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Game theoretic applications to environmental and natural resource problems

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ABSTRACT. Game theory has been useful as an analytical framework for assessing environmental and resource regulations and policies. The papers in this volume provide the latest methodological and applied works in game theory to a wide range of natural and environmental resource problems such as fishing, grazing, pollution, climate change, water allocation, and stochastic production processes. The findings in the papers suggest that game theory is an effective tool for the analysis of the efficient use of shared natural resources; it can be used to identify stable agreements between parties to a resource conflict, and show how non-cooperation over global public goods/bads has a high social cost tag.

Game theory has earned recognition as an analytical tool for the study of strategic behavior of agents in the field of economics and is increasing its influence in other social sciences, such as politics, sociology, and law. Recent years have witnessed a shrinking world with competition over natural resources that leads to increased levels of extraction of various natural resources and pollution of the environment with ensuing general degradation of the Earth's ecosystems.

Game theory has been useful in providing frameworks to assist policy makers in assessing regulations and stable policies (e.g., Carraro and Filar, 1999; Hanley and Folmer, 1998; Patrone *et al.* 1999; Finus, 2001; Carraro and Fragnelli, 2004; Dinar *et al.,* 2008). It has also been used to analyze fishery and other natural resource problems earlier (e.g., Munro, 1979; Levhari and Mirman, 1980; Sumaila, 1995; Hannesson, 1995) This special issue[1]

[1] This special issue contains a selection of papers presented at the Sixth Meeting on Game Theory and Practice Dedicated to Development, Natural Resources,

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includes more recent applications of game theory to problems involving land, water, fisheries, climate change, water allocation, pollution, and other natural resources.

Here, a game is defined as any activity involving two or more individuals, each of whom recognizes that the outcome for her/himself depends not only on her/his own actions but also those of others. A game is a description of strategic interaction that includes the constraints on the actions that players in the game can take. Game theory is a multi-person decision theory or the analysis of conflicts and rivalry. It has also been defined as a mathematical tool for analyzing strategic interaction between and among individuals who may be persons, firms, stakeholders, or nations.

Game theoretic applications have found fertile ground in the area of development, natural resources, and the environment because of their attributes. Natural resources, the environment, and even development problems are usually common pool in nature and include environmental externalities; they usually involve more than two players and are therefore amenable to multi-player analysis in a strategic fashion. Usually, each player in the game has an interest in the use of the resource, which it wants to enhance or maximize but also to conserve for future periods. Finally, the interests of the stakeholders are often conflicting, a situation that makes for relevant game theoretic applications.

The papers contained in this volume cover a wide range of recent topical issues in the area of game theoretic applications to development, natural resources, and environmental economics and management, including (i) international fisheries (Munro), (ii) traditional grazing rights in semi-arid African pastoralist systems (Goodhue and McCarthy), (iii) production games applied to uncertain investments (Flåm and Ermoliev), (iv) wastewater pollution abatement across an international border (Fernandez), (v) cooperation in water use (Fisher and Huber-Lee), and (vi) coalition theory in the design of international environmental agreements (Finus, Sáiz, and Hendrix). The six papers together describe some of the latest methodological and applied works in game theory with respect to a wide range of natural and environmental resource problems.

The first paper in the special issue, authored by Munro, is concerned with the relevance of game theory to understanding the economics and management of internationally shared fishery resources. The paper reviews several elementary game theory concepts that have policy relevance, yet are poorly understood by many policy makers. It also reviews the economics of transboundary resources (i.e., resources that migrate between the Exclusive Economic Zones – EEZ – of two or more countries), and comes to the conclusion that the theory for this class of problems is well developed. On the other hand, a review of the management of straddling stocks (i.e., fish stocks that migrate between the EEZ of one and more countries and the high seas) reveals that more theoretical work is required. It is argued by the

and the Environment, which took place in July 2006 in Zaragoza, Spain and was funded by the Spanish Ministry of Education and Science and the Government of Aragon (http://www.iamz.ciheam.org/GTP2006/FinalPapers.htm). In all, six papers were accepted after the usual review process.

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author that the economics of the management of shared resources cannot be fully understood without the use of game theory.

In the second paper, Goodhue and McCarthy use fuzzy set theory to model the incompleteness and flexibility of traditional grazing rights in semi-arid African pastoralist systems. The paper argues that traditional pastoralist land management institutions in sub-Saharan Africa have been stressed by (i) an increasing human population, (ii) private enclosure of grazing land, (iii) government-sponsored privatization, and (iv) the increasing prevalence of violent conflicts and livestock theft. The authors then compare individual and social welfare levels under the traditional system to individual and social welfare levels under private and common property systems. They find that whether the traditional system is preferred to private property or not depends on whether the value of mobility, as defined by the traditional system, is higher than the right of exclusion inherent in private property. Results from the analysis show that, under some conditions, the imprecision that characterizes traditional rights can result in higher social returns than a common property regime characterized by complete symmetric rights across all members of the user group, accompanied by the complete exclusion of non-members.

The third paper by Flåm and Ermoliev develops stylized models to reveal the large applicability of stochastic production games. A two-stage, stochastic production game model is developed that is quite tractable in analysis, computation, and realization. The paper computes a core in terms of shadow prices that equilibrate in competitive, endogenous markets. Such prices emerge as optimal dual solutions to coordinated production programs. This paper should have broad appeal to economics, finance, insurance, and other related fields.

The paper by Fernandez develops a differential game model to compare incentives for pollution abatement of upstream and downstream countries under cooperative and non-cooperative strategies. The model is applied to the Tijuana River, for which the prevailing water flow is from south (in Mexico) to north (in the US), where pollution stock accumulates. Asymmetry exists between the upstream (Mexico) and downstream (US) countries in terms of the costs they face stemming from damages and emissions between the countries. This influences the incentives of Mexico and the US to abate wastewater pollution. The paper shows that the cost minimizations goal is met when the US finances pollution abatement in Mexico. Several sharing rules (Shapley value, Chander Tulkens rule, Helsinki rule, egalitarian rule) are analyzed. The author shows that in most cases of cooperation, transfer payments are positive from downstream to upstream countries and lead to reductions in the flow and stock of pollution. The size of the transfer varies according to the rule and sensitivity analysis of changes in abatement costs and damages.

Fisher and Huber-Lee, in their contribution, apply the Water Allocation System (WAS) as a tool for analyzing optimal water management and the resolution of water conflict. WAS is a method of dealing with water issues that focuses on water values rather than water quantities. The values considered are public or social, not private ones. WAS is also used

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for analyzing infrastructural development and other policy analysis. The authors show that the grand coalition of all parties is always at the core of the game involved and hence stable. They then proceeded to estimate the benefits of such cooperation for Israel, Jordan, and Palestine.

In the last paper of this special issue, Finus, Sáiz, and Hendrix consider new developments in coalition theory for the design of international environmental agreements. The authors apply an empirical model of climate change to analyze single versus multiple coalition agreements, open versus exclusive membership with majority and unanimity voting, and, finally, no transfer versus transfer with four different transfer schemes. The authors spend time explaining what each of these terms means before going into the analysis, which is a helpful way to introduce the reader to the analysis in the paper. The authors arrive at a number of interesting results including (i) the lack of serious cooperation at the international level on climate change is costly and (ii) the effort to get as many countries as possible into a "climate boat" may not be the best strategy. It is more important to get the inclusion of key players such as China, USA, and India, according to their analysis.

Conclusion

Some key results from this volume include (i) game theory is essential for analyzing the economics of the management of shared resources; (ii) under certain conditions, the imprecision that characterizes traditional rights can result in higher social returns than a common property regime; (iii) it is possible to compute a core in terms of shadow prices that equilibrate in competitive, endogenous markets; (iv) in most cases of cooperation, transfer payments are positive from downstream to upstream countries and lead to reductions in the flow and stock of pollution; (v) the grand coalition of all parties is always at the core of the game involved and hence stable; and (vi) the lack of serious cooperation at the international level on climate change is costly.

We have presented in this short paper a summary of the key issues analyzed in this special issue of *Environment and Development Economics*. Our goal is to introduce the reader, through this little peek, to this interesting collection of papers that document some of the most recent applications of game theory to development, natural resources, and the environment.

References

Carraro, C. and J.A. Filar (eds) (1999), *Control and Game-Theoretic Models of the Environment*, Boston: Birkhauser.

Carraro, C. and V. Fragnelli (eds) (2004), *Game Practice and the Environment*, Cheltenham, UK: Edward Elgar.

Dinar, A., J. Albiac, and J. Sanchez-Soriano (eds) (2008), *Game Theory and Policy Making in Natural Resources and the Environment*, London: Routledge.

Finus, M. (2001), *Game Theory and International Environmental Cooperation*, Cheltenham, UK: Edward Elgar.

Hanley, N. and H. Folmer (eds) (1998), *Game Theory and the Environment*, Cheltenham, UK: Edward Elgar.

https://doi.org/10.1017/S1355770X08004609 Published online by Cambridge University Press

Hannesson, R. (1995), 'Sequential fishing: cooperative and non-cooperative equilibria', *Natural Resource Modeling* **9**: 51–59.
Levhari, D. and L.J. Mirman (1980), 'The great fish war: an example using a dynamic Cournot–Nash solution', *Bell Journal of Economics* **11**: 322–334.
Munro, G. R. (1979), 'The optimal management of transboundary renewable resources', *Canadian Journal of Economics* **12**: 355–376.
Patrone, F., I. García-Jurado, and S. Tijs (eds) (1999), *Game Practice: Contributions from Applied Game Theory*, Dordrecht: Kluwer.
Sumaila, U.R. (1995), 'Irreversible capital investment in a two-stage bimatrix game model', *Marine Resource Economics* **10**: 163–183.

https://doi.org/10.1017/S1355770X08004609 Published online by Cambridge University Press