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Optimal policies for climate change: A joint consideration of CO_2 and methane

Xiao-Bing Zhang[a], Jing Xu[b,*]

[a] School of Economics, Renmin University of China, Beijing 100872, China
[b] School of Public Finance and Taxation, Southwestern University of Finance and Economics, Chengdu 611130, China

HIGHLIGHTS

- This paper studies the optimal policies under joint accounting of CO_2 and methane.
- A dynamic model is theoretically developed and calibrated to the global warming case.
- Different policies are solved under asymmetric information and pollutant correlation.
- It is optimal to levy tax on both CO_2 and methane.
- A mixed policy with tax on CO_2 and quota on methane is the second-ranked choice.

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ABSTRACT

Climate change mitigation requires the reduction of greenhouse gas (GHG) emissions. The majority of the discussions on climate change policy focus exclusively on the reduction of carbon dioxide (CO_2) emissions but ignore other important GHGs such as methane. This paper investigates the optimal choice of policy instruments under the joint consideration of CO_2 and methane in a dynamic setting with asymmetric information and pollutant correlations. We develop a dynamic programming model with two state variables and calibrate it to the global warming case. The results show that it is optimal to levy tax on both CO_2 and methane. A mixed strategy that implements a tax on CO_2 and a quota on methane is the second-ranked choice.

1. Introduction

Climate change has been raising concerns globally since the Kyoto Protocol was signed in the 1990s. Although governments, agencies and the public all agree on the necessity to control, mitigate and adapt to climate change, no consensus is gained on the regulating policy choices. Theoretically, intensive discussions exist on the price (tax) versus quantity (quota) comparison, see e.g. Weitzman [1], Pizer [2], Endres and Finus [3], and Karp and Zhang [4]. In practice, the public also debates on the policy options. For instance, the US Vice President Al Gore advocates carbon tax, while the UK Environment Secretary David Miliband proposes an alternative system including both individual carbon quotas and a national quota to be allocated or sold to industries.

The majority of the discussions on climate policy design focus on the emission reduction of carbon dioxide (CO_2) [5,6], the most important GHG. However, CO_2 is not the only cause of climate change. Methane, which contributes 18% of the total expected global warming [7], is also one of the most important GHGs. Shindell et al. [8] point out that both the CO_2 and methane are with the most radiative forcing associated with human activity. In addition, methane is an extremely potent greenhouse gas with 25 times the warming potential of carbon dioxide over a 100-year time period. As stated in Michaelis [9], policy measures against global warming should tackle not only the emissions of carbon dioxide, but also the emissions of methane and others.

Taking methane into consideration, the interaction of multiple GHGs in joint production, or abatement process should not be neglected. The correlation effect can be either substitutive or complementary [10]. For instance, carbon capture and storage could reduce methane with the pre-combustion technology, making the two pollutants substitutes in this case. The synergies and tradeoffs between pollutants cause different environmental policies correlated, which further emphasize the need for policy coordination [11]. Hence,

* Corresponding author.
E-mail addresses: xbzhmail@gmail.com (X.-B. Zhang), xuj@swufe.edu.cn (J. Xu).

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ignoring the other pollutant methane as well as the interaction between GHGs, and implementing CO_2 policy independently will hardly ensure efficiency in climate change mitigation.

Another challenge in designing climate policy is the considerable uncertainty about the cost of reducing emissions [12]. The cost uncertainty arises partly due to the uncertainty about the level of future baseline emissions [2]. Weitzman [1] shows that uncertainty (asymmetric information) in costs leads to a potentially significant efficiency distinction between otherwise equivalent price (tax) and quantity (quota) regulations in pollution control. Though this well-established result is important guidance for the optimal instruments in climate change control and has valuable policy implications (see the discussions in e.g., Tol [13]), it is constrained with one pollutant and in a static setting, i.e., pollution does not accumulate over time. However, this is not the case in climate change due to atmospheric concentration of GHGs [14]. The damage of GHGs depends not on the flow of emissions in a single year as airborne particulate matter or volatile organic compounds, but on the accumulated stock of emissions which persists for decades. Correspondingly, the Kyoto Protocol and Framework Convention on Climate Change set a upper limit of emissions on the atmospheric stock of GHGs [15].

As more than one pollutant exist, and the danger of global warming depends on the stocks [16], the policy analysis on climate change requires multiple-pollutant modeling in a dynamic setting. However, previous literature focuses either on a single stock pollutant (e.g., [14]) or on multiple flow pollutants (e.g., [17]) in the price-versus-quantity policy debates. To fill in the gap, this paper uses a stochastic dynamic framework with multiple GHGs (CO_2 and methane) to investigate the optimal policy instruments (taxes versus quotas) against global warming, under asymmetric information and pollutant correlations.

We build a dynamic model consisting of a representative firm and a regulator, facing two stock pollutants with correlations in the abatement process. We derive the theoretical solutions under different price-and-quantity policy combinations, and calibrate the model to the climate change case. The simulations yield the results under different policy schemes, among which the policy of taxing both carbon dioxide and methane dominates other policy choices with the lowest total social cost. In addition, a mixed policy that implements a tax on carbon dioxide and a quota on methane is always the second-ranked policy option.

The rest of the paper is organized as follows. The next section reviews previous studies in the literature. Section 3 describes the general model and derives the solutions under different policy instruments. Section 4 calibrates the model to the climate change case and Section 5 presents the results and discussions. Finally, Section 6 concludes the paper and highlights the policy implications of the results. Some technical details are relegated to appendix.

2. Literature review

Previous literature has acknowledged the prevalence of both the tax and quota policies [18]. A number of studies investigate the effect of carbon tax [19–21] and quota [5,22,23] in climate change mitigation, respectively. The literature on price-versus-quota policy comparison starts with Weitzman [1] who utilizes a static framework. To account for the stock externality of GHG emissions in climate change, following studies have employed the dynamic setting. For instance, Hoel and Karp [16,14 and Pizer [2] conclude that taxes dominate quotas for the control of CO_2 in a dynamic program model and in an integrated climate economy model, respectively. Newell and Pizer [15] account for the serial correlation of cost shocks and find that a price-based instrument generates several times the expected net benefits of a quantity instrument. All above mentioned literature confirms the dominance of emission taxes over quotas, however historical evidence suggests that command and control type of regulations are still predominant instruments worldwide due to different enforceability capacities [24]. Endres and Finus [3] show that an agreement under cost-inefficient quota regime may be superior to an efficient tax agreement with respect to ecological and welfare criteria. Karp and Zhang [4] also recognize the advantage of quotas over emission taxes where investment policy is information-constrained efficient with the use of quotas. In Chiu et al. [25], they find that the economic effects of taxes and quotas on energy prices are uncertain, which depend on market structures. All these studies focus on a single pollutant - CO_2, the most important GHG.

The literature on multiple pollutants emphasizes the interaction between them [26] and how the joint accounting of multiple pollutants affects the policy makings. Caplan and Silva [27] explore efficient mechanism to control correlated externalities. Silva and Zhu [28] find double dividends in a multi-pollutant setting, and Ambec and Coria [29] analyze the interplay of environmental policies with multiple pollutants. Fullerton and Karney [30] also study policy interactions (suboptimal tax or permit policy) when polluting inputs can be substitutes or complements. On the choice of policy instruments for multiple pollutants, Ambec and Coria [17] investigate how multi-pollutant interactions in abatement efforts influence the optimal policies with two flow pollutants. Meunier [31] analyzes the effect of a second unregulated externality on the price- quantity choice, involving interactions in demand system and the external cost. However, previous studies on the tax or quota regulation for multiple pollutants appear in a static setting only.

Regarding multiple pollutants in a dynamic framework with stock pollutants, the existing research does not focus on the choice of policy instruments. For example, Michaelis [9] calculates a scenario of efficient charge system with a dynamic optimization model. Moslener and Requate [32] analyze the optimal path of abatement in dynamic multi-pollutant problems, and characterize it to the greenhouse problem in Moslener and Requate [33]. Kuosman and Laukkanen [34] study both flow and stock pollutants, and show that the optimal policy is often a corner solution, in which abatement should be focused on a single pollutant. Yang and Menon [35] also study climate change mitigation with correlated pollutants using a regional dynamic general-equilibrium model. Unlike in this paper, there is no uncertainty (asymmetric information) in their studies, which implies the equivalence of price and quantity regulations.

Though previous research has important implications in environmental regulation, the findings based on a single stock pollutant [2,14,15] or multiple flow pollutants [17] may not be fully applicable to climate change problem. Therefore, the contribution of this paper lies in two folds. On the one hand, this study is the first attempt to theoretically accommodate multiple pollutants (as well as their correlations) and a dynamic framework (with asymmetric information) in the price-versus-quantity policy debates. On the other hand, with a more realistic setting and calibrated simulation in this study, the policy implications on optimal regulatory instruments of multiple GHGs can be well applicable to global climate change issue.

3. The model

3.1. Elements of the model

In each time period t, a representative firm is emitting two pollutants: pollutant 1 (e.g., CO_2) and pollutant 2 (e.g., methane). The total abatement cost for the firm is:

$$C(E_1(t),E_2(t),\theta(t)) = \frac{m_1}{2}(\overline{E}_1-E_1(t))^2 + \frac{m_2}{2}(\overline{E}_2-E_2(t))^2 + \omega(\overline{E}_1-E_1(t))(\overline{E}_2-E_2(t)) + \theta(t)[(\overline{E}_1-E_1(t)) + (\overline{E}_2-E_2(t))] \tag{1}$$

where $\overline{E}_i$ presents the laissez-faire emission level of pollutant i ($i = 1, 2$) and $E_i(t)$ is the emission of pollutant i in period t. The parameters m_i ($i = 1, 2$) are positive and the parameter ωin the cost function reflects