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Wagener, F.

**DOI**
10.1007/s13235-022-00456-w

**Publication date**
2022

**Document Version**
Final published version

**Published in**
Dynamic Games and Applications

Dynamic Games and Applications (2022) 12:747–750
https://doi.org/10.1007/s13235-022-00456-w

# Dynamic Games in Environmental Economics and Management

**Florian Wagener**[1,2]

Accepted: 26 May 2022 / Published online: 28 June 2022


*The preparation of this Special Issue was overshadowed by the passing of one of its editors, professor Ngo Van Long of McGill University, Canada (1948–2022), who was one of the major contributors of the field. He is fondly remembered by all who had the privilege to know and to work with him.*

Environmental economics thinks about the optimal use of natural resources, like water, oil, the air we breathe, or the physical environment we live in. The fundamental question is the problem of externalities: costs that are generated by one group of actors, which have to be borne by another group. Time scales play an important role: the benefits of the industrial revolution were realised immediately, but we are still dealing with the costs of the concomitant $CO_2$ pollution. The evolution of underlying stock variables can be influenced to some extent, at a cost, and their management therefore presents an investment problem.

Dynamic games come into the story naturally, as they provide the right framework to analyse actions of multiple actors that generate costs and benefits over time. To provide an impetus to research efforts on dynamic issues of competition and cooperation in environmental management, the editors had invited contributions to a Special Issue of *Dynamic Games and Applications* with exclusive focus on environmental economics and management. Eleven such contributions are collected in the following pages. Six of them can roughly be classified as dealing with pollution problems, while the other five address more general resource problems. The whole spectrum of dynamic games is present: differential games, population games, overlapping generation games, repeated games, and mean-field games.

The seminal contribution of Engelbert Dockner and Ngo Van Long [6] analysed a differential game of countries that have to cope with global pollution, and two of the articles in this Special Issue took it as their starting point. Yanase and Kamei [12] extend the Dockner–Van Long model by allowing the two countries to trade. They find that under frictionless trade, the same levels of environmental and social welfare are achieved under international cooperation, open-loop Nash equilibrium, and linear Markov-perfect Nash equilibrium, and these free-trade policies outperform noncooperative environmental policies in the absence of trade. Positive trade costs can reverse this outcome in certain configurations.

✉ Florian Wagener
f.o.o.wagener@uva.nl

1 Amsterdam School of Economics, University of Amsterdam, Amsterdam, The Netherlands

2 Tinbergen Institute, Amsterdam, The Netherlands

In an important theoretical contribution, Schumacher et al. [10] develop a framework to analyse globally defined discontinuous strategies for a symmetric differential game. Applying it to the Dockner-Van Long model [6], they find the supremum of the possible values that can be achieved by Markov-perfect Nash equilibria. It is of interest to note that there is no single Nash equilibrium that achieves the supremum for all initial states of the game.

Also de Frutos et al. [5] consider a model of transboundary pollution, but instead of looking at the effects of trade, they investigate strategic investment in cleaner technologies. In particular, they look at technologies that can reduce the ratio of emissions to industrial output, and they study the simultaneous dynamics of the stocks of pollution and of clean technology, which is assumed to be a public good. As a technology that reduces a proportion of emissions is most effective if the rate of emissions is high, investing in this technology pays only if the stock of pollutant is not too large. The article duly establishes that in a highly polluted environment, the economy chokes: emissions have to be low, in order not to exacerbate environmental damages further, but investment into the clean technology is also low, as it is not effective to reduce the already low emissions.

Dynamic cooperation between asymmetric players is the theme of Cabo and Tidball [3]. A standard approach is to cooperate and to distribute the gains resulting from cooperation according to a particular procedure. The authors propose, not to distribute the resulting gains, but instead to distribute the required effort levels. Moreover, they require this procedure to be time-consistent, to have the property that higher contributions result in higher benefits, and that higher past emissions should result in higher contributions. They show that such a procedure exists and that it is equivalent to an asymmetric Nash bargaining scheme.

The usual recipe for obtaining a first best outcome is to have agents internalise external costs. Lahkar and Ramani [8] show that once this central requirement is fulfilled, convergence to a socially optimal equilibrium obtains also if agents are assumed to be less than fully rational. Their context is a population game where individual players cannot influence the general outcome. If a regulator charges social costs arising from actual firm production as taxes to the firms, firms playing a Cournot game will converge to a socially optimal steady state over time.

Carmona et al. [4] propose a mean field game to model electricity production by many producers. Only once, at the beginning of the game, producers can invest in a renewable production asset; during the game, they can control the rate of electricity produced by nonrenewables. A free competition regime is contrasted to a solution where the producers collude: under competition, energy demand is met better than in the collusive case, at the cost of more emissions. The consequences of introducing a regulator are investigated, who can set a time-independent carbon tax as well as a penalty for not matching demand.

Karp and Rezai [7] forcefully argue the point that trade liberalisation and the establishment of property rights to a resource should be considered as policy complements. They consider a small resource-rich economy with a manufacturing sector employing industrial capital and a resource sector, both competing for available labour. If the economy is closed, conservation of the resource, and its resulting abundance, makes industrial capital relatively scarce, and hence increases its real return. It however also increases the return on labour, as the resource yields more harvest. If the economy opens up for trade, and the resource stock can be accessed by everyone, the resulting lowering of the resource frees up labour from harvesting that is employed in the manufactoring sector, decreasing labour's real returns, and increasing the real return to capital. By establishing property rights, more conversation is effected, which counteracts the decrease in labour's real returns.

When extracting several resource stocks, it is efficient to start with the stock whose marginal extraction costs are lowest, then to go to the next cheapest, and so on. A violation of this order is the source of a major inefficiency, which is shown by van der Meijden et al. [11] to occur robustly for a wide range of demand specifications. In particular, they show that this 'sequence effect' is tied to oligopolies, as it disappears under the perfect competition.

Similar to the Cabo-Tidball contribution [3], cooperation between asymmetric players is investigated by Mason [9]. Intuitively, it may seem that it should be the larger partner that dictates the terms. The article discusses how social preferences may change this picture. It is natural to expect that if the larger player feels altruistically towards the smaller player, then the smaller player will obtain a larger share of the outcome. But the article shows that this is also the case if the smaller player feels envious towards the larger player: being envious helps to stiffen the smaller player's resolve, and ends up benefitting this player.

Illegal water extraction from aquifers is a global problem, which is modelled by Biancardi et al. [2] as a leader-follower game between a leading far-sighted regulator and a number of following myopic extractors. The latter have the choice to declare to the regulator, and to pay tax on, a fraction of their extraction. As the remainder of the extraction is obtained illegally, they pay a fine when discovered cheating. The article calibrates the model on a particular aquifer in Spain and analyses the effects of the two policy instruments, taxation and the imposition of fines.

The final article in this collection, by Aliakbari Sani et al. [1], addresses the knotty but highly topical problem of efficiently building grid network capacity and producing energy for a large, growing—and by definition mobile—fleet of electrical vehicles. The contribution here is to ensure that the resulting expansion plan is robust with respect to variations in the actual energy demand.

The editors wish to thank all authors and all reviewers for their contributions that have made this special issue possible. They want to especially thank Georges Zaccour for his support when Ngo Van Long could not continue his editorial role.

**Data Availability** Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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