European Journal of Operational Research 000 (2017) 1–11

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Sustainable allocation of greenhouse gas emission permits for firms with Leontief technologies

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ARTICLE INFO

Article history:
Received 11 May 2016
Accepted 7 October 2017
Available online xxx

Keywords:
Game theory
Production situations
Limited greenhouse gas emissions permits
Games with externalities
Bankruptcy problems

ABSTRACT

In this paper we deal with production situations where a cap or limit to the amount of greenhouse gas emissions permitted is imposed. Fixing a tax for each ton of pollutant emitted is also considered. We use bankruptcy rules to define cooperative games with externalities associated with these situations and analyze the existence of coalitionally stable allocations of the emission permits. We prove that the constrained equal awards (*CEA*) rule provides stable allocations and as a direct mechanism, it is incentive compatible. These two facts have interesting managerial implications to control pollution emissions.

1. Introduction

Concern about climate change and, in particular, about global warming in the atmosphere is nothing new. In 1992, the Framework Convention on Climate Change (FCCC) took place in Rio de Janeiro (UNFCCC, 1992), in which the signatory countries pledged to take measures to avoid climate change, but without setting out specific measures. In 1997, the FCCC took place in Kyoto, from which the so-called Kyoto Protocol (UNFCCC, 1998) came into being, whereby the signatory countries committed themselves to reducing their greenhouse gas (GHG) emissions to certain levels until 2020 (considering the Doha Amendment to the Kyoto Protocol in 2012), but did not establish the procedure that each country should follow to achieve its emission target. More recently, in 2015, the FCCC took place in Paris, from which the so-called Paris Agreement (UNFCCC, 2015) came into being. In this binding agreement 188 countries have committed to controlling their GHG emissions, contrary to the Kyoto Protocol where only certain countries committed, and have indicated their national contributions will be subject to a gradual reduction every five years, see Carraro (2016) for an interesting summary. Thus, each country has a limit or target for each period to be divided among the sectors involved.

The most common approaches in economic theory to control pollution emissions involve the use of taxes and cap-and-trade systems. Tax systems are price instruments in which the government agency fixes the price per unit of emissions (tax), but the quantity remains unknown. In contrast, cap-and-trade systems are quantity instruments in which the authority fixes the quantity of emissions allowed (cap), but the price per unit is determined by means of a certain market (trade). The European Union Emissions Trading Scheme is probably the best known trading scheme. Nevertheless, both systems are widely used in practice, see Carl and Fedor (2016) for a survey of the carbon revenues from the cap-and-trade and carbon tax systems in the World, together with uses of those revenues by the governments. These systems have attracted considerable attention for many years and there is a large volume of literature. There are many papers comparing the efficiency, advantages and disadvantages of both systems. For example, Cooper (1998), Nordhaus (2007), and Avi-Yonah and Uhlmann (2009) suggest that carbon taxes are better than cap-and-trade systems. However, Keohane (2009) suggests that cap-and-trade systems have interesting advantages when compared with the application of taxes. A different option is the so-called safety valve (Jacobi & Ellerman, 2004), which is somewhat of a combination of both methods.

This paper falls within the latter idea of combining quantity instruments (cap-and-trade) and price instruments (carbon taxes). Therefore we try with our model to contribute by giving an insight into how to mitigate some of the potential/possible shortcomings of both models: cap-and-trade and tax systems. In particular, the overestimation of the limit in the cap-and-trade system, the no-control of the abatement of emissions, if any, in the tax system, and the difficulties of measuring how much companies actually pollute in both systems. The first two drawbacks are related to the possibility of lack of success in the abatement of emissions and

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https://doi.org/10.1016/j.ejor.2017.10.011
0377-2217/

the latter is associated with the authority's knowledge of the real emissions.

The economic and social implications that arise from the previous agreements and control instruments can be studied from different fields of OR/MS, depending on the analysis that is intended to be carried out. See Tang and Zhou (2012) for a survey on OR/MS research developments in environmental and sustainable issues; and (Dinar, Albiac, & Sánchez-Soriano, 2008; Finus, 2001; Patrone, Sánchez-Soriano, & Dinar, 2008) for applications of Game Theory to natural resources management and environmental problems. Some interesting problems that arise are the allocation and management of GHG emission permits or allowances; the effect of GHG emission control systems on the behavior of companies; the analysis of international agreements; the effects of these measures on competition, collaboration or co-opetition between companies, etc.

In this paper we study the problem of allocation of carbon dioxide emission permits for firms by using bankruptcy rules. We analyze the consequences in the cooperation among companies when we consider that externalities can arise. In order to do so, we use the context of production situations in which there is a cap on the emissions, ex ante cooperation among companies by utility transfers is possible, trading among companies is allowed and there is a fixed tax on the carbon dioxide consumption. To the best of our knowledge, no research has examined this approach to the allocation of GHG emission permits. Our research aims to fill this gap in the literature by examining the following key questions:

(a) How to model externalities when companies can coordinate their claims on carbon dioxide emission permits and the allocation of those permits is to be carried out by using a bankruptcy rule?
(b) How to allocate carbon dioxide emission permits to obtain a stable allocation of the global profits among the companies?
(c) How the parameters defining the problem (cap, allocation rule and tax) can be fixed or used in order to manage and control the carbon dioxide emissions efficiently?

To this end, we consider production situations where several firms own resource bundles that can be used to produce various products which they sell at the given market prices. All firms have the same production function but differ in the amount of resources which they can manage, so they are different in size. Under the market conditions mentioned above, using games with externalities or in partition function form (Thrall & Lucas, 1963) together with arbitration by applying bankruptcy or rationing techniques (Aumann & Maschler, 1985; Curiel, Maschler, & Tijs, 1987; O'Neill, 1982), we examine the process of allocating the carbon dioxide emission permits in order to analyze under what conditions we can obtain stable allocations of the emission permits and stable distributions of the total profit generated by the market. Likewise, we study how the cap on the emissions, the allocation rule and the per unit tax on the emissions can be used for managing and controlling the gas emissions.

The rest of the paper is organized as follows. In Section 2 a review of the related literature is presented. Section 3 describes our proposal. In Section 4 some preliminaries on TU-games and bankruptcy problems are given together with the description of linear production situations with an external limited resource (*LPP* situations). In Section 5 a further approach is provided by using bankruptcy techniques to deal with $f-LPP$ situations and the $f-LPP$ games with externalities associated with these situations and we prove that if there are stable allocations of the permits, then there are stable allocation of the total profits. In Section 6, if the total demand exceeds the cap, we prove that, under certain conditions, using the *CEA* rule the allocation of carbon dioxide emission permits obtained is coalitionally stable, i.e., there is no group of firms that can complain by arguing it is unfair. Moreover, we show that the *CEA* rule as a direct mechanism is incentive compatible. In Section 7 we describe the managerial implications of our proposal. Some concluding remarks are given in Section 8. All proofs of the results may be found in the appendix.

2. Literature review

In this section we review the literature of two different topics related to the abatement of GHG emissions: (i) the impact of GHG emission control policies on the behavior of the companies with respect to their operational decisions, (ii) how to allocate carbon dioxide emission permits. Finally, we review the more specific game-theoretic literature related to our model.

The effects of the GHG emission control policies on the operational decisions of the companies have been studied during recent years from OR/MS perspective. Some recent papers are Bai and Chen (2016) and Hong, Chu, and Yu (2016), where there is only one decision maker: the firm. However, the analysis of the behavior of the companies when there is more than one decision maker is usually carried out by using some game-theoretic approach. Among the latest works, He, Wang, and Wang (2012) compares the effectiveness and efficiency of cap-and-trade and tax systems in the context of power generation in terms of different criteria. For their analysis, they use a Nash–Cournot competition model. In the particular case of the cap-and-trade systems, the agents must purchase the allowances of emissions at an exogenously given price. The grandfathering case for the cap-and-trade case is studied in He, Wang, and Wang (2010). Luo, Chen, and Wang (2016) consider two competing manufacturers who have different emission reduction efficiencies and study the effects of pure competition and co-opetition on emission reduction efficiency under a cap-and-trade policy. Yenipazarli (2016) uses a multi-stage leader (regulator)-follower (firm) Stackelberg game model to investigate the impact of emission taxes and emissions trading on the optimal production (new product or remanufactured) and pricing decisions of a manufacturer. Siddiqui, Tanaka, and Chen (2016) study the impact of market structure with renewable portfolio targets and show that social welfare under perfect competition between renewable and non-renewable is lower than when the non-renewable energy sector exercises market power in a Cournot oligopoly. However, we have not found any paper that studies the effect of the externalities that can arise when an allocation mechanism is set to distribute the carbon dioxide emission permits, if the coordination and prior compensation among companies is allowed when requesting the permits.

With regard to the GHG emissions allocation, Zhou and Wang (2016) review the literature on the carbon dioxide emission allocation and classify the allocation methods into four groups: indicator, optimization, game-theoretic and hybrid approaches. Moreover, they distinguish between different application levels: countries, regions or firms. Likewise, they conclude that the game-theoretic allocation methods are based on cooperative games, dynamic games and incomplete information games. However, bankruptcy techniques are not mentioned in this survey. Giménez-Gómez, Teixidó-Figueras, and Vilella (2016) propose the use of bankruptcy rules, based on the selection of some desirable principles, as mechanisms to allocate the global carbon budget among countries. Kampas and White (2003) examine a variety of permit allocation rules in order to allocate nitrate emissions for a small catchment in South West England. Some of the permit allocation rules that they study are bankruptcy rules. They then compare the results obtained by applying the allocation rules and the results obtained from an asymmetric Nash's bargaining solution in order to compare the correspondence between ex-ante and ex-post criteria of equity. Nevertheless, the above mentioned papers mainly focus