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# Joint Production[1]

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Joint production is one of the basic concepts of ecological economics. It means that several outputs of a single production activity necessarily emerge together. From the application of thermodynamics it follows that all production is joint production if all input and output streams are taken into account, i.e. joint products are intrinsic to production processes. In fact, joint products are often wastes or polluting substances. The analysis of joint production has a long history in economic analysis. Considerations of joint production give rise to philosophical concerns relating to responsibility and knowledge. The concept of joint production is easily comprehensible and relevant to many issues of environmental and sustainability policy.

## Introduction – What is Joint Production?

In a nutshell, joint production means that several outputs of a single production activity necessarily[2] emerge together.[3] In the refining of crude oil, for example, gasoline, kerosene, light heating oil and other mineral oil products are jointly produced. In the refining process, harmful sulphurous wastes and carbon dioxide emissions are also necessarily generated. The occurrence of joint production is a characteristic of a particular production system. It refers to the material and physical base of the underlying production activity. It means that in this particular production system, it is not possible to produce the principal output without its joint outputs. Supposing that the production activity is pursued for (at least) one intended principal product, the presence of joint production itself does not say anything about whether the jointly emerging by-products are desirable (i.e. goods) or undesired (wastes). In the vast majorities of instances, however, while one or several products may be desirable, other outputs are undesired and may even be harmful wastes.

When taking into account the full range of input and output streams of a production activity it can be shown from thermodynamics that basically all production is joint production. Hence, joint production is a ubiquitous phenomenon. However, this fact which is based on the physical and material foundation of production, also has a broader dimension: The concept of joint production captures the particular characteristic of human activity which is the structural cause of many environmental problems – namely that it always has unintended side effects.

## Thermodynamics and the ubiquity of joint production

The usefulness of thermodynamics derives from its applicability to all real production processes, which are the basis of economic activity. 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,

[1] This article, in significant parts, draws from material previously published in Baumgärtner et al. (2001 and 2006).
[2] The New Palgrave entry on joint production (Nadiri 1987) calls this necessity “intrinsic jointness”.
[3] A formal definition of joint production is given in Baumgärtner et al. (2006: Section 2.4).

Ayres 1978, Faber et al. 1983, and many more). Using the notion of joint production allows us to incorporate this insight about economy-environment interactions into ecological economics. This can be seen from the following argument.

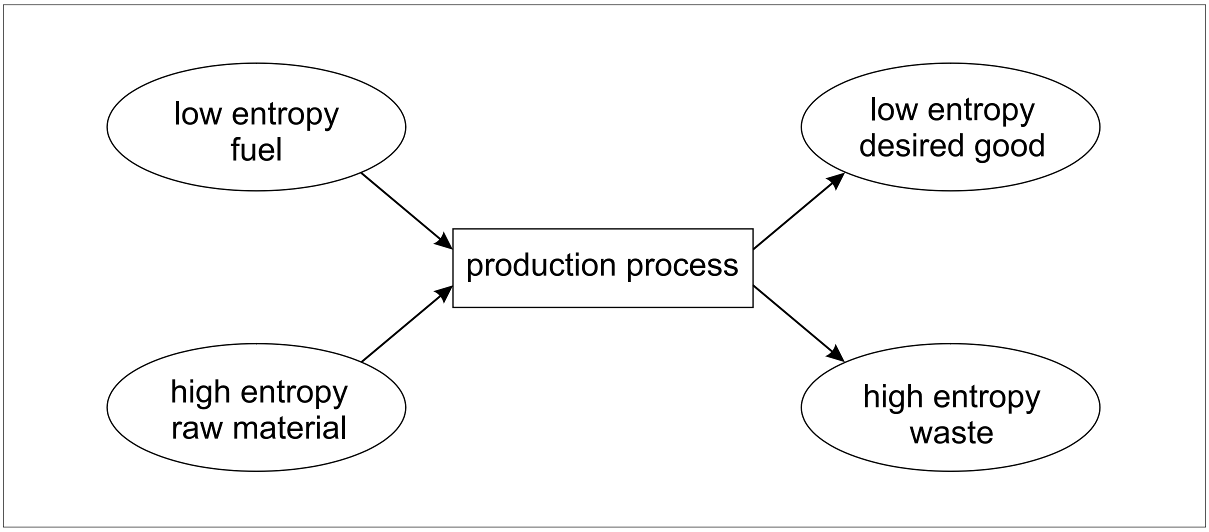
From a thermodynamic point of view, energy and matter are the fundamental factors of production. Every process of production is, at root, a transformation of these factors. Hence, production processes are subject to the laws of thermodynamics, which in an abbreviated form can be stated as follows:

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 (Source: Baumgärtner et al. 2001).




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 concept of joint production 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. $CO_2$, 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 economic analysis.

## Joint Production and Economics

### *Economic analysis of Joint Production*

The analysis of joint production has a long tradition in economics. 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, and Piero Sraffa devoted considerable effort to the study of joint production (Kurz 1986, Baumgärtner 2000: Chapters 5–8). Within the substantial body of literature both on theory and applications of joint production 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, the thermodynamic discussion leads us to conclude 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 (e.g. Dyckhoff 1996). For example, a range of 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. Joint production is important for balancing and managing the flows of material and energy (Spengler 1999), e.g. in engineering and chemistry.

There is a range of theoretical results about the economics of joint production (cf. Baumgärtner et al. 2006: Section 1.3): 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). Literature on general equilibrium theory has implicitly dealt with joint production when investigating the most general assumptions under which certain results hold, for example the existence and efficiency of general equilibrium (Arrow 1951, Arrow and Debreu 1954, Debreu 1951 and 1959, McKenzie 1959). Pigou (1920) and Lindahl (1919) conceived mechanisms to internalise negative externalities, thereby re-establishing optimality of any general competitive 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 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.

*Joint Production and External Effects*

Having identified joint production as a structural cause of many environmental problems, it is useful to highlight the connection with another prominent economic concept for modelling environmental problems – the concept of externality. In welfare-based environmental economics, joint production is typically modelled in an implicit way, mediated by the dis-utility generated to a third party by, e.g., the emission of a joint product. Following a standard definition of an externality, "[an] *externality* is present whenever the well-being of a consumer or the production possibilities of a firm are directly affected by the actions of another agent in the economy. [...] When we say 'directly', we mean to exclude any effects that are mediated by prices." (Mas-Colell et al. 1995: 352)

In the externality approach the relationship between the agent causing the effect and the agent affected is conceptualised as an issue of welfare loss of the person affected by the external effect. Hence, without affected economic agents and their valuation of the effect, an externality does not exist. 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. 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. As some effects of current joint production will only show up in the future, 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 2000: 293–294).

## Joint Production and Philosophy

Joint production 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.

*Ethics*

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 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).

*Epistemology*

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 used to be 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 (Baumgärtner et al. 2006: Chapter 16).

In summary, 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.

## Relevance of Joint Production for policy

Joint production draws our attention to the fact that economic activity is inextricably linked to side effects. Naturally, this leads to issues that are relevant for environmental and sustainability policy.

*The 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, 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. 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 longer time scales. Such accumulation may, and often does, lead to the unanticipated and unpleasant surprises. Clearly, the social management of such problems demands much longer time horizons than those typically applied to the principal products.

*Communication and Awareness: 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 largely brought about not by the scientific community, but by laypeople. 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.

Concerning the solution, 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.

## Conclusion

The concept of joint production can provide a translation of the insights from thermodynamics, which is notoriously difficult for those who are not trained in the field, into a language that can easily be understood. At the same time it allows ecologists to get in touch with economists and to make use of the large body of knowledge available in economics. In summary, joint production constitutes a foundational concept for ecological economics since

- it is applicable to the natural systems with which humans interact,
- it is descriptive of economic activity,
- it relates to the areas of responsibility and human knowledge, and
- it is transparent and comprehensible to practitioners, policy makers and the wider public.

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.

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