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The Research Progress on Social Cost of Carbon

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Abstract: The study of the social cost of carbon increasingly becomes an important research direction of the current climate change economics and the social cost of carbon is also an important concept in environmental policy, which is the marginal external cost caused by the increase of carbon dioxide emissions. Calculating the social cost of carbon is to measure the externality of the carbon, which has a great significance for climate policy formulation. This paper focuses on the definition of social cost of carbon, mainly discusses the impact of the discount rate on the social cost of carbon, and introduces the model to calculate the social cost of carbon. In the end, the status of carbon social costs is discussed accordingly.
Keywords: Carbon social costs; Research progress; Uncertainty; Discount rate.

1 Research background

Global climate change is one of the most important and challenging problem in the world today. Generally speaking, global climate change means huge changes of climate in the average state statistical significance or climate change that lasts for a long period of time (typically for 10 years or longer) in the global scope. At present, the fact that the world is warming has been internationally recognized, we must take measures to cope with climate change and global warming has been recognized by all walks of life [1]. The core issue of global warming is the carbon dioxide emissions caused by the burning of coal, oil, gas and other fossil fuels. Climate change affected people's welfare in many ways. The economics of climate change, specifically, is to analyze the cost of adapting to and controlling global warming by statistical methods, and to assess the benefits of what responding measures taken brought. In economics, an important concept related to climate change is the "carbon price", or, more precisely, is the price of carbon dioxide emissions. The social cost of carbon is one of the statements of the carbon price. The social cost of carbon which means the marginal present-value cost imposed by greenhouse gas emissions is determined by a complex interaction between factual assumptions, modeling methods, and value judgments.

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The social cost of carbon has emerged as a central concept in the economics of climate change and can be computed using large-scale computational Integrated Assessment Models that obtain this value by optimizing current emissions in a model for the global carbon cycle with temperature dynamics related to a global economy description. The basic attributes of climate change also give the special characteristics of the corresponding climate comprehensive evaluation model which is different from other models [2]. The present analysis employs a stochastic climate-economy model that accounts for uncertainties in baseline economic growth, baseline emissions, greenhouse gas mitigation costs, carbon cycling, climate sensitivity, and climate change damages. The unusual feature of climate change is the arrival delay of impacts, with persistent consequences spanning over centuries or possibly millennia into the future. One point of difficulty for the Integrated Assessment Models was choosing the rate at which to discount future costs and benefits. A suitable discount rate and an appropriately chosen carbon price can guide policy-makers to the adoption of behaviors and technologies that achieve societys economic-environmental goals at the least economic cost.

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2 Related concepts

In this section, we will give the definition of the social cost of carbon, and describe the path of the social cost of carbon.

2.1 The social cost of carbon

Sources of climate change are from the excessive emissions of carbon dioxide and other greenhouse gas, which indicates that emissions of carbon dioxide and other greenhouse gases have externality. In order to internalize externalities, climate change economics introduced the concept of the social cost of carbon, the externalities of carbon dioxide and other greenhouse gases were monetized valuation, which provided a useful reference for the establishment of climate policy.

Carbon emissions of social costs (social cost of carbon, hereinafter referred to as SCC) is to represent the damage of climate change caused by emissions of carbon dioxide with a monetary value, and considering the carbon dioxide and other greenhouse gases in atmosphere will accumulate over time, it also includes an increase of the carbon dioxide caused by the coming period loss discounted to present value. SCC measures the externality of greenhouse gases such as carbon dioxide, which is the sum of present value of the future economic losses caused by additional economic losses and additional emissions.

Setting what losses to parts of the social cost has not been uniformed, but in general, including a substantial impact brought by climate change, such as, agricultural production, change of ecosystem, rising of sea levels, social mortality, disappearance of biological species, and so on. These effects can be converted into social costs, represented with economic value. The most important greenhouse gases in the earth's air include the following several kinds: water vapor (H_2O), ozone (O_3), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrogen chlorofluorocarbons (CFCs, HFCs , HCFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6), and so on. Since the spatial and temporal distribution of water vapor and ozone vary widely, during the period of the reduction measures planning, these two gases are generally not taken into account. For percentage contribution of global warming, the huge content of carbon dioxide leads to the large proportion with about 55%. Carbon dioxide (CO_2) is the primary GHG and the majority of research on the benefits of mitigation has focused on CO_2. By the corresponding conversion, SCC can be viewed as a basic unit of measurement of all the social costs of greenhouse gases. For example, total emission calculated by carbon dioxide is 3.67 times over by carbon. The specific conversion is shown in Table 1.

Table 1: The greenhouse gas carbon dioxide into the 1995 IPCC GWP values [3].

Greenhouse gas	1995 IPCC GWP values
CO_2 carbon dioxide	1
CH_4 methane	21
N_2O nitrous oxide	310
HFC-23	11700
HFC-32	650
HFC-41	150
HFC-125	2800
HFC-134	1000
HFC-134a	1300
HFC-143	300
HFC-143a	3800
Carbon dioxide as carbon	3.67

Here, global warming potential (GWP) is an index of a substance to produce the greenhouse effect. GWP is the quality of carbon dioxide from the greenhouse effect of greenhouse gases corresponding to the same effects of carbon dioxide in a 100-year time frame. Carbon dioxide is viewed as the reference gas because of its biggest influence on global warming.

2.2 A sub-optimal "business-as-usual" (BAU) and the optimal policy (OPT)

"Business-as-usual" (BAU) refers to the analysis of possible trajectories of future economic and environmental changes, based on the assumption that there is no significant reduction in emissions.

The optimal policy response to climate change refers to the implementation of this policy is to find a balanced path between reducing the current cost of emissions and the damage to the future caused by global warming.

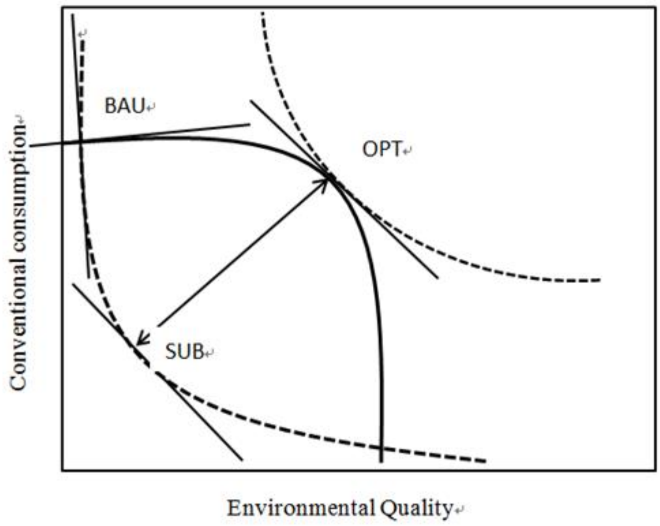

Figure 1: Static decisions of allocation between consumption and environmental quality in the absence (OPT) and presence (BAU) of a negative externality [4].

In Figure 1, the concave solid line between the environmental quality (x coordinate) and traditional consumption (y coordinate) is the production possibility curve diagram, the slope of the line can be seen as negative environmental quality price and dotted line in the graph represents the indifference curve. Based on welfare economics, we assume that the social indifference curves showing the allocation of resources on a consistent preference. OPT point is the tangent point of the indifference curve and production possibility curve, the individual's willingness to pay (WTP) for the environment quality is equal to the marginal cost of environmental quality in traditional consumption at this point. The second advantage (no control) is the intersection of production possibility curve and indifference curve. In this configuration, a typical individual willingness to pay for environmental quality is higher than the marginal cost of the environmental quality. From BAU point to OPT point, the utility of the indifference curve is higher and higher. The equilibrium of the BAU point is the result of a negative externality. Estimates of costs and benefits of greenhouse gas mitigation must be conditional on a scenario that specifies a reference path of consumption and environmental quality, as well as on the "felicity" function and pure rate of time preference assumed for the typical individual and the technology described by particular production, damage and mitigation functions. On an optimal path, a plausible estimate of the marginal cost and benefit of mitigation is about $200 per ton of carbon ($55/tCO_2). On a BAU path the marginal cost would be about $160/t of carbon ($44/tCO_2), but the marginal benefit would be about $1500/t of carbon ($410/tCO_2).

3 Calculation on the social cost of carbon

The tool for the estimation of the SCC is the so-called integrated assessment models (IAM). Using IAMs, this approach could essentially be scaled up to account for more states of the world. If the social cost of carbon was pinned down precisely, policy makers could use the parameter to set the optimal carbon tax. For this reason, dozens of researchers used different families of models to estimate the SCC.

In 2009, the Obama Administration convened an Interagency Working Group to survey the literature and assign a range of quantitative values to the social cost of carbon for using in official policy analysis. The Working Group employed three major models of the interplay between climate change and the global economy.

The three most commonly used models are DICE [Dynamic Integrated Climate and Economy] developed by William Nordhaus [5], PAGE [Policy Analysis of the Greenhouse Effect] developed by Chris Hope [6], and FUND [Climate Framework for Uncertainty, Negotiation, and Distribution] developed by Richard [7, 8].

There are some problems in these three models. FUND mistakenly predicts a huge reduction in mortality from warming, and then values the lives supposedly saved on the basis of their per capita incomes. As a result, it makes the morally offensive assumption those human lives in poor countries are worth less than in rich ones. PAGE has produced a wide range of estimates, the higher of which the working group ignored, and most of its estimates assume that developed nations will adapt to climate change at near-zero cost. DICE assumes on very thin evidence that most people in the world would prefer a warmer climate, and recommends a very slow "climate policy ramp" as a result.

Pearce [9] pointed out that the complexity of integrated assessment models on estimate the social cost of carbon is different. But all the key ideas of the model are the same. The logic of all three models is that the emissions are converted to concentration, then estimation of temperature variation from the concentration level, temperature changes eventually lead to economic damage. At last the duration of the damage is discounted to the value of the current period.

Whether it is based on early American, or recent global research, if abatement on the optimal path, the total cost of climate change is about 1%-2% GDP when a doubling of greenhouse gases. Early researches, Cline [10], Nordhaus [11], Titus [12], etc., mainly estimate the total loss of the United States. Fankhauser [13, 14] were estimated global losses of the first true sense.

Golosovetal [15] derive an analytical formula for the SCC in an integrated assessment model, based on specific assumptions such as logarithmic utility and climate-change damages proportional to output and exponential in the atmospheric CO_2. Gerlagh and Liski [16] add a more comprehensive description of the climate system and associated temperature-change delays, and study the implications of the formula for the optimal policies in a general-equilibrium context with time-inconsistent preferences. Bijgaart, Gerlagh and Liski [17] develop a closed-form formula that approximates the SCC for a general economy, and then explore the capacity of the analytical approach to capture the key SCC drivers and thus to replicate the results of the deterministic IAMs.

The discount rate has a great impact on the social costs of carbon. Arrow and Weitzman [18] summarize the arguments in favor of using a DDR schedule and discuss the problems by using different constant discount rates to evaluate inter and intergenerational benefits. If we hold the path of damages constant and use a constant discount rate of 4%, the SCC in 2000 increases from \$10.70 per ton of CO_2 (in 2013 U.S. dollars) [19]. Newell and Pizer [20] according to the state space model of the estimated value of decline discount rate get the SCC is \$19.50. Groom et al. [21] based on the random walk model estimation decreasing the discount rate, the social cost of carbon calculated value of \$ 27. "Stern Report" used a fixed discount rate of 1.4% to estimate SCC which is over \$ 200 per ton CO_2 (in 2005 dollars) [22]. Weitzman [23] used 3% of the "risk adjusted decline discount rate" to calculate the SCC value of \$183 per ton CO_2, closer to the "Stern report" adopted by the low discount rate. Decreasing the discount rate will greatly increase the social cost of carbon. The mapping of carbon emissions to economic costs is associated with significant uncertainties. One of the types of uncertainty might be captured by the so-called equilibrium climate sensitivity parameter. To address uncertainty, the Interagency Working Group adopted Roe and Baker's [24] fat-tailed distribution on climate sensitivity-i.e., the change in mean global temperature caused by a doubling of greenhouse gas concentrations-which implies a 20% chance of exceeding. Ackerman and Stanton [25], for example, found that assigning plausible values to uncertain parameters can result in a carbon price as high as \$900 per ton of carbon dioxide. Anthoff et al. [26] found that even higher values can arise in a sensitivity analysis involving low time preference and high risk aversion, though their central estimate was \$16 per ton based on their interpretation of decision-makers' revealed preferences in the absence of equity weighting.

4 Conclusions

The social cost of carbon could therefore theoretically inform assessment of the desirable intensity of climate policy, and it plays a crucial role in any cost-benefit analysis of emission abatement initiatives. As our review makes clear, there is much more work to do on this topic. There are still plenty of unsolved problems in the IAMS, such as the empirical validation of time preference, to better characterize the uncertainty of climate change, and so on. At present, the international climate change has not yet formed a binding global mechanism. Countries to deal with climate change are to take unilateral action. If we can determine the monetary value of the damage caused by the increase of emissions, we can use the cost-benefit approach to assess the policy, which is the meaning of the existence of SCC. SCC can be considered as an indicator of climate policy in countries.

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