Introduction

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Game theory is one of the most useful mathematical tools that economists and mathematicians have been using to deal with complex economic and policy problems. At the same time, environmental issues are at the heart of many domestic and international policy processes, where interactions among different stakeholders play a crucial role. It is therefore natural to adopt game theory as one of the analytical instruments that can enhance our understanding of the interrelations between the economy and the environment, and that can also provide practical suggestions for policy interventions.

The existing literature on game theory and the environment is vast (Cf. Carraro, 2002, 2003; Finus, 2001; Hanley and Folmer, 1998; and many others). Therefore, when designing this book, and the conference where the chapters of this book were presented and discussed, the main questions were: What are the original features of the book? How does it differ from the many books already published on the application of game theory to environmental matters?

Of course, each single chapter contains some innovative results that will be highlighted below. However, the design of the book also contains some specific features that are worth mentioning. First, the book is the outcome of interdisciplinary work involving economists and mathematicians. Some of the chapters have been written by mathematicians who possess sophisticated mathematical tools and look for an interesting environmental economic problem to apply them to. Other chapters have been written by economists who seek adequate tools to deal with relevant policy issues. All chapters are the outcome of the interactions between these two groups of researchers, who helped each other through personal and on-line discussions and through the reviewing process.

A second distinguishing feature of this book is the ‘practice’ of game theory. The goal was indeed to induce the authors to look for practical solutions to environmental problems and to use game theory to identify these concrete solutions. Despite the fact that this second goal has not always been achieved by the chapters in this book, it is clear, when reading the various chapters, that there is a common denominator defined by the objective just described.

The book is divided into three parts. The first is devoted to climate policy. This is one of the major environmental problems and certainly one where game theory has been largely used, notably to assess the prospects of future climate negotiations. This is also the main objective of the four chapters in Part I of the book. They all use game theory to identify the incentives to sign an international climate treaty as a function of countries' characteristics, political institutions, policy strategies and future commitments. For example, Currarini and Tulkens recognise that international agreements on climate change control require approval by domestic political institutions. Therefore, they employ a voting game-theoretic model to characterise the stability of such agreements when each country's participation is conditioned upon a domestic ratification vote. To describe the pre-treaty or no treaty international situation, they propose a concept of (non-cooperative) political equilibrium and prove its existence. They then move to the diplomatic level, and employ a coalition formation game to show that there exist cooperative joint policies, yielding a treaty, that are ratified by all countries and that can be considered *stable* at the international level. The problem addressed in this chapter has been widely neglected by the existing literature and this chapter actually provides a major innovation in the economic analysis of climate change negotiations and international environmental agreements.

The second chapter, by Bosello, Buchner, Carraro and Raggi, addresses another important but neglected issue, namely how equity can influence the participation decision of countries that negotiate on climate change control. A widespread conjecture suggests that a more equitable distribution of the burden of reducing emissions would enhance the incentives for more countries – particularly big emitters – to accept an emission reduction scheme defined within an international climate agreement. This chapter shows that this conjecture is only partly supported by the empirical evidence that can be derived from the recent outcomes of climate negotiations. Even though an equitable sharing of the costs of controlling GHG emissions can provide better incentives to sign and ratify a climate agreement than the burden sharing implicit in the Kyoto agreement, a stable global agreement cannot be achieved. A possible strategy to achieve a global agreement without free-riding incentives is a policy mix in which global emission trading is coupled with a transfer mechanism designed to offset incentives to free-ride.

The third chapter, by Carraro and Marchiori, is also aimed at assessing the validity of a practical policy proposal. In particular, this chapter analyses issue linkage as a way to increase cooperation on environmental problems where the incentives to free-ride are strong. The goal is to determine under what conditions players prefer to link negotiations on two different

economic issues rather than to negotiate on the two issues separately. Suppose that players are asked to vote on issue linkage before starting negotiations. Under what conditions would they vote in favour of issue linkage? The answer to this question is not trivial. Issue linkage may indeed increase the number of cooperators on the provision of a public environmental good (a typical issue characterised by strong incentives to free-ride). However, at the same time, issue linkage may reduce the number of cooperating players on the other economic issue which is linked to the provision of a public good. Players therefore face a trade-off. This chapter analyses this trade-off within a game-theoretic framework and shows under what conditions issue linkage is players' equilibrium strategy.

The fourth chapter of Part I, by Císcar and Soria, has a more methodological flavour. Most studies assessing the Kyoto Protocol on climate change have implemented a (simultaneous) single-stage game with an *open-loop* information structure, where countries decide at once and at the same time their mitigation efforts for all future periods. Alternatively a (sequential) multi-stage game can allow a player to react to past moves of the other players. The information structure of this second game is called *feedback*. The goal of this chapter is to compare the outcomes under the open-loop and feedback frameworks. For that purpose a numerical two-region (Annex B and non-Annex B countries) integrated assessment model of the economic and climatic systems is coupled with a non-cooperative five-stage game. When the game is solved with utility payoffs, the open-loop and feedback Nash equilibria provide very similar outcomes. With consumption payoffs, the outcomes are different. Therefore, this chapter suggests that the information structure of the game may matter and must be carefully analysed.

The second part of the book is devoted to another important environmental and economic issue. How can stakeholders, whether domestically or internationally, share the costs of undertaking emission abatement or more generally the cost of environment-friendly activities? In this part, cost sharing methods are applied to different environmental problems and practical answers to the above question are proposed.

In the first chapter of Part II, by Tijs and Brânzei, a group of agents aims to work together in a joint project that can have different forms. Each feasible form corresponds to a subset of a given set of basic units. The cost of the chosen project is the sum of the costs of the basic units involved in the project. The benefit of each of the agents is dependent on the form of the chosen project. A related cooperative game may be helpful in solving the question of how to share the costs. Under certain conditions this game turns out to be a convex game. For structured joint projects also a flexible procedure using cost sharing rules from the taxation literature applied to

simple cost sharing problems is proposed. It is worth noticing that many well-known cases in the cost sharing literature fit in the model proposed in this chapter and that some earlier results are special cases of the results which are obtained in this chapter.

Chapter 6, by Moretti, focuses on sharing the cost of waste collection. Due to economies of scale imposed by the need for specialist staff and facilities, inter-municipal cooperation can be very beneficial in achieving groupings large enough to develop – at an affordable cost – a waste collection system suitable to the high standards demanded by EU legislation. Moreover, municipalities want a cost allocation mechanism that is efficient, equitable and provides appropriate incentives to cooperate. The aim of this chapter is to offer a model for ex-ante quantitative evaluation of specialist staff and facilities (and their costs) required for supplying waste collection in new emerging contexts of inter-municipal cooperation. A validation of the model on a real situation is also presented.

Chapter 7, by Fragnelli and Marina, proposes a framework to share environmental insurance costs. There are risks, in particular environmental risks, that are too large and heavy for a single insurance company, but they can be insured by n companies. This chapter uses a game-theoretic approach to analyse how the n insurance companies should split the risk and the premium in order to be better off. Under suitable hypotheses, there exists an optimal decomposition of the risk, from which a cooperative game can be defined and its properties and some particular solutions analysed.

In the final chapter of Part II, by Keiding, the environmental costs to be shared are those related to consumption activities. For the assignment of environmental effects to activities, Keiding proposes to use the method of cost allocation, applied to a multiple of different environmental impacts considered as different ‘costs’. This leads to a consideration of vector cost allocation and its relation to ordinary one-dimensional cost allocation methods; in particular, he considers the stability of cost sharing rules under composition of cost functions, a property which is important in the application at hand. In addition, the author exploits the well-established methodology of DEA (Data Envelopment Analysis) in order to aggregate vectors of environmental effects into a single index of relative environmental impact of a consumption activity. An application of the last part of the approach is given, based on Danish national accounts data and using emission data as a proxy for environmental effect.

Part III deals with environmental management and pollution control. The first chapter, by Bischi, Lamantia and Sbragia, proposes a dynamic model to describe the commercial exploitation, by a population of strategically interacting agents, of a common property renewable resource. The

population of players is assumed to be divided into two groups: cooperators, who decide their harvesting policy by maximising the overall profit of their group, and defectors, who just maximise their own profit. An evolutionary mechanism is introduced to describe how the share of defectors and cooperators within the population changes over time. The chapter provides a qualitative study of a two-dimensional non-linear dynamical system that describes the time evolution of the resource stock and the population share between cooperators and defectors. The long run evolution of this dynamical system is analysed by analytical and numerical methods, and the role of some economic and ecological parameters is investigated.

Chapter 10, by Flâm and Godal, analyses emission trading in an oligopolistic market. Oligopolistic firms use factor inputs that generate emissions of greenhouse gases. The producers are entitled to emission permits, and they exchange parts of these. Each firm, when planning its net purchase of permits, anticipates the market clearing price. This chapter models the clearing mechanism as a core solution of a transferable-utility production game. Agents may reckon that they affect prices of products and permits. The existence and characterisation of the equilibrium is discussed.

The final chapter, by Currarini and Marini, presents a new cooperative equilibrium for strategic form games, denoted Conjectural Cooperative Equilibrium (CCE). This concept is based on the expectation that joint deviations from any strategy profile are followed by an optimal and non-cooperative reaction of non-deviators. The authors show that a CCE exists for all symmetric supermodular games. Furthermore, they discuss the existence of a CCE in specific submodular games derived from the environmental literature.

As a whole, the eleven chapters of this book improve the toolbox we have to deal with environmental issues and, at the same time, provide some interesting applications and practical solutions to some relevant environmental policy problems. The work to achieve this result has been long and difficult. All chapters have been reviewed twice and revised accordingly. All chapters have been presented at a conference in Alessandria and there discussed and compared. The organisation of this entire process has been possible thanks to the financial and organisational support of the Fondazione Eni Enrico Mattei, of the University of Eastern Piedmont and of 'Ambiente, Territorio e Formazione'. The role of Alberto Cassone, Vice Dean of the University of Eastern Piedmont, and of Fabio Gastaldi, Dean of the Faculty of Sciences, has also been very important in facilitating the organisation of the Alessandria meeting. Special thanks also to Lucia Ceriani, Monica Eberle, Anna Iandolino and Giovanni Monella for their help in the organisation of the meeting. All reviewers did an excellent job to enhance the quality of the chapters. We are very grateful to them, as well as to all

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