1. Introduction: Joint Production and Ecological Economics*

with Harald Dyckhoff and John Proops

1.1 Introduction

Human existence is unthinkable without its relationship to nature. This relationship is twofold. On the one hand, humans depend in a variety of ways on nature and the services it provides. Examples include resources such as water, food and fuels; functions such as the regulation of climate, floods and diseases; cultural services such as recreation as well as aesthetic and spiritual fulfilment; and the space for unfolding all kinds of human activity. On the other hand, human activity impacts the natural environment: humans intentionally shape their natural environment to form their space of living; they take resource materials from, and release substances into, natural ecosystems; and in so doing they alter natural processes and functions.

The imperative of sustainability requires sustaining nature's functioning and services for humans over the long run. So, the relationship between humans and nature must be of a certain quality. This poses a challenge for how humans should act towards nature. The challenge has many facets which have to be addressed when studying the relationship between humans and nature, and when developing recommendations for sustainable policy:

- There is an inextricable interaction of processes from the natural sphere, traditionally analysed by the natural sciences; the social and economic sphere, traditionally analysed by the social sciences; and categories of human thinking, which is the domain of philosophy. This requires an interdisciplinary approach.

*Sections 1.2–1.6 are based on Baumgärtner, Dyckhoff, Faber, Proops and Schiller (2001).

- Natural, social and economic processes are dynamic and characterised by the modification of stocks on a multitude of different time scales. In addition, they may be irreversible.
- The imperative of sustainability requires consideration of long time horizons.
- Since natural, social and economic processes are inextricably intertwined, one faces complex systems. This complexity is aggravated when considering the long run.
- Knowledge about the relevant processes and systems is generally restricted by a high degree of uncertainty and fundamental ignorance. Again, this restriction is aggravated when considering the long run.
- Human action is multifarious and cannot analytically be grasped by one single paradigm. The concept of *homo economicus*, which highlights self-centred optimising behaviour and dominates the current social sciences, needs to be complemented by other concepts of the human that feature, for example creativity, free will, communal sense and responsibility.

In the face of such a major challenge, some people may just resign and decide that sustainability is a myth and of hardly any practical relevance; others may revert to isolated ad-hoc action which falls short of addressing the challenge of sustainability in a proper way. But what is actually needed is an all-encompassing, consistent and systematic perspective on the problem and corresponding guidance for action.

In this book, we argue that the concept of *joint production* can be an essential element of such a perspective, and a fruitful tool to develop guidance for sustainable policy. The notion of joint production denotes the phenomenon that several outputs *necessarily* emerge together from economic activity. These joint outputs may all be desired and positively valued goods. But in the vast majority of instances, some of them are undesired and may even be harmful to the natural environment. An example is the refining of crude oil, in which gasoline, kerosene, light heating oil and other mineral oil products are produced; but harmful sulphurous wastes and carbon dioxide emissions are also necessarily generated.

The concept of joint production captures the particular characteristic of human activity – namely that it always has unintended side effects – which is the structural cause of many environmental problems. With this, it is a natural starting point for analysing how environmental problems emerge and how they can be solved in a sustainable manner. Also, the concept of joint production is suitable for the systematic and unified consideration of all the aspects mentioned above.

With this book, we aim at a comprehensive analysis of economy-environment interaction which takes the aspects mentioned above seriously. We develop concepts that are interdisciplinary and allow a general, consistent and systematic analysis. In so doing, we contribute to the conceptual foundation of environmental policy. With this, our book should be of central interest to the field of *ecological economics*, which is commonly understood as 'the science and management of sustainability' (Costanza 1991) and, thus, has the same research aim. Besides making a significant contribution to ecological economics, this book is also relevant to other research fields, such as environmental and resource economics, environmental policy and regulation, environmental valuation, as well as environmental ethics and responsibility.

In this introductory chapter, we outline the argument of the book. The remainder of the book then elaborates this argument in detail. In Section 1.2, we make reference to the laws of thermodynamics in order to show how joint production is implied by the First and Second Laws. There is a review of the analysis of joint production in economics in Section 1.3, pointing out its extensive history and range of applications. Section 1.4 relates joint production to philosophy, showing how its consideration gives rise to ethical and epistemological concerns. The comprehensibility of joint production is stressed in Section 1.5, while Section 1.6 shows how the concept of joint production is constitutive and supportive of such notions as holistic policy analysis, the precautionary principle, time horizons and external effects. Section 1.7 explains the approach and plan of the book.

1.2 Joint Production and Thermodynamics

Why is joint production such a ubiquitous phenomenon and useful notion in ecological economics? We believe that this is because joint production is intimately related to the laws of thermodynamics. The application of thermodynamics is widely recognised as an essential element in much current ecological-economic thought, since it gives rich insights into the nature of economy-environment interactions. The usefulness of thermodynamics derives from its applicability to *all* real production processes, which are the basis of economic activity. Thus, thermodynamics relates ecological economics to the natural sciences, such as chemistry, biology and ecology, which also facilitates interdisciplinary research.

The laws of thermodynamics lead us to recognise that the human economy is an open subsystem embedded in the larger, but finite, system of the natural environment (Boulding 1966, Georgescu-Roegen 1971, Daly 1977, Ayres 1978, Faber et al. 1995[1983], and many more). The strength of the concept of joint production is that it allows us to incorporate this insight about economy-environment interactions into ecological economics. This can be seen in the following argument.

From a thermodynamic point of view, energy and matter are the fundamental factors of production. Every process of production is, at root, a transformation of these factors. Hence, in this view production processes are subject to the laws of thermodynamics, which in an abbreviated form can be stated as follows:

First Law: Energy and matter can be neither created nor destroyed, that is, in an isolated system matter and energy are conserved.

Second Law: In every real process of transformation a positive amount of entropy is generated.

One can describe the process of production as a transformation of a certain number of inputs into a certain number of outputs, each of which is characterised by its mass and its entropy. From the laws of thermodynamics it then follows that every process of production is joint production; that is, it results necessarily in more than one output (Faber et al. 1998, Baumgärtner 2000: Chapter 4). In particular, industrial production processes which generate low entropy desired goods *necessarily and unavoidably* jointly produce high entropy waste by-products. We can represent this thermodynamic constraint on real production processes as in Figure 1.1. For example, in the production of iron one starts from

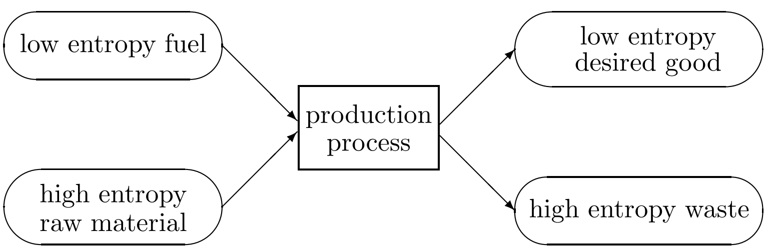

Figure 1.1 Production processes generating low entropy desired goods necessarily and unavoidably jointly produce high entropy waste materials.

iron ore. In order to produce the desired product iron, which has lower specific entropy than iron ore, one has to reduce the raw material's entropy. This is achieved by employing a low entropy fuel, for example coal, which provides the energy necessary for this process. From a thermodynamic point of view, one may therefore consider production as a shifting of high entropy from the raw material to the waste product. At the same time, it becomes apparent that the inputs are also joint in the sense that high entropy iron ore and low entropy fuel are complementary (cf. Christensen 1989: 28–29). Hence, the fundamental idea of joint production applies on both the input and the output side.

In that sense, the concept of joint production can capture the essential thermodynamic constraints on production processes as expressed by the First and Second Laws, through an easy-to-use and easy-to-understand economic concept.

This holds for production in both economic systems and ecosystems. Joint production, therefore, is also a fundamental notion in ecology, even though it is not often expressed as such in that discipline. Organisms and ecosystems, as open, self-organising systems, necessarily take in several inputs and generate several outputs, just as does an economy. Indeed, such natural systems are the earliest examples of joint production.

The power and generality of the joint production concept can be demonstrated through the way it embraces four central issues in ecological economics: irreversibility; limits to substitution; the ubiquity of waste; and the limits to growth.

Irreversibility is explicitly included within the above thermodynamic formalisation of joint production, as it is necessarily the case that the production process generates entropy and is therefore irreversible. *Limits to substitution* are also included, as the requirement that high entropy materials inputs must be converted into lower entropy desired goods requires that the material inputs be accompanied by an irreducible minimum of low entropy fuels. The *ubiquity of waste* can be easily derived from the thermodynamically founded joint production approach. It follows from the necessity of jointly producing high entropy, which very often is embodied in undesired material, and hence constitutes waste (for example CO_2, slag, etc.). The combination of the above three issues leads to the notion of *limits to growth*, further emphasising the power and generality of the joint production concept for ecological economics.

1.3 Joint Production and Economics

The analysis of joint production actually has a long tradition in economics. Many economists – for example Adam Smith, John Stuart Mill, Karl Marx, Johann Heinrich von Thünen, William Stanley Jevons, Alfred Marshall, Arthur Cecil Pigou, Heinrich von Stackelberg, John von Neumann, Piero Sraffa – devoted considerable effort to the study of joint production. As a matter of history, the analysis of joint production contributed to the abandonment of the classical theory of value and the establishment of the neoclassical theory of value (Kurz 1986, Baumgärtner 2000: Chapters 5–8). For ecological economists it is interesting to note that several of these authors, in particular von Thünen, Marx and Jevons, emphasised that environmental pollutants come into existence as joint products of desired goods.

There is a substantial body of both theory and applications of joint production in the economics and business administration literature. In general, within this literature two cases are distinguished:

1. all joint products are desired goods, and

2. at least one output is undesired while at least one other is desired.

While the former is the case which has received most treatment in the literature, the thermodynamic discussion suggests that it is the second case that is of particular interest in ecological economics.

The theory of joint production has been extensively developed in business administration (for example Dyckhoff 1996a). For example, joint production is necessarily the case in chemical transformation processes, and in processes of splitting and separation (Riebel 1955, Oenning 1997). A range of computer-based models and methods has been developed to solve the resulting problems concerning the planning and cost allocation of joint production (Oenning 1997). Further, the quantitative relations between inputs and outputs in joint production can be described with input/output graphs, and one can use linear or non-linear algebraic systems generalising Koopmans' (1951) activity analysis. There are also relevant dynamic and stochastic graph-theoretic models in computer science (for example Petri nets) as well as models in process engineering and chemistry, which are particularly important for balancing and managing the flows of material and energy (Spengler 1999). Even the problem of allocating ecological effects to joint products is being addressed (Schmidt and Häuslein 1997).

Important theoretical results about the economics of joint production include the following. Joint production of private and public goods may reduce the usual problem of under-provision of public goods in a decentralised economy (Cornes and Sandler 1984). Under joint production of goods and polluting residuals, and making the realistic assumption that the assimilative capacity of the natural environment for these pollutants is limited, a steady state growth path does not exist (Perrings 1994, O'Connor 1993).

The modern literature on general equilibrium theory does – with a few exceptions (for example Sraffa 1960, Pasinetti 1980, Salvadori and Steedman 1990, Kurz and Salvadori 1995) – not explicitly investigate the properties of economies characterised by joint production. Instead, it is focussed on identifying the most general assumptions under which certain results hold, for example existence and efficiency of general equilibrium. Yet, by doing so it implicitly supplies insights into the economics of joint production. Arrow and Debreu (1954) and Debreu (1959) have shown that even in cases of joint production – be they goods or bads – under standard assumptions there exists a general equilibrium in a competitive economy if (i) the individual production sets are all convex and (ii) the possibility of free disposal is given, that is unwanted and harmful joint outputs can be disposed of at no costs. McKenzie (1959) showed the same result using a weaker assumption about disposal (disposal is possible but not necessarily free and the economy is 'irreducible'), yet only for a technology characterised by constant returns to scale. Furthermore, any general competitive equilibrium, in particular under joint production, is Pareto efficient in the absence of negative externalities (Arrow 1951a, Debreu 1951). Pigou (1920) and Lindahl (1919) have conceived mechanisms to internalise such externalities, thereby re-establishing optimality of the equilibrium. In the case of negative externalities exhibiting the character of public bads, however, this mechanism can only be established under very restrictive and unrealistic assumptions. In particular, every individual is assumed to reveal a personalised willingness to pay for the absence of the public bad and not to act as a free rider.

In summary, while modern economic theory has produced many interesting results concerning the existence and efficiency of equilibrium under joint production, in the case which is most relevant from the ecological-economic point of view – joint production of bads causing public negative externalities – we are essentially left with a negative result.

1.4 Joint Production and Philosophy

The concept of joint production, with its foundation in thermodynamics and economics, stresses that economic activity generally produces two kinds of output: the intended principal product and unintended by-products. We would expect, and indeed observe, that producers will focus their attention and energies on the former, while the latter will be largely ignored, at least to the extent permitted by legal constraints and social mores. This inattention to the undesired products raises two issues of a philosophical nature, one relating to responsibility, that is ethical, and one relating to knowledge, that is epistemological.

Turning first to ethics, the thermodynamically necessary by-products bring with them new issues of moral responsibility. This becomes obvious if we consider the hypothetical case of single production where *no* by-products are generated. In such an idealised world, assuming the existence of perfect markets and a fair social and legal order, the ethical problem for producers of a desired product is narrowly limited as long as they trade their products on the market and obey the legal order. In contrast, joint production implies that economic activity, in addition to the intended products, also results in *unintended* outputs, which often go unnoticed. This lack of knowledge and attention often results in a social and legal order that typically neglects joint products. However, these joint products may be harmful, for example to other producers, consumers, or to the natural environment. As a consequence, both the producer, and the wider society demanding the desired principal product, now face complex ethical problems. Inattention to joint production may therefore easily result in ethical negligence. An example is the inattention to waste in the nuclear industry. From the inception of nuclear power it was recognised that very dangerous and long-lived waste materials would be produced as by-products. Nevertheless, for the first thirty years of commercial power generation, unconscionably little attention was paid to the disposal of this waste (Proops 2001).

Concerning the second issue, epistemology, the area to which we draw attention is that of surprise and ignorance (Faber et al. 1992). Even if one were to suppose that it were possible to produce only principal products, this could still give rise to unanticipated and unwanted environmental effects (for example CFCs are a principal product, not a by-product). However, we believe that unwanted waste by-products are likely to be a greater source of unpleasant environmental surprises because, as mentioned above, they are not the focus of attention for their producers. The story of waste chlorine in the nineteenth century is one of ignorance of, and inattention to, the effects of emitting this waste product, with damaging and unforeseen consequences for air and water quality (Faber et al. 1996b; see also Chapter 16).

What lessons can we learn from this discussion? Considering the concept of joint production naturally leads one to address issues of ethics and epistemology, requiring one to discuss economic questions in a philosophical context. In particular, the concept creates an awareness of both (i) the ethical dimension of economic action due to unintended joint outputs, and (ii) our potential ignorance, primarily of the effects of unwanted by-products.

1.5 Joint Production as a Comprehensible Principle

It is clearly desirable that fundamental concepts of ecological economics should be easily comprehensible. It has often been noted in the literature (for example by Norton 1992) that the scientific approach is sufficient neither for the recognition of environmental problems, nor for their solution. Concerning recognition, as a matter of history, the awareness of environmental degradation was, to a large extent, brought about not by the scientific community, but by laypeople. Often, it was individuals or small groups who first publicly noted that the natural environment was being changed. For, in everyday life, attentive human beings can recognise many dimensions of the natural environment, while science, by its nature, has to reduce the wholeness of an event to only those aspects to which its methods are suited.

The second important reason why central concepts of ecological economics should be easily comprehensible for 'the person in the street' concerns the solution of environmental problems. In democratic societies, decisions about what kind of environmental policy is to be enacted are made (effectively) by ballot. Hence, voters have to understand environmental issues and their proposed solutions.

We have often noted in discussions with scientists who had no background in economics, but also with laypeople, that they were able to comprehend the nature of an environmental problem and to appreciate a proposed solution much more easily when such issues were explained in terms of joint production, rather than in other economic terms, for example production functions, damage functions, externalities, Pigouvian taxes, etc.

1.6 The Concept of Joint Production and Environmental Policy

We have outlined the relationship of joint production to thermodynamics, economics and philosophy, and argued that joint production is also an eminently comprehensible notion. Furthermore, the notion of joint production is particularly useful for the discussion of some environmental policy issues. The concept of joint production naturally leads to these issues, which are currently being discussed in ecological economics, as part of a single framework of analysis. This further demonstrates, we believe, the power of the joint production approach.

Universality of the concept

The concept of joint production may be employed at several different levels of aggregation. It can be used for the analysis of an individual production process, of a firm, of an economic sector, or of a whole economy. It is also suited to examine environment-economy interactions in which economic activities and resulting environmental effects are separated by long time intervals, as in the example of CO_2 emissions. In both cases today's effects on the natural system are caused by stocks of these substances, which were accumulated mainly from emissions up to several decades ago.

Holistic approach to policy

Taking a joint production approach to economy-environment interactions stresses the necessary relationships between various sorts of inputs into production processes, and the corresponding sorts of outputs. As illustrated in Figure 1.1, much, even most, production requires inputs of low entropy fuels and high entropy raw materials, and generates low entropy desired goods and high entropy wastes. Thus, this thermodynamically based joint production representation shows us that the two issues, of natural resource use and of pollution from waste, are necessarily and intimately related: the resource is the mother of the waste. So it is conceptually incomplete to consider natural resources and pollution as separate issues. Seeking to understand either on its own leaves out this relationship, with potentially profound implications for policy analysis. In summary, the theory of joint production tells us that sound environmental policy can come only from an integrated and holistic conceptualisation of the production and consumption processes.

Time scales and time horizons

Joint production leads one to the recognition of different time scales and time horizons. Desired principal products are generally produced and consumed over relatively short time scales, leading to relatively short time horizons of decision makers with regard to such outputs. However, jointly produced waste outputs are often emitted into the environment, where they can accumulate over significantly longer time scales. Such accumulation may, and often does, lead to the unanticipated and unpleasant surprises discussed earlier. Clearly, the social management of such problems demands much longer time horizons than those typically applied to the principal products.

Precautionary principle

The discussion in Section 1.4, concerning how awareness of potential ignorance and responsibility follows from the perspective of joint production, gives additional support to applying the precautionary principle. Indeed, a frequently perceived weakness of this principle is its lack of apparent conceptual foundation. We consider it supportive of both the concept of joint production and the precautionary principle that an analysis of the former so directly gives rise to the latter.

External effects

Within the environmental economics literature, with its roots in welfare economics, the usual analytical method for understanding environmental damage is through the notion of external effects. There is postulated a relationship between economic actors, which is asymmetrical and not mediated by a market; for example if one smokes in a lift, it causes uncompensated offence to one's fellow passengers. In the usual externality approach this relationship is conceptualised as an issue of welfare/utility loss of the person affected by the external effect. That is, the description is based on the effect. One could, however, recast this relationship starting from the cause of the effect. Very often one would observe that the starting point is an unintended joint product. In the example of smoking in the lift the desired product of nicotine in the bloodstream has an unwanted joint product of smoke in the lift. Therefore, we observe that there exists a duality between an explanation based on the effect, that is the externality approach, and an explanation starting from the cause of the effect, that is the joint production approach.

We also note that welfare effects will only be taken account of once they have been experienced; that is, external effects are matters of the ex post. On the other hand, the concept of joint production can alert one to the potential of environmental harm; that is, considering joint production ex ante creates a motive for actively exploring as yet unknown potential welfare effects (Baumgärtner and Schiller 2001: Section 6, Baumgärtner 2000: 293–294). We therefore argue that the concepts of joint production and externality are complementary.

1.7 Approach and Plan of the Book

The discussion in Sections 1.2–1.6 has suggested that the concept of joint production can unify the different perspectives of the natural sciences, economics and philosophy, and thus serve as a fruitful tool to develop guidance for environmental policy. In the different parts of the book, we investigate joint production from these different perspectives. In this sense, the book is heterogeneous. Different specific methods are employed, for example mass, entropy and exergy balances (Chapter 3), constrained optimisation (Chapters 8 and 10), and philosophical reasoning (Chapters 11–14). While this heterogeneity may pose a potential problem, it also allows the reader to take alternative entries to the subject of joint production and this book. Also, the diversity of perspectives is unified by the common subject of joint production, a common conceptual framework, and a common way of presenting arguments so that they can easily be related to each other.

Part I lays the conceptual foundations of joint production. As a starting point, we take the observation that joint production is a ubiquitous phenomenon. Employing a natural science perspective, in particular from thermodynamics, we show that this is not accidental, but a necessary characteristic of all productive activity. Accordingly, we define joint production in such a way that the inevitability of joint outputs is captured, and the temporal dimension is taken into account. On a conceptual level, we go on to explore implications of joint production for the dynamics of ecological-economic systems – such as multiple stock dynamics and complexity – and investigate the role of joint production for the emergence and solution of environmental problems.

Part II approaches joint production from a welfare economic perspective. To start with, we survey how joint production was analysed in the history of economic thought. Thereby, we identify remaining gaps in the current economic understanding of the issue. One of these gaps is related to the valuation of joint products, which is crucial for dealing with joint production. We study the particular aspect of ambivalence, that is, a joint product may potentially be both positively and negatively valued. We also study how joint production of harmful pollutants affects intertemporal economic decision-making and the dynamics of capital and pollutant stocks. One important conclusion from this part will be that taking joint production and stock dynamics seriously increases the complexity of economic valuation up to a point where the economic approach of ‘rational’ and ‘efficient’ policy-making ceases to be a helpful tool in meeting the challenge associated with sustainability (see Section 1.1).

In response to this, in Part III we adopt an ethical perspective on joint production as a complement. It is centred around the concept of responsibility. We define this concept and explore the limits of responsibility, and we relate it to joint production, complexity, and uncertainty. This forms a conceptual basis for the precautionary principle. Distinguishing between individual and collective responsibility, we discuss the role of both the individual as economic agent and politics at large. From this perspective, we sketch an approach to sustainable policy which complements the economic approach where it falls short of meeting the challenge of sustainability (cf. Section 1.1). We find that politics has to assume responsibility to a much greater extent than currently acknowledged.

While the analysis in Parts I through III is mainly theoretical, Part IV presents empirical case studies from the paper, chlorine, cement and sulphur industries. These serve to illustrate the general results from the previous parts, and offer an empirical approach to the phenomenon of joint production. Indeed, these (and other) real-world cases of joint production in some ways inspire our conceptual and theoretical analysis of the phenomenon. Ultimately, they demonstrate that the perspective of joint production developed in this book is fruitful in that it allows one to see real-world problems in a new way and to identify the policy-relevant structure of the respective problems.

After studying joint production from different perspectives in the four parts of the book, the concluding Chapter 19 summarises the key insights and draws conclusions concerning the foundations of environmental policy.