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Joint Production

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1. Introduction

The concept of joint production can be considered as one of the conceptual foundations of ecological economics. In support of this claim, a survey of the articles published in the journal Ecological Economics, and of the books published by their authors, reveals a common theme: that the production of wanted goods gives rise to additional unwanted outputs (bads), which may be harmful to the environment. The fundamental economic notion describing this relationship is that of joint production. Briefly put, this means that several outputs necessarily emerge together from a single productive activity. An example is the refining of crude oil, in which gasoline, kerosene, light heating oil and other mineral oil products are produced; however, harmful sulphurous wastes and carbon dioxide emissions are also necessarily generated.

In the following, we advance our argument as follows. In Section 2, we make recourse 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 3, pointing out its extensive history and range of applications. Section 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 5, while Section 6 shows how joint production is constitutive and supportive of such notions as holistic policy analysis, the precautionary principle, time horizons and external effects. Section 7 concludes.

2. Joint Production and Thermodynamics

Why is joint production such an ubiquitous 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 economics thought, since it gives rise insights into the nature of economy-

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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. 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 from 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:

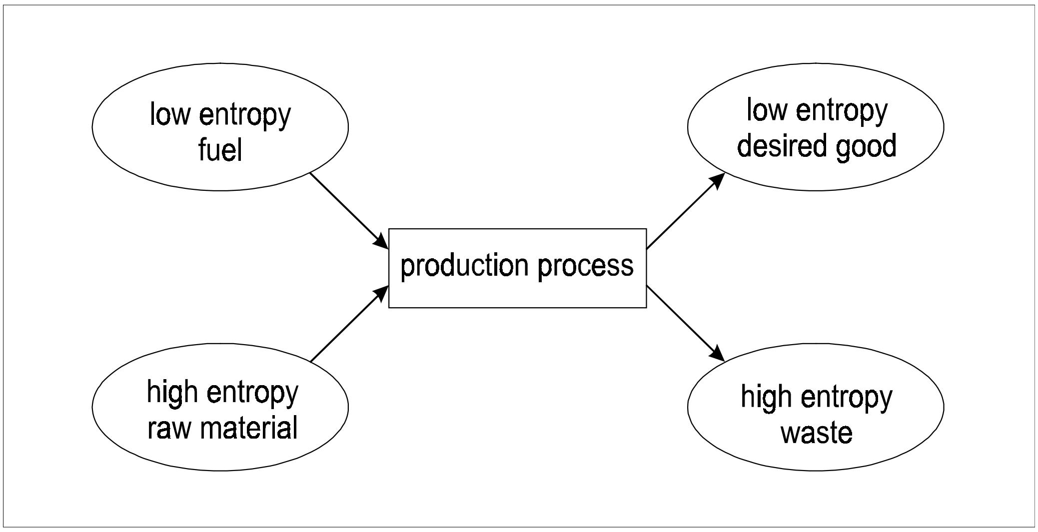
First Law: Energy and matter can be neither created nor destroyed, i.e. in an isolated system matter and energy are conserved.

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; i.e. it results necessarily in more than one output (Faber et al. 1998, Baumgärtner 2000: Chap. 4). In particular, production processes which generate low entropy desired goods necessarily and unavoidably jointly produce high entropy waste materials. We can represent this thermodynamic constraint on real production processes as in Figure 1.

Figure 1: Production processes generating low entropy desired goods necessarily and unavoidably jointly produce high entropy waste materials.

For example, in the production of iron one starts from 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, e.g. 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 and low entropy fuel are complementary (cf. Christensen 1989: 28-29). Hence, the fundamental idea of joint production applies both on 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 (e.g. CO2, 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.

3. Joint Production in Economics

Having developed the concept of joint production as a necessary consequence of thermodynamics, we now review the way this theory has evolved in economics. This will help us to assess how far economic theory has already laid the ground for implementing this approach in ecological economic analysis.

The analysis of joint production actually has a long tradition in economics. Adam Smith, Johann Heinrich von Thünen, John Stuart Mill, Wiliam Jevons, Karl Marx and Alfred Marshall – all 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: Chaps. 5 to 8). For ecological economists it is very significant 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:

all joint products are desired goods, and

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, our above thermodynamic discussion leads us to conclude that it is the second case that is of interest in ecological economics.

The theory of joint production has been extensively developed in business administration (e.g. Dyckhoff 1996). 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 Koopman's (1951) activity analysis. There are also relevant dynamic and stochastic graph theoretic models in computer science (e.g. 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).

A well-known problem in the theory of joint production is that, from the firm's point of view the allocation of costs between joint products is essentially arbitrary. Perhaps as a result, with few exceptions (e.g. Sraffa 1960, Pasinetti 1980, Salvadori and Steedman 1990, Kurz and Salvadori 1995) the modern literature on general equilibrium theory does 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, e.g. existence and optimality 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, i.e. 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-optimal in the absence of negative externalities (Arrow 1951, 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, thereby having no incentive to act as a free-rider.

In summary, while modern economic theory has produced many interesting results concerning existence and optimality 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.

4. Joint Production and Philosophy

The above thermodynamic foundation of joint production stresses that economic activity generally produces two types of output: the desired principal product, and the undesired waste product. We would expect, and indeed observe, that manufacturers 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, i.e. ethical, and one relating to knowledge, i.e. epistemological.

Turning first to ethics, the thermodynamically necessary waste products bring with them new issues of moral responsibility. This becomes obvious if we consider the hypothetical case of single production where waste products are not generated. In such an idealised world, assuming the existence of perfect markets and a fair social and legal order, the producers of a desired product do not face any ethical problem as long as they trade their products on the market and obey the legal order. Joint production now implies that economic activity, in addition to the intended products, also results in unintended outputs, which often are unnoticed. These joint products are therefore outside the social and legal order. At the same time, they may be harmful, e.g. 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 an ethical problem. Inattention to joint production may therefore easily result in ethical negligence. An example is the inattention to waste in the nuclear industry. From the beginnings 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 (e.g. 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 of 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. 1996).

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 products.

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 (e.g. 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 lay-people. 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 have the possibility to 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 lay people, 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, e.g. production functions, damage functions, external effects, Pigouvian taxes, etc.

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. We should now indicate some issues where the notion of joint production is likely to be especially useful for the discussion of environmental policy. In particular, we want to show that the concept of joint production could naturally lead to these issues, 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.

The Universality of the Concept

The concept of joint production may be employed at several different levels. 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, e.g. with CO2 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, 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 misses out this relationship, with potentially profound implications for policy analysis. In summary, the theory of joint production tells us that sound environmental policies can come only from an integrated and holistic conceptualisation of the production and consumption processes.

Time Scales and Time Horizons

An aspect of the awareness of potential ignorance and responsibility towards which our analysis has led us, is that of time scale. 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, joint products which constitute waste 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 applied to the principal products.

The Precautionary Principle

The discussion in Section 4, concerning how the 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 notions of joint production and precaution 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; e.g. 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, i.e. the externality approach, and an explanation starting from the cause of the effect, i.e. the joint production approach.

We also note that welfare effects will only be taken account of once they have been experienced; i.e. 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; i.e. considering joint production ex ante creates a motive for actively exploring as yet unknown potential welfare effects (Baumgärtner 2000: 293-294, Baumgärtner and Schiller 2001: Section 6). We therefore argue that the concepts of joint production and external effects are complementary.

7. Conclusions

We have argued for the concept of joint production to be considered a foundational notion for ecological economics. We have drawn upon thermodynamics, economics and philosophy in our exploration of joint production, and have shown that it is constitutive and supportive of such fundamental notions in environmental thought as the precautionary principle and external effects.

Within the ecological economics literature, it seems that the entropy concept already has foundational status. However, we believe that entropy has been less fruitful as a tool of analysis than was originally anticipated. This is partly due to the fact that concepts and methods of thermodynamics, e.g. the notion of entropy or the idea of adiabatic changes, are fairly complicated and highly abstract. As a consequence, most economists who are not trained in that field find them strange, unfamiliar and probably not even plausible, let alone useful. In our opinion it is therefore indispensable to provide some kind of translation of the insights from thermodynamics into a language that economists understand and with which they are familiar.

The concept of joint production provides such a translation. In contrast to the entropy notion, which is notoriously difficult, it can easily be explained and its relevance to environmental problems is usually obvious. At the same time, it allows ecologists to get in touch with mainstream economists and to make use of the large body of knowledge available in economics.

In summary, the notion of joint production might constitute a foundational concept for ecological economics since

it is applicable to the natural systems with which humans interact (cf. Section 2),

it is descriptive of economic activity (cf. Section 3),

it relates to the areas of responsibility and human knowledge (cf. Section 4), and

it is transparent and comprehensible to practitioners, policy makers and the wider public (cf. Section 5).

Hence, the concept of joint production unifies thermodynamic-ecological, economic and philosophical principles. Viewing joint production in this way opens up directions for fruitful research drawing on various concepts and methods of economics and of the natural sciences. Hence, we believe that the concept of joint production has the potential to become an important conceptual element of ecological economics.

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