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Global resilience to climate change: Examining global economic and environmental performance resulting from a global carbon dioxide market☆

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ABSTRACT

In this study, we investigated global economic and environmental resilience in the presence of climate change. In particular, we examine the possibility of mitigating carbon dioxide (CO_2) emissions without stressing standards of living. Here, we set up a cross-country CO_2 market constrained by a quota, where CO_2 is optimally re-allocated based on relative shadow prices of the pollutant. The objective is to stabilize global emissions without hindering global incomes and in the process achieve a single CO_2 price. We introduce a re-allocation model that takes into account each country's underlying polluting technology. The model solutions are then used to investigate whether a single, global price for CO_2 is attainable. Our results suggest that global CO_2 emissions could stabilize without stressing global incomes, with a global CO_2 market achieving equilibrium. With a CO_2 market, countries would then have the incentive to consider adopting, improving, or investing in additional abatement technologies to move beyond current capabilities, while continuing to increase standards of living.

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1. Introduction

Environmental sustainability and economic growth continue to shape the agenda of international policy discussions. There is a growing concern about climate change, and at the same time countries seek economic growth. In terms of climate change, scientists agree that increased carbon dioxide (CO_2) emissions in the atmosphere from human activity contribute to the current process of global warming through an amplification of the greenhouse effect. The concern is that if human activity continues as is, global warming could potentially have adverse impacts on the Earth. One adverse impact is the melting glacial ice causing sea levels to rise, potentially displacing populations along coastal areas. In this context, our study introduces a unique framework that examines whether global environmental and economic progress are simultaneously possible, with the ultimate goal of achieving a globally uniform CO_2 price by means of a global CO_2 market.

☆ The views expressed in this study are those of the authors and cannot be attributed to the Economic Research Service nor the U.S.D.A.

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Table 1
CO_2 pricing studies.

Study	Approach	Analysis level	Shadow prices[c]
Lee and Zhang (2012)	DF[a]	Chinese manufacturing industries	$0–18.82
Qi et al. (2004)	DF	Country	$308.5
Salnykov and Zelenyuk (2005)	DF	Country	$133.85–478.4
Dang and Mourougane (2014)	DF	Country	$240–786
Wang et al. (2011)	DDF[b]	Chinese provinces	$71.3
Marklund and Samakovlis (2007)	DDF	Country	$871
Wei et al. (2013)	DDF	Chinese thermal industries	$0.04–496
This study	DDF	Country	$719.33

[a] Distance function.
[b] Directional distance function.
[c] Averages and ranges (low to high).

Can attaining a uniform price for CO_2 help mitigate the effects of global warming and incentivize progress in standard of living? In a global CO_2 market where relative country level prices for this pollutant are known, countries could re-allocate this pollutant based on its relative price differences, in essence taking advantage of arbitrage opportunities. The goal is to achieve equilibrium in this market so that global CO_2 emission levels become stable?? Once an equilibrium carbon price is achieved, there would be no further arbitrage opportunities which would then incentivize countries to consider investing in, improving, or adopting additional abatement technologies to further raise standards of living without additional carbon dioxide emissions.

To investigate this possibility this paper introduces an innovative three step approach to arrive at a Pareto efficient outcome in a market characterized by a non-marketed good, or bad, such as CO_2. In the first step, we assess the marginal abatement value of CO_2 at the country level using established theoretical and empirical techniques that exploit duality relationships from Production Economics. In step two, we use these techniques to uniquely set up a global carbon market characterized by a global carbon quota. In this global market, CO_2 and incomes will optimally re-allocate across countries based upon each country's technological capabilities, without losses in global income and without additional global emissions. In step three, the optimal values for CO_2 and incomes are then used to calculate updated shadow prices for CO_2, and to analyze if this global CO_2 market will tend towards an equilibrium. The findings in our study suggest that it is possible for CO_2 emissions to stabilize, global income to increase, attaining a uniform price for CO_2 across countries. The main contribution of this study stems from steps two and three of our approach, the unique application of the Production Economics techniques to the global carbon market and investigation of shadow prices post estimation.

To accomplish our goal, we uniquely employ the well-established theoretical and empirical tool known as the directional distance function (DDF). The DDF allows us to model the assumption that countries desire to simultaneously increase income and reduce emissions, and it allows calculations of relative CO_2 shadow prices by exploiting the duality between the DDF and the revenue function. Most importantly, the (parametric) DDF is instrumental in our global CO_2 market, accounting for technological capabilities across countries.

DDFs have been used to create indices of efficiency and productivity especially when the technology produces some bad, undesirable output. In addition, these functions model technologies when prices of inputs or outputs are not observable. Single output technologies could be modeled using production functions given input quantities, while multi-output technologies could be modeled using cost functions given input prices and output quantities, but when prices are not available, distance functions could be used (Weber and Xia, 2011). Here, prices of CO_2 are not observable. Further, (Directional) Distance functions also allow for computation of shadow prices, elasticity of substitution, technical change, and optimal reallocation models. The DDF has its roots in the shortage function that was introduced by Luenberger (1992), and it has been extended by Chambers et al. (1996). Under certain conditions, Chambers et al. (1996) have shown that Shephard's input and output distance functions are special cases of directional distance functions.

Similar approaches have been used in previous studies of shadow pricing pollutants like SO_2 (Coggins and Swinton, 1996; Swinton, 1998) employing Shephard's output distance function (Shephard, 1970). In this paper, the shadow pricing approach will be similar to Färe et al. (2005) where directional distance functions have been used to obtain shadow prices of SO_2 for a sample of U.S. utility companies. DDF functions have also been used in Weber and Xia (2011) and Summary and Weber (2012) where a stochastic DDF has been estimated for thirty universities that participated in nanobiotechnology research and for academic departments at Southeast Missouri University to analyze grade distribution and grade inflation, respectively. In the Data Envelopment Analysis (DEA) literature, recent efficiency studies such as Barros et al. (2012), Zhang and Xie (2015), and Zhang et al. (2013) have employed non-parametric, non-radial DDF approaches to focus on the simultaneous input and output-oriented efficiencies in a technology with undesirable outputs. In contrast, our study requires a parametric DDF both for shadow price calculations and for the set-up of the CO_2 global market.

A non-exhaustive list of previous studies pricing CO_2 is presented in Table 1. Based on the past and current studies presented, shadow prices at the country level seem to be on the average higher relative to firm or industry level prices. Estimates of shadow prices for CO_2 vary across studies as expected. Reasons could include the methods used, i.e. output (input) distance functions vs. directional distance functions, stochastic vs. deterministic approach, parametric vs. non-parametric approach,