A study on transboundary air pollution based on a game theory model: Cases of SO$_2$ emission reductions in the cities of Changsha, Zhuzhou and Xiangtan in China

Guang-Ming Shi $^a$, Jin-Nan Wang $^b$,*, Fei Fu $^b$, Wen-Bo Xue $^b$

$^a$ Institute of Environmental Economy and Policy, Hunan Research Academy of Environmental Science, Changsha 410006, China
$^b$ Chinese Academy of Environmental Planning, Beijing 100012, China

**Abstract**

China now faces severe air pollution problems while consuming a huge quantity of coal. At present, due to the emission charges and the emissions trading policy failed to effectively prompt enterprises to reduce emissions and improve air quality. Therefore, improving air quality through regional negotiations and cooperation may be feasible and effective. In this study, which was based on game theory, a transboundary air pollution model was established to conduct an empirical study on the cost-effectiveness of cooperative SO$_2$ reduction in three cities of Hunan province in China. Four gain allocation mechanisms, i.e., the nucleolus, Nash-Harsanyi allocation solution, Shapley value and Separable Cost Remaining Benefit (SCRB) principle, were employed to allocate the gains of cooperation, and the fairness and stability of the different allocation mechanisms were also analyzed. The results show that if a gain-sharing mechanism can reasonably allocate the gain from full cooperation, it is then feasible and effective for the three cities to fully cooperate to reduce SO$_2$ emissions. Among the four gain allocation methods investigated in this empirical study, the stabilities of gain allocation for full cooperation using SCRB principle and Nash-Harsanyi allocation method were higher than those using the other two allocation methods. The results provide clear empirical evidence that regional gain allocation may affect the sustainability of cooperation. Therefore, although it was desirable to reduce SO$_2$ emissions through cooperation, the long-term sustainability of cooperation should be taken into account in developing relevant policies.

*Corresponding author. Fax: +86 10 84918581.
E-mail addresses: wangjn@caep.org.cn, wangjin1962@126.com (J.-N. Wang).
Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.

http://dx.doi.org/10.1016/j.apr.2016.09.003

1. Introduction

Given rapid industrialization and urbanization, China’s economy has grown rapidly in the last 30 years of Reform and Opening-up, and it is now the world’s second largest. In the process of rapid economic development, large quantities of resources and fuel (especially coal) have been consumed, which has resulted in dramatic increases in the emission of air pollutants such that air pollution in China is among the worst in the world (Kan et al., 2012). Meanwhile, with the rapid increase in vehicle ownership, China’s air pollution has been transformed from traditional coal-burning pollution to the complex pollution derived from the mixing of coal-burning and vehicle exhaust pollutants, which has therefore led to serious air pollution problems in China’s megacities (e.g., Beijing, Tianjin, and Shanghai) (Watts, 2005; Chan and Yao, 2008).

Because many air pollutants (e.g., SO$_2$ and NO$_x$) can be transmitted over long distances, the air pollution in an area is no longer caused by emissions from single point and non-point sources, and transboundary air pollution problems caused by other regions have become more frequent and severe and have led to the regional, comprehensive and complex characteristics of China’s air pollution. Therefore, to improve air and environmental quality in an area, it is necessary to implement cooperative controls on multi-regional/area emissions that focus on pollutants transmitted over long distances (Chinese Academy of Engineering and Chinese Ministry of Environmental Protection, 2006).

Generally, transboundary pollution within a country can be resolved through the central government’s collection of sufficient pollutant emissions taxes or by emissions trading so that each region is able to reduce pollutant emissions
2002). However, because it is impossible to collect pollutant emission taxes when different countries are involved, it is therefore necessary for countries to cooperatively negotiate emission reductions to solve transboundary air pollution problems.

Although the Chinese central government is levying emission charges on the country’s regional governments, the proportion of the charges was too low and failed to effectively prompt enterprises to reduce emissions and improve air quality; moreover, at present, an emissions trading policy has not been established in China (Zhang et al., 2012). In this case, improving air quality through regional negotiations and cooperation may be feasible and effective. Based on the above discussion, the purpose of this study was to use cooperative and non-cooperative game models under the cost-effectiveness analysis of the game theory framework and then conduct an empirical study on a case involving three cities (Changsha, Zhuhou and Xiangtang) in Hunan Province, China, to investigate the cost and effects of SO₂ emissions control through non-cooperation or cooperation among the cities. Furthermore, the allocation of the gain from cooperation to facilitate each of the regions to stably reach an agreement on cooperating to reduce SO₂ emissions was analyzed to provide references for negotiating transboundary air pollution conflicts among different regions in China.

2. Literature review

Globally, due to rapid economic development, the consumption of large quantities of energy and the emission of pollutants, European countries in the late 20th century experienced local, regional and global air pollution and environmental problems such as cross-regional acid rain pollution caused by SO₂ emissions and global climate change caused by CO₂ emissions. To establish references for negotiation and decision-making between different countries to form effective agreements, in the late 1980s, many scholars investigated multi-regional and global environmental air pollution problems under the premises of certain actions. Mäler (1989) for the first time employed game theory and systems analysis to study the transboundary pollution problem of acid rain in Europe, and many similar studies on transboundary acid rain followed. Chambers and Jensen (2002) established a two-stage game model to analyze the effects of untied aid from developed countries to developing countries on reducing transboundary emissions and showed that in the short term, untied aid did not effectively reduce pollutant emissions in developing countries.

Under the condition of asymmetric information, Huber and Wirl (1996) constructed a model based on principal-agent theory to interpret whether environmental subsidies from Austria, a Western European country, to the former Czechoslovakia, an Eastern European country, helped reduce sulfur emissions. The simulation results showed that the subsidy from Austria was effective only in the case that the former Czechoslovakia itself had attached sufficient importance to environmental and air quality. Caplan and Silva (1999) constructed a two-stage Stackelberg game model under the condition that the government prompted the region to reduce pollutant emissions by levying pollution taxes to compare and analyze the effectiveness of implementing acid rain control policies in the two governments’ games (American games and European games). The results showed that the game whereby the government imposed pollution taxes and regional governments reduced emissions according to the taxes was more effective. van Ierland (1991) integrated SO₂ and NOₓ into the game theory framework to analyze the cost-effectiveness of the cooperative control of transboundary air pollution for 28 European sovereign countries. The results showed that an optimal result was obtained when all the nations cooperated fully. Kaitala et al. (1992) analyzed the cost-efficiency of a Finnish/Soviet SO₂ agreement. After evaluating the results of a Nash equilibrium and a full cooperation outcome, it was found that the payments by Finland based on the agreement between the two countries should have been sufficiently high to induce the then still existing Soviet Union to undertake the abatement required for a full-cooperative outcome. Subsequently, Kaitala et al. (1995) also investigated transboundary acid rain pollution in Finland, Russia, and Estonia. Halkos (1996) constructed a game theory model under the condition of incomplete information and applied the model to an analysis of transboundary acid rain pollution. The study results showed that in the case of incomplete information, the gains under full cooperation were lower than those under complete information.

In addition, when multiple parties cooperate to solve the problem of transboundary pollution, each participating party must gain from the cooperation (Missfeldt, 1999); therefore, some scholars have investigated the gain allocation problem using game theory. Eyckmans and Tulkens (2003) used the CLIMNEG global simulation model to simulate the global climate change mitigation agreement of six regions and used the Germain-Point-Point gain/cost sharing mechanism to allocate the gain from the cooperative reduction under different cooperation situations. They found that the gain-sharing mechanism could better encourage the states to cooperate in reducing emissions. Because a cost-sharing mechanism using the Shapley value method could not meet the requirement of individual rationality, Jorgensen and Zaccour (2001) designed a dynamic sharing mechanism to solve that problem, which enabled the benefits of each of the cooperative parties in any given time period to be greater than those without cooperation in the same time period. To ensure that states are able to form a long lasting and stable coalition and prevent free-riding after cooperative reductions in emissions, Eyckmans and Finus (2004) constructed an almost ideal sharing scheme to address the free-rider issue that might arise in coalitions. The scheme first allocates the gain that likely arises through the free-riding to each state by using the gain arising from full cooperation among the nations and then evenly distributes the remaining part of the gain among the nations based on certain proportions; however, in this scheme, the gain from full cooperation is still unable to offset the benefit of each state from free-riding. Nagashima et al. (2009) adopted four commonly used benefit/cost sharing mechanisms to examine the stability of an international climate change agreement and found that all four mechanisms promoted the greater coalition, but no single mechanism was able to facilitate full cooperation among all the countries. Dellink and Finus (2012) investigated the stability of a climate change agreement among 15 regions worldwide, including the United States and China, under conditions of uncertainty or certainty and found that when there was a good benefit-sharing mechanism, uncertainty helped each country form a good partnership and greatly reduced free-riding behavior; on the contrary, when there was not a good cost-sharing mechanism, uncertainty only exacerbated mistrust among the nations and therefore was unable to help the coalition achieve greenhouse gas emission reductions.

Lange et al. (2010) investigated the payment preferences in gain-sharing mechanisms of citizens from different countries on climate change mitigation cooperation; Carlsson et al. (2013) studied the payment preferences in cost-sharing mechanisms of citizens from China and the US on climate change cooperation. These studies revealed that citizens from different nations had a strong preference for the gain-sharing mechanism that allowed their respective nation to incur lower costs, and the level of the preference was correlated to the subjects’ own perception of their fairness. Xue and Li (2013) established a game theory model to investigate the control of China’s total SO₂ emissions and employed the minimum cost remaining savings method to reallocate the benefit generated in the process of full cooperation, but the study did not address the stability issue of full cooperation after reallocating the cost.
دریافت فوری متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات