO_2 and NO_x is not considered.

The contribution of this study is to investigate the respondent preferences to green development of China's coal-fired power industry considering the differences in environmental consciousness and various emissions based on the CE model. To reduce hypothetical bias, we incorporate a "cheap talk script"[3] method in the design of questionnaires following Carlsson et al. (2005) and Cummings and Taylor (1999).

3. Current status and environmental externalities of China's coal-fired power industry

Currently, China's power supply mix is dominated by coal-based power generation.[4] Fig. 1 shows that prior to 2011, the proportion of thermal power (dominated by coal-based power) generation in the national total is approximately 85%, and since 2011, this proportion has decreased due to China's renewable energy development and the restraint in coal consumption growth. However, in 2014 the proportion was still approximately 75%.

The high proportion of thermal power generation results in the excessive environmental externality in China's electricity production. According to the Annual Statistic Report on Environment in China (2006–2014), the emission of NO_x, SO_2 and smoke dust from thermal power industry accounted for 55.74%, 39.30% and 16.17% of China's total emission of industrial sectors respectively (Fig. 2).

Fig. 2 shows further that, SO_2 and smoke dust emission has taken on a decreased trend in China's thermal power industry since 2006. This is caused by stricter regulation standards. China published *Standards for Air Pollutant Discharge from Thermal Power Plants (GB 13223-1991) (SAPD)* for the first time in 1991. The standard was improved in 1996, 2003, and 2011. Along with increasingly stricter standards, China's thermal power sector was making increasingly cleaner production.

However, unlike the continuously decreasing emission trend of SO_2 and smoke dust, NO_x emission saw an increase at first and then began to decrease in 2012 (Fig. 2). This phenomenon is probably due to the fact that China's government paid more attention to the regulation of SO_2 and smoke dust than of NO_x prior to 2011. The fourth amendment of the *SAPD (2011)* was much stricter than the *SAPD (2003)* in the emission limit of NO_x from coal-fired power plants, significantly reducing the upper limit for NO_x from 45 to 1500 mg per cubic meter to 100 mg per cubic meter for coal-based power plants.

Differing from the localized impact on the environment of emissions from SO_2, smoke dust, NO_x, CO_2 emission has a global impact.

[3] Estimation results of willingness to pay from experiments often demonstrate significant differences between responses to the real and hypothetical valuation questions. Such differences are usually called "hypothetical bias". In order to avoid the bias, Cummings and Taylor (1999) put forward the "cheap talk script" method. By involving actual payments or designing a context that will happen, the "cheap talk script" method can elicit responses to hypothetical valuation questions that were indistinguishable from responses to valuation questions (Cummings and Taylor, 1999).

[4] Coal used by power generation generally includes hard coal, bituminous coal, and poor lean coal. Around 90% of coal used in China's power generation sector is bituminous coal (Zhang, 2007).