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Performance evaluation of climate policies in China: A study based on an integrated assessment model

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ABSTRACT

China has the world's highest levels of carbon dioxide (CO_2) emissions, and its adoption of optimal measures to address climate change is extremely important. In this article, we assess the performance of various Chinese policies aimed at addressing climate change in terms of cost effectiveness, cost-benefit efficiency, and their contribution to a reduction in emissions with a new single-region model, DEMETER-CCPE. Our analysis shows that the performance of these Chinese policies strongly depends on the principles and indicators used in the evaluation. When climate-specific cost indicators are considered, the mixed policy performs best in terms of cost reduction. When cost-efficiency indicators are used, a single policy performs better to some extent. From the perspective of evaluating the contribution to emissions reduction, the development of non-fossil-fuel-based energy technologies offers the greatest opportunity for reducing emissions in a mixed-policy scenario. Finally, this article study possible 'burden' and 'free-rider' scenarios in order to explore the effect of different levels of joint actions between China and the rest of the world (ROW) on a performance evaluation of policies to address climate change.

1. Introduction

In response to climate change, countries are adopting various policies to control CO_2 emissions. The implementation of such policies often has high economic costs, including macroeconomic costs, such as reductions in the gross domestic product (GDP), reductions in consumption, higher energy costs, and additional investment needed for producing energy. However, implementing policies to address climate change can also achieve potential benefits from climate damage reduction. Undoubtedly, the mitigation of CO_2 emissions is a long-term dynamic process. If targets are established for controlling concentrations of CO_2, the principles or indicators in a performance evaluation of those policies can not only show the way toward reducing emissions and the cost of doing so but also lead to potential benefits from preventing future damage. Hence, a comprehensive and reasonable assessment of various climate policies is critical in order to devise the correct mix of policies to achieve the desired goals.

Studies evaluating policies to address climate change usually use one of two kinds of analysis. The first is the use of cost-effectiveness analysis (CEA). Many studies use social utility maximization as a basis for determining the optimal climate policy (e.g., Duan et al., 2014; Gerlagh et al., 2004; Gerlagh and van der Zwaan, 2006; Maddison, 1995; Nordhaus, 1993; Nordhaus and Boyer, 2000; Nordhaus and Yang, 1996; Robinson, 1993; Van der Zwaan et al., 2002; Wigley et al., 1996), which refers primarily to reductions in consumption, reductions in the gross domestic product (GDP), increased energy costs, and additional investment in energy production caused by the implementation of policies to address climate change. The second is the use of cost-benefit analysis (CBA). Several studies have evaluated and monetized the potential benefit of preventing harm to assess climate policies (e.g., Bollen et al., 2009; Goulder and Mathai, 2000; Islam et al., 2003; Lind, 1995; Maddison, 1995; Manne et al., 1995; Tol, 2001).

The damage from climate change can be divided into two categories (Manne et al., 1995): market damage, or the effect of damage from climate change on goods sold in markets, such as food and energy; and nonmarket damage, or the effect of damage from climate change on services with no market value, such as biodiversity, environmental quality, and human health. The calculation

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of indirect benefits includes those from controlling emissions of other pollutants and from changes in the economy.

The previous CBA studies are primarily at the global level, and less attention is paid to regional climate policies. Global actions to address climate change are influenced to great extent by actions of particular countries, such as the United States, member countries of the European Union (EU), and China. China is the world's leader in terms of CO_2 emissions, at approximately 9245.10 million tonnes in 2015 which is around 27.60% of total global emissions (BP, 2016). Therefore, the implementation of policies in China to address emissions not only affects its domestic sustainable development but also has a strong impact on activities globally. However, it is difficult for a global model to consider and describe specific characteristics of economic development, energy use, and climate policies for every region. Moreover, except for controlled targets to reduce concentrations of CO_2, countries often adopt different emissions reduction policies, whether carbon taxes, subsidies, or other mixed policies. And many single-region integrated assessment models (IAMs) have been established to evaluate specific countries' climate policies (Wang et al., 2005, 2009; Wen et al., 2014; Zhu et al., 2014; Duan et al., 2014; Wu et al., 2016), such as the Chinese Energy-Economy-Environmental Model with Endogenous Technological change by employing Logistic curves (CE3METL) (Duan et al., 2014). However, regional damage to the climate is affected by the stock of global CO_2 (Nordhaus and Boyer, 2000), so single-region IAMs cannot easily evaluate potential benefits from preventing damage. Therefore, it is important to build a single-region model which addresses regional climate damage in order to evaluate the performance of regional climate policies from the perspective of cost-benefit efficiency.

In analyzing and evaluating the performance of regional climate policies in the medium and long term, we should focus on the following factors: (1) long-term horizon; (2) regional climate policies and mixed policies; (3) definition of a country's damage from climate change; and (4) evaluation based on comprehensive perspectives. Therefore, we built a single-region model, DEMETER-CCPE, which includes a regional assessment of damage from climate change, the expansion of energy technologies, a two-factor learning curve, limits to China's import and export trade, and an evaluation of performance in terms of emissions reduction (or abatement). Using this model, we simulate different policy scenarios for China and assess the abatement performance of Chinese climate policies from three perspectives: cost effectiveness, cost-benefit efficiency, and contribution to abatement. In summary, DEMETER-CCPE allows us to provide a theoretical analysis of principles and indicators for evaluating the performance of policies in China to address climate change.

The remainder of this paper is organized as follows: Section 2 provides an overview of our adaptation of DEMETER and gives a detailed explanation of how we extend the original model to our single-region model. Data and scenario setting are presented in Section 3. We highlight our most important results in Section 4, in terms of simulated CO_2 emissions levels and analyze the performance of China's policies to reduce emissions. In Section 5, we present our main conclusions and recommendations.

2. Model

2.1. The DEMETER-CCPE for China

Our model framework is based on the global integrated assessment model (IAM) called DEMETER (decarbonization model with endogenous technologies for emission reductions), which includes one representative consumer, one economic sector, two energy sectors (fossil fuel based and non−fossil fuel based), and a public agency that can impose taxes to limit CO_2 emissions. By distinguishing between old and new capacities, which enables the model to incorporate learning-by-doing, as seen in bottom-up approaches, this model mainly addresses the effect of endogenous technological progress on the optimal timing of abatement of CO_2 emission and the optimal path of emissions reduction policy required over time (Van der Zwaan et al., 2002).

In this paper, we improve on the DEMETER model to create a new version, DEMETER-CCPE (decarbonization model with endogenous technologies for emission reductions in an evaluation of Chinese climate policy), which evaluates a single region's policy addressing climate change. In this model, the object is still social utility maximization, which is obtained by the per capita consumption with regional climate damage feedback; see Equation (1).

$$W = \sum_{t=1}^{\infty} (1+\rho)^{-t} L_t \ln[(C_t - D_t)/L_t] \tag{1}$$

where ρ is a utility discount rate of 3.5% per year, C_t is the consumption level, D_t is the regional damage from climate change, and L_t is the population. The structure of the DEMETER-CCPE model is shown in Fig. 1. The original DEMETER model is presented in the Appendix.

2.2. Assessment of regional damage from climate change

Models assessing abatement policies for a single region or country have difficulty in accounting for potential benefits from preventing damage from climate change because regional damage is affected by accumulated CO_2 emissions. However, this benefit is an important part of assessing the performance of policies to abate damage in a single region or country.

Therefore, an emission ratio pathway (Θ_t) is used to calculate the share of CO_2 emissions between China and ROW expressed as $\widetilde{Em}_t^{ROW} = \Theta_t \widetilde{Em}_t^{domestic}$. The pathway of the emission ratio between China and ROW is calculated by original DEMETER model and our Chinese version of DEMETER model under Base scenario (see section 3.2) without any climate policy. The different levels ($\Delta\Theta_t$) of joint actions between China and ROW can be represented by the adjustment of the emission ratio pathway, which might impose additional abatement pressure for China or lead to China to be a 'free-rider' to address climate change.

Therefore, an accounting of global incremental emissions can be rewritten as Equation (2).

$$\widetilde{Em}_t = (1 + \Theta_t + \Delta\Theta_t)\widetilde{Em}_t^{domestic} \tag{2}$$

where $\widetilde{Em}_t$ is the global CO_2 incremental emissions, $\Delta\Theta_t$ is the parameter of levels of joint actions between China and ROW. Such levels of joint actions comprise 'burden' and 'free-rider' scenarios for China defined as the increasing and decreasing adjustments of the abatement ratio of China in the world in this model, respectively. Moreover, the increasing and decreasing adjustments of the abatement ratio start to emerge with the increasing ($\Delta\Theta_t > 0$) and decreasing ($\Delta\Theta_t < 0$) adjustments of the CO_2 emission ratio pathway (Θ_t), respectively. This can be explained as follow: the increasing and decreasing adjustments of the CO_2 emission ratio pathway (Θ_t) lead to decreasing and increasing adjustments of the CO_2 emission share of China in the world; the abatement ratio of China in the world is increased by the decreasing adjustment of the CO_2 emission share while it is decreasing by the increasing adjustment of the CO_2 emission share in this model.

Equation (3) accounts for incremental emissions of domestic