Ecol Res (2007) 22: 8–9
DOI 10.1007/s11284-006-0071-3

Kenneth J. Arrow

Eco(nomics/logy)

Received: 30 August 2006 / Accepted: 25 September 2006 / Published online: 10 November 2006

Abstract This note discusses the analytic tools available for studying the interrelations between the economy and the ecological system. It points out the importance of the concept of cooperative games as an addition to the emphasis on non-cooperative games in both economics and ecology. The relation between both concepts of the games and the market system is discussed.

Keywords Economics · Ecology · Games · Cooperation · Market

The coincidence of prefixes in the two subjects is thoroughly appropriate. The Greek root means *household* and it signifies an interacting set of individual activities, both complementary and competitive with each other. The predator benefits from the growth in both numbers and individual size of the prey, yet one cannot say the relation is entirely beneficial to the latter. One nation may gain from the growth in other nations from increased exports to them but also lose as they compete for scarce resources such as oil.

The analysis of these interactions is a common feature of ecology and economics, and increasingly, analytic tools are being exchanged between them. Especially noteworthy has been the development of non-cooperative game theory, as emphasized in Levin's paper (2006). This theory has the right framework for representing interactions of entities with differing criteria for success.

From what I understand, non-cooperative game theory has had a success in evolutionary biology even exceeding that it has enjoyed in economics. Each player (individual, gene, species, firm) chooses a strategy, which is optimal for it given the strategies of the other players. A set of strategies consistent with each other under this definition is an equilibrium. The rules of the game are the biological and/or economic conditions, which permit the strategy choices and define the *payoff functions*, the criteria by which each player defines optimality for itself.

It is clear that, among socially interacting individuals, there may easily be many situations in which all players will gain by agreeing strategies that do not define an equilibrium. The *prisoners' dilemma* and the *tragedy of the commons* are well-known parables which illustrate this point. In these, there are good sets of strategies that nevertheless do not define an equilibrium, because it will pay one or more players to shift if they believe the others will not. This problem arises obviously in global warming. If all countries but one agree to restrict emissions, that one country will have a strong incentive to increase emissions. The cost of the emissions falls on all countries while only a small fraction falls on it, but it can reap the entire economic gain from increased energy use.

Indeed, if we define an equilibrium to be inefficient if there is a choice of strategies for all players that will make all better off than in the equilibrium. Then it can be shown that, for almost all games, the equilibrium is inefficient in this sense.

This raises the possibility of gains by making agreements on the choices of strategies, i.e., by cooperation. Indeed, von Neumann and Morgenstern (1944) assumed that the outcome of any economic transaction would be efficient (i.e., there would not be any choice of strategies which could make every player better off than in the strategies chosen). They referred therefore to cooperative games, in which players can make explicit contracts on the choices of strategies.

Unlike the case with non-cooperative games, there is really no general theory of cooperative games. Indeed, there seem to be deep paradoxes in this concept. Nevertheless, in the analysis of economic–ecological systems, the cooperative element is clearly important. The idea that a mutually advantageous gain will, or at

K. J. Arrow
Department of Economics, Stanford University,
Stanford, CA 94305-6072, USA
E-mail: arrow@stanford.edu
Tel.: +1-650-3273957
Fax: +1-650-7255702

least should, be taken is very appealing and strongly supported in experiments.

In the mainstream of economic theory, an analytically and practically appealing solution is possible. This is the theory of competitive equilibrium. If a number of conditions are met and if a price system is introduced, then in effect one can have a game that is both cooperative and non-cooperative. We are assuming a world of commodities, which can be produced, bought and sold in varying quantities. If, for each commodity, a price is set at which all transactions take place, if each individual in the economy takes the prices as given and optimizes accordingly, and if the resulting supplies and demand are equal for all commodities, then the outcome is efficient (provided a number of other assumptions are met). The competitive system is a non-cooperative game, since each individual optimizes, taking the rest of the economy (specifically, the prices) as given, yet its outcome is efficient and therefore like that of a cooperative game.

The assumption most likely to fail in the case of economic–ecological interactions is that all commodities are priced. A notorious example of failure is in the case of what have been labeled *fugitive commodities*, those which are so mobile that no one can establish ownership. Water, air, fauna, and even the air- and water-borne seeds of plants are the prime examples. Dumping wastes in water and air cannot be traded on an ordinary market. Ecological services are usually fugitive commodities.

This discussion suggests two categories of remedies, which can be combined. One is to invent mechanisms that resemble market prices as much as possible. Among these are taxes intended to reflect the harm imposed on others and tradable permits (cap and trade).

Another is to enter into explicit agreements or other social decisions (e.g., laws), to set quotas or impose restrictions. For example, particular lands and marine areas can be set aside, so that certain prescribed activities cannot take place at all there. Requirements for minimum levels of energy efficiency are another example.

All of these are possible depending on circumstances. When the market works, it has the advantage not only of achieving efficiency but in doing so without requiring any one agent to accumulate a vast amount of information about the preferences and productivities of others. At the opposite extreme consider a system of regulation, which sets an individually defined input or output quota for each firm to meet. Either the regulatory agency would need to know a great deal about the trade-off between output and environmental damage for each firm or the regulatory system would be highly inefficient. Market-like instruments (taxes or tradable permits) generally require much less knowledge by the regulating authorities (for example, it is not necessary to know the production capabilities of individual firms). However, one cannot be completely confined to these instruments.

There has been considerable discussion of changing social norms. I think of social norms as one way of expressing the outcomes of cooperative games. They work through the network of social relations among humans. However, their creation and diffusion is by no means a well-understood process. I would not refrain from trying to create ethical patterns, which might or might not be taken up, but I would think that formal agreements that create appropriate (market or legal) incentives will still have to be the dominant process in seeking to improve economic–ecological patterns. Indeed, formal processes may help to engender social norms.

References

Levin S (2006) Learning to live in a global commons: socioeconomic challenges for a sustainable environment. Ecol Res 21:328–333

von Neumann J, Morgenstern O (1944) Theory of games and economic behavior. Princeton University Press, Princeton