1 Theoretical frontiers of environmental economics

Carlo Carraro and Domenico Siniscalco

Environmental economics was the subject of a comprehensive research programme in the 1960s and 1970s. This programme dealt with a wide range of issues and policy problems, such as the economics of natural resources, the methods and problems in the correction of externalities, the management of common property goods, the economics of nature preservation. Against this background, suitable analytical tools were provided by the theory of non-renewable and renewable resources; the theory of missing markets; Pigovian taxation and the theory of property rights; the economics of public goods; welfare economics. All in all, the research programme was very successful and in the following decade it gave rise to several textbooks, from Baumol and Oates (1975) to Siebert (1987), Pearce and Turner (1990). At the beginning of the 1990s, no less Partha Dasgupta (1990) was claiming that environmental issues were 'very cold' as topics for analytical investigation and 'dead' as research problems.

In recent years, however, scientists have highlighted a set of 'new' environmental phenomena, such as global warming, ozone layer depletion, acid rains, fresh water and ocean pollution, desertification, deforestation and the loss of bio-diversity (e.g., cf. UNEP (1991)). Some of the above phenomena, such as ozone layer depletion, were newly discovered; some others were known, but attracted new attention, due to their scale and socio-economic implications, such as global warming. In both cases, the new environmental problems entered the agenda of policy makers and became the centre of world-wide debate and a massive diplomatic effort, culminating in the UN Conference on Environment and Development, held in Rio de Janeiro in 1992 (for a discussion, see World Bank (1992), Siniscalco (1992), IPCC (1995)).

The new environmental phenomena have a global scale and for the first time pose a serious threat on the well-being of future generations. Most of all, they share a set of common features: they are closely related to demography, economic growth and industrialisation; they can have a very long-run dimension, affecting future generations as well as the present ones; they have an intrinsic transnational or global dimension, due to nature of the externalities involved; they have important international repercussions through trade and factor mobility. The economists community increasingly recognised that the above common characteristics require new analytical tools and fresh policy analyses (the discussion is summarised in Carraro and Siniscalco (1992)).

The close links between environmental resources and development call for a new viewpoint, which goes under the name of *sustainable development* (Bruntland (1987)). Sustainability, among other implications, requires analysis of the environment as a dimension of socio-economic development, and not as a separate issue, which can be analysed in partial equilibrium or even in isolation from the rest of the economy. Economists, in particular, have to integrate the environment in the theory of growth, with special emphasis on the long run and on the role of innovation and technical progress. And they have to take into account the fact that a substantial part of pollution is produced by firms, which interact in various, not always competitive, market structures.[1]

The global and international dimension of the environmental issues requires an even wider departure from standard analysis. In a world of global externalities, the efficient protection of the environment requires international coordination of environmental policies, and more particularly self-enforcing agreements among sovereign countries. The same applies in a context where costly national environmental policies have important international repercussions through trade and factor mobility, even in the absence of any transnational externality. These two dimensions, in turn, require a shift from the standard literature on government intervention to a literature on negotiations between nations.

Against this background, in the present decade environmental economics have gathered a new momentum, and are now considered a lively and relevant subject, not only on policy but also on analytical grounds. In some cases, the required tools were taken from other areas of economics; in other cases, the analytical requirements provided an impulse for original applications and developments.

Indicators of this new interest in environmental issues and their economic analysis are provided in a recent survey by us on the articles submitted to international conferences and journals on environmental economics (see, Siniscalco (1996)). The survey shows that papers related to sustainable development *and* to the international dimension of environmental policy account for about 40 per cent of the total sample considered and their share is constantly increasing.

The existing new environmental economics literature is not yet systematised in a sufficient way to be reflected in a textbook, but is now an established field of research. For this reason, we believe it is time to take stock and publish a volume containing a coordinated set of surveys. With this aim we asked the best scholars in the field to produce broad reviews of their own specific research areas. Different viewpoints and subjects still need to be developed, but the resulting volume represents a substantial leap forward, *vis-à-vis* similar works, such as the *Handbook of Natural Resources and Energy Economics* or the *Handbook of Environmental Economics*.[2] These volumes, such as the mainstream textbooks mentioned at the beginning of this Introduction, devote little attention to the literature on the new environmental economics but rather represent the up-to-date reviews of the more traditional approach. Such an approach analyses environmental issues in a closed, competitive, full-information economy. We rather propose to analyse them in an open, generally non-competitive economy, with transnational or global externalities. Even when closed-economy issues are analysed the focus is on interactions between trade, industrial and environmental issues and policies, thus stressing the importance of a new approach in which environmental problems are no longer isolated from all other economic dimensions.

Notice that, even if this volume provides a broad survey of the recent developments in the new economics of the environment, we decided not to use the word 'handbook' in the title. We are quite conscious that the material presented herein is still a preliminary study of the problems posed in the recent literature and it is likely to be subject to a rapid evolution which will yield new achievements and results. Therefore, we prefer to see this book as a stimulus to further research. By proposing the state of the art on new environmental problems, analytical tools, and economic policies, the book will provide the right framework upon which further developments can be based. This is going to be particularly helpful in a field, the new environmental economics, in which scholars coming from different fields (international trade, growth theory, industrial organisation, game theory, macroeconomics, labour economics) are joining in their efforts to improve our understanding of complex economic phenomena.

The material presented in this volume can ideally be divided into three parts. The chapters by Andrea Beltratti and David Ulph deal with the relationship between environment, economic growth and technological innovation. These chapters emphasise the link between sustainable development and technical progress as the main way to achieve substantial intergenerational environmental protection. In particular, David Ulph shows how environmental and industrial policies can be adapted to foster firms' technological innovation, whereas Andrea Beltratti analyses how technical progress affects the equilibrium growth path of economies in which environmental concerns must no longer be neglected.

A second set of chapters by Lans Bovenberg and Michael Hoel analyses the issue of the optimal design of environmental taxation. Lans Bovenberg reviews the highly debated problems related to the possible emergence of the so-called 'environment–employment double dividend'. The chapter singles out the conditions under which a joint increase in environmental quality and employment can actually be achieved by an appropriately designed tax policy scheme. Michael Hoel analyses the optimal implementation of environmental taxes at the international level. Should tax rates be coordinated across countries and/or across sectors? How can further additional policy tools, e.g., trade tariffs, be used to achieve the first-best optimal taxation scheme in the presence of countries' heterogeneity?

The third set of surveys, by Alistair Ulph, Michael Rauscher and Scott Barrett, deals explicitly with the international dimension of environmental policy. Alistair Ulph discusses the way in which trade policy can be used to protect the environment and how to reduce the possible negative consequences of environmental policies on trade flows. Michael Rauscher discusses the impact of coordinated and non-coordinated environmental policies (e.g., environmental dumping) on capital mobility. Scott Barrett takes into account all these effects when studying the formation of international agreements to protect the global environment. The analysis of such self-enforcing agreements, carried out in the context of non-cooperative game theory, is important when exploring the possibility of protecting the global environment in the absence of a supra-national institution with the power to design and enforce global environmental policies.

The literature in this area is still developing. Further advances require new developments of the theory of non-cooperative coalition formation. The last two chapters provide the latest results developed by game theorists and also consider applications to environmental issues. In particular, the chapter by Hideo Konishi, Michel Le Breton and Shlomo Weber focuses on games without externalities and discusses the endogenous formation of coalitions for the provision of public goods. The chapter by Francis Bloch complements the previous one by analysing the formation of coalitions in games with both negative and positive externalities. Environmental applications concern international environmental agreements as well as environmental innovation and R&D.

Given the survey nature of the chapters contained in this volume, we do not summarise the articles in detail. We would rather conclude by concentrating on what is missing in the volume and recommend for further reading.

First, the volume ignores the demographic dimension of environmental deterioration, as the topic is very poorly analysed by economists, with very few exceptions (e.g., Baldwin (1995)). This gap should be filled by taking into account the possibility of characterising endogenous population growth as well as migrations.

Second, as an editorial choice, the volume mainly deals with theoretical frameworks, as a good review of empirical work in this area would require a volume by itself. We therefore limit ourselves and recommend further reading starting with Musu and Siniscalco (1996) for data problems, to IPCC (1995) and Carraro and Galeotti (1995) for a review of the existing models. Moreover, we do not deal with applied issues like waste and water management.

Third, the articles of this volume only marginally touch upon some very recent research topics, such as the links between financial markets and environmental protection or the political economy of environmental policy.

Lastly, and most importantly, what is really missing is an integration of the different approaches analysed in the various surveys collected in this volume. But this cannot be done at this stage, and still requires substantial work.

Notes

1 Several recent contributions on the theory of environmental policy when markets are imperfectly competitive are contained in Carraro, Katsoulacos and Xepapadeas (1996).
2 Cf. Kneese and Sweeney (1993), Bromley (1995).

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2 Growth with natural and environmental resources

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1 Introduction

Exploitation of natural resources and environmental assets is a dynamic process, given that utilisation and (spontaneous or induced) regeneration flows affect the quantity and/or the quality of the stock. Optimal exploitation of natural and environmental resources has therefore to be forward-looking, as economic agents need to take into account the consequences of economic activity on the future availability of resources. However, devising optimal exploitation plans is in practice an enormous challenge, due to incomplete information (e.g., about models of the interrelationships among economic and ecological subsystems), genuine uncertainty (e.g., about the possibility of a future climate change or about future environmental policies or technologies) and international links (in the case of uniformly mixing pollutants like CO_2, policies decided by one country in isolation from the international community may not be effective).

Devising optimal exploitation plans is an enormous challenge also in theory. Of course, there are several reasons why it is important to perform a theoretical study of the relationship between economic activity and the use of resources: it may be a source of inspiration for empirical models aimed at building quantitative tools assisting policy makers in the creation of economic and environmental policies (many large-scale econometric models based on optimising agents for studying demand for resources are nowadays based on the assumptions of intertemporal maximisation); it may enlarge the range of phenomena considered by economists, for example to take into account variables that are fundamental to issues of sustainability of growth and its compatibility with the environment, like the laws of thermodynamics and population, and may motivate economists to devote more attention to the analysis of complex systems.

However, such a large reward does not come without a large cost. Economists who wish to study optimal exploitation policies face a very difficult modelling exercise, and are presented with several issues which go beyond the standard difficulties met in studying other economic problems. The effort to model not simply any exploitation policy but a policy which is regarded as optimal in the face of given a certain intertemporal objective function requires sophisticated mathematical instruments. There is not complete freedom in the description of the system: analytical results may be obtained only in small models containing two or three state variables. Economists have in general accepted this methodology, and have studied systems which have been simplified from many points of view, producing a large literature that directly or indirectly is concerned with issues of environment and economic growth. It will be clear in what follows that the particular specification of the model dictates to a large extent the problems that can possibly be discussed with the equations chosen, and this makes many results highly model specific. Indeed, among the many variables which it would be necessary to consider, e.g., physical and human capital, natural capital, reproducible and exhaustible resources, population, one has to make choices in order to solve the models analytically, at the cost of reduced generality and applicability. This has to be kept in mind, especially when it comes to deriving environmental policy implications.

The chapter starts by describing a general reference model, which highlights in a synthetic but unifying form the main issues of growth with natural and environmental resources. While it may be worth waiting until the end of the second section before describing the plan of the chapter in more detail, since at that stage it will be possible to refer to the general reference model, it may be useful to specify immediately what is not considered explicitly in this chapter for reasons of space. First, even though the economic literature on growth and the environment can in some sense be traced back to Malthus, this chapter will be limited to the analytical models that have appeared since the 1970s. Secondly, not all interesting aspects of the main building blocks of these models, that is preferences, productive structure and institutions, will be discussed with equal detail. The space devoted to criteria which are alternative to maximisation of discounted utility will not be as large as this topic deserves; similarly, there will be basically no discussion of models with endogenous population growth. Also, even though typically the existence of environmental resources is connected with ill-defined property rights, requiring various public instruments to internalise some interactions among agents, there will be an emphasis on solutions to planning problems rather than on competitive systems, even though a section will be devoted to a summing up of rules for environmental policy.

2 A reference structure

In order to describe the issues and the variables which will be discussed in this chapter it may be useful to start with a general structure, composed of two blocks describing preferences and technologies.

2.1 Preferences

The preference block is specified as a maximisation of discounted future utilities

$$\max \int_0^\infty e^{-\delta t} u(c,E,p,P)dt$$

where c is the flow of consumption, E is the stock of environmental asset, p is a flow of pollution and P is a stock of pollution.[1] With subscripts denoting derivatives, $u_c>0$, $u_E>0$, $u_p<0$, $u_P<0$, $u_{cc}<0$, $u_{EE}<0$, $u_{pp}<0$, $u_{PP}<0$, while the cross-derivatives may have any sign.[2] Before discussing the arguments of the utility function, note that a strictly positive δ is necessary to obtain a finite integral of utilities and to be able to compare alternative policies. δ reflects preference towards the present, and is often taken as representing discrimination against future generations (see Ramsey (1928)). Criteria other than maximisation of discounted utility, such as the Rawlsian criterion and the overtaking criterion, are sometimes recommended to preserve equality of treatment across generations (see Dasgupta and Heal (1979) and Heal (1993) for a general discussion).

The variable c may be interpreted as consumption of a single good or as an index of consumption obtained from different varieties, see Grossman and Helpman (1991). The latter interpretation may be appropriate to represent heterogeneous varieties with decreasing pollution/output ratios, even though a similar description may be achieved by considering heterogeneous intermediate goods in the production function. The other arguments of the utility function usually do not appear all together; the possible choices are whether to include pollution or environmental assets, and whether to consider stocks or flows.

Including flows rather than stocks may not be realistic but simplifies considerably the overall structure. The choice between pollution and environment becomes important in 'genuine' growth models where variables may grow for ever. Solutions with a permanently increasing stock of environment or pollution may not make much practical sense. Indeed it is common to assume an upper bound to the stock of pollution, beyond which the environment loses its role of life-support system. Many different cases may again arise. One can consider the 'original state' as a situation that can only be damaged by human actions, but others may contend that the intervention of humanity can continuously increase the quality of the environment; for example, one may prefer New York City plus some surrounding environmental amenities to amenities without New York City.

A final question regards aggregation: is it meaningful to think of one stock (or flow) of environment when there are many relevant environmental media, like amenities, quality of air and water, and so on? Growth models have to be aggregate in order to preserve analytical tractability, and therefore assuming the existence of one giant stock is in some sense an excusable necessity (this problem will be taken up again in the conclusions). Another way to justify such aggregation is to think of the model as describing a specific phenomenon of interest, e.g., air pollution in a closed economy.

2.2 *Technology*

The block describing the structure of the economy is composed of a production function and an ecological relation, keeping track of the effects of economic activity on natural and environmental resources. Production is obtained by a function which in general can be written as

$$Y = F(K, H, L, E, r, T, X, w)$$

where K is the physical capital stock, H the human capital stock, L the stock of labour, r a flow of natural resources extracted from a stock of initial dimension S_0 (in the case of exhaustible natural resources there is a total constraint over the planning horizon $\int r_t dt \leq S_0$), T is technological knowledge, w is waste. X is the flow of intermediate goods obtained from a production function

$$X = F_X(K_X, H_X, L_X, E_X, T_X)$$

where the subscript denotes the use of a certain factor of production by the intermediate sector. Constraints on the function F can be of various natures, e.g., one may assume homogeneity of degree one in all the inputs or assume the existence of globally increasing returns to scale. Moreover, various assumptions about the elasticity of substitution may be made, e.g., a constant elasticity lower or larger than one. Technology may be assumed to be constant or exogenously growing or accumulated as a result of accumulation of capital. The same is true of the function F_X; to the extent that some factors of production are a common good, one does not need to distinguish between the inputs to the two functions, e.g., one might plausibly have $F_X(K_X, H, L_X, E, T_X)$.

The description of the production block is completed by the dynamic