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By Mikael Skou Andersen

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Keywords: *circular economy environmental economics externalities sustainability.*

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An Introductory Note on the Environmental Economics of the Circular Economy

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I. Introduction

The concept of a circular economy – currently widely promoted in Asia – has its conceptual roots in indus- trial ecology, which envisions a form of material sym- biosis between otherwise very different companies and production processes. Industrial ecology emphasises the benefits of recycling residual waste materials and by-products through, for example, the development of complex interlinkages, such as those in the renowned industrial symbiosis projects (see Jacobsen 2006). However, in more general terms, it promotes resource minimisation and the adoption of cleaner technologies (Andersen 1997, 1999).

In industrial ecology, it is implied that a circular economy will be beneficial to society and to the economy as a whole. Benefits will be obtained, not only by minimising use of the environment as a sink for residuals but – perhaps more importantly – by minimising the use of virgin materials for economic activity. Intuitively, the potential benefits seem straightforward, but it is important to stress that the perspective prevailing within the circular economy approach is, in fact, based on physical rather than economic observations.

The assumed benefits are based on the fundamental observation that the loss of material residuals, in physical units, is minimised. But how far should society go in the recycling of materials? While the first and most straightforward recycling options provide evident benefits, once the recycling road is embarked upon, the subsequent benefits gradually become more and more difficult to achieve. It has to be acknowledged that at some stage there will be a cut-off point where recycling will become too difficult and burdensome to provide a net benefit. A circular economy cannot promote recy- cling in perpetuity.

Many adherents of the circular economy approach are strong proponents, on environmental and ethical premises, of material reuse and recycling. However, in a market economy (and in some planned economies as well), the prices of materials and natural resources will be too low and will mainly reflect the costs associated with mining and short-term values, but not with depletion nor the environmental costs. In such cases, only a limited range of circular options will make sense from the perspective of company managers. It can be argued that if companies are rational and profit-seek- ing, the recycling and reuse options should already have been realised. In a conventional capitalist econ- omy, recycling will be undertaken only where it is desirable from a private economic viewpoint.

Decision-makers responsible for public policy-mak- ing need to transcend such narrow perspectives and institute mechanisms that secure that recycling and re- use takes place where it is socially desirable and effi- cient. As a first step, it is necessary to analyse more carefully from a socio-economic perspective how cir- cular economy principles can provide net benefits. Environmental economics offers an analytical approach that can be of considerable help in identifying which material streams and which recycling options provide the greatest benefits to the economy – if circular rather than open-ended principles are introduced. Environ- mental economic analysis in public policy-making pre- sumes, in practice, an in-depth understanding and description of the environmental consequences of vari- ous choices, thereby making the analysis interdisciplin- ary in nature. Environmental economics also offers the basis for introducing ''externality adders'' to market prices in the form of environmental taxes and charges,

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so that prices can reveal the true situation, thereby allowing market actors to take account of the real costs in their mutual transactions.

This paper provides an introduction to the approach of environmental economics and indicates its potential for achieving a sound and efficient circular economy.

II. A Circular Economy

The conventional perception of the economic system is that it is open-ended. Production, P, is aimed at pro- ducing consumer goods, C, and capital goods, K. In turn, capital goods produce consumption in the future. The purpose of consumption is to create ''utility'', U, or welfare. Sometimes natural resources, R, are also considered within this linear perspective (Fig. 1).

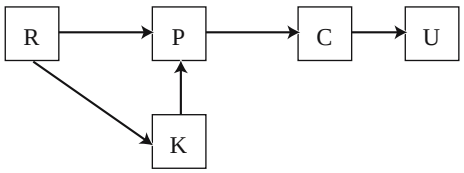


Fig. 1: The conventional open-ended economy. P production, C consumption, K capital goods, U utility, R natural resources

The open-ended system converts to a circular system when the relationship between resource use and waste residuals is considered. The first law of thermodynamics states that total energy and matter remains constant in a closed system (the planet can be regarded as such a closed system). The implication is that the amount of waste generated in any one period must be equal to the amount of resources depleted. Capital goods can function as a temporary embodiment of resources, but when consumed, they are converted to waste somewhere in the environmental system. Energy cannot be destroyed, but it can be converted or dissipated. However, due to the stocks of natural resources embodied in capital goods, in actual practice, the relationship between resource use and waste in any one period is slightly more complicated.

In the open-ended system, the box r represents recycling. Some of the waste can be converted back to resources. In this way the economy becomes circular. Not all waste is recycled, however – partly due to missed opportunities and partly due to some basic physical laws (Fig. 2).

To understand why this is the case, we need to consider the second law of thermodynamics. The term entropy describes how well matter and energy is organised; the more organised and uniform these are, the lower the entropy. However, as resources are extracted from clean ores and circulated through the economy, their entropy increases. While this is especially evident for fossil fuels that end up in the atmosphere as CO2 molecules, increasing entropy applies to most metals as

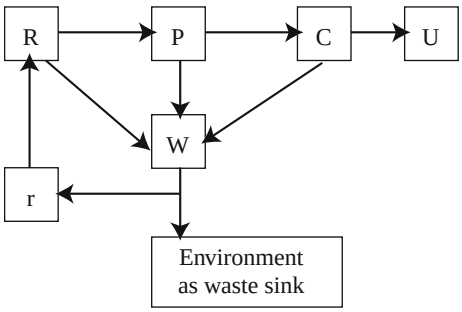


Fig. 2: The simplified circular economy. r Recycling, W waste

well. The deterministic thesis of Georgescu-Roegen (1971) states that the degree of entropy is bound to increase as humans extract more and more matter and energy for the economy. Circulating matter and energy would reduce the need for new inputs to the economic system and help delay the increasing entropy.

III. Four Economic Functions of the Environment

As a precursor to the environmental economic analy- sis, we begin by briefly considering the functions of the environment as seen from the perspective of econom- ics (cf. Pearce and Turner 1990). The environment clearly has values in its own right, but in neoclassical environmental economic analysis an anthropocentric approach is applied, with emphasis on the utility of the environment for humans, as measured in terms of economic welfare.

From this perspective the environment can be acknowledged as fulfilling four basic welfare economic functions: (1) amenity values; (2) a resource base for the economy; (3) a sink for residual flows; (4) a life- support system. Pearce and Turner (1990) present these four functions and their interlink ages within the context of ''The circular economy'' in their textbook on environmental economics, but the conceptual and theoretical understanding here differs (compare with above) fundamentally from that of industrial ecology. The circular economy from the environmental economics perspective is based on a material balance principle (Kneese et al. 1970), which implies that all material flows need to be accounted for, although it will be the economic values, not the physical flows, that guide their management.

Amenity values are the pleasures that the environ- ment provides directly to humans without interference from the economic system; examples include the beauty of landscapes or the existence value of partic- ular species. Even if these landscapes or species have never been observed or experienced

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directly, such as whales or the panda, humans may accord the species some value in relation to human welfare and will experience some loss if conditions for the species deteriorate.

Secondly, the environment provides a resource base, which functions as an input for the economy, both in terms of renewable and non-renewable resources. Many biological resources are renewable and can be harvested for economic purposes with no or limited impact, as long as the harvest does not exceed the annual yield. Fish stocks are a good example of this. More problems arise in the case of non-renewable resources (e.g. fossil fuels) where the physical stock, by definition, will be depleted as the resources are brought into the economic system. It is important to under- stand, however, that depletion is possible both for non- renewable and renewable resources.

Thirdly, the environment functions as a sink (waste bin) for the residuals of economic activity, whether the emissions are waterborne, airborne or solid. The environment has a certain assimilative capacity for receiving residuals from the economic system, but once the assimilative capacity is exceeded, environmental damage begins to surface. Human beings, themselves, form part of the environment and exceeding the assimilative capacity of the human body with residuals from, for instance, air pollution or toxins is tradition- ally a case for concern for human health, just as sur- face-water pollution gives rise to more general environmental concern.

Finally, the environment functions as a life-support system, both for humans and non-humans. This func- tion acknowledges the inherent biological character of the environment and that the life-support function can be influenced as a result of economic activities.

The four economic functions of the environment are mainly analytical categories. There are interactions among them, however, which require a further sophistication of the environmental economic analysis. The life-support function for biological systems can, for instance, be impaired as a result of the environment being used excessively as a sink for residuals. This aspect has been addressed by the specific concept of ecological utilisation space (cf. Opschoor and Weter- ings 1994).

Figure 3 shows the linkages between the four eco- nomic functions of the environment – and underlines the significance of the circular economy. Residuals that are discharged to the environment do not only have the potential to cause harm (if waste exceeds assimilative capacity) by affecting amenity values and the life- support function, they have also been lost from the point of view of the economic system. This loss of residual materials from the economic system can be postponed for non-renewable resources if a circular economy that promotes recycling and reuse is insti- tuted.

However, there is the additional issue of minimisa- tion. Some environmental economists argue that the input of materials and resources to the economy should be kept at a minimum and that a minimisation approach is a necessary prerequisite to the circulation of residuals. The argument for reducing the scale of material circulation lies with the second law of ther- modynamics and the concept of entropy.

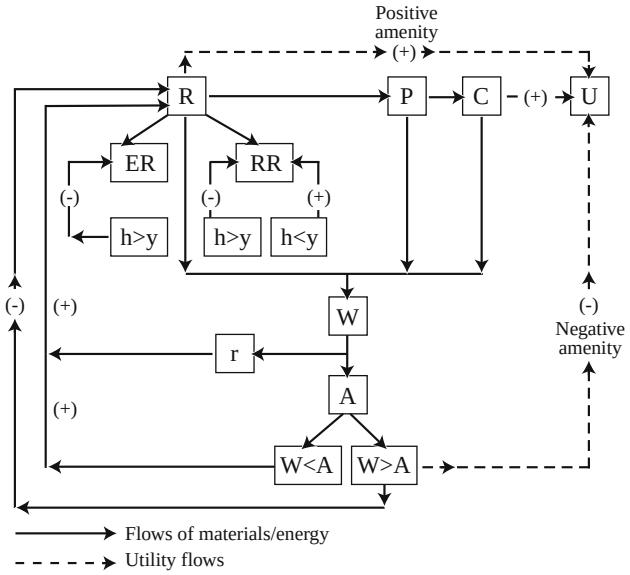


Fig. 3: The circular economy. Source: Pearce and Turner (1990). P production, C consumption, K capital goods, U utility, R natural resources, r recycling, W waste, ER exhaustible resourc-es, RR recyclable resources, A assimilative capacity, h harvest, y yield

a) *Sustainable development and sustainable economic welfare*

Before examining how values can be attached to the economic services and disservices related to the envi- ronment, we need to consider briefly the implications associated with requirements for sustainable develop- ment with respect to the choice of economic approach. The UN's World Commission defines sustainable development as a trajectory where future generations are secured the same level of welfare as present living generations. The implication of this approach, as seen from an economics standpoint, is a requirement for constant consumption or, phrased in a slightly more abstract manner, constant utility. In order to maintain annual yield at a constant level, there will be, in the absence of technological progress, a requirement for the stock of environmental resources to be kept con- stant. Environmental resources should be managed in such a way that the future yield does not diminish and future generations will not be worse off. In this man- ner, environmental resources can be viewed as a bank account where the capital (deposited amount) remains constant so as to generate a steady stream of interest to live on.

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The requirement for constant yield and a constant stock of natural capital is restrictive. It has become customary to distinguish between strong and weak versions of sustainable development. Within the weak form of sustainability, the substitution of natural capital and other types of capital is allowed, such that the depletion of natural capital has to be compensated through savings in other types of capital, such as human capital or physical capital. While often regarded as a relaxation of the sustainability criteria, even this weaker definition of sustainability would be a challenge for many countries which do not have systems in place that are able to account for whether or not the extraction of fossil fuels is compensated through reinvestments in education (human capital) or infrastructure (physical capital). The strong version of sustainable development, which does not allow for substitution, is normally made less rigid so that focus is on the non-substitutability of certain types of critical capital.

The economic sustainability definition is usually associated with Hardwick's savings rule, which suggests that the rents from natural resource extraction should be reinvested in other types of capital and that the government should ensure this by instituting a tax on natural resource extraction so as to guarantee a sustainable level of savings. In the case of fossil fuels, Hartwick's savings rule implies that income from fossil fuel taxes would be reinvested in other types of capital and that these would yield a level of annual rent in the future similar to the present extraction of fossil fuels.

External effects

Pigou (1920) (predecessor to John Maynard Keynes at Cambridge) drew attention to the significance of mar- ket failures in terms of externalities in the economic system, including externalities such as environmental externalities. External effects occur wherever ''a transaction between A and B has unwanted, positive or negative, consequences for third party'', but Pigou's favourite example was impacts from pollution.

We can categorise such effects – in particular the negative external effects – in terms of the four economic functions of the environment and the economic concept of sustainability. Economic activities can hence:

- impact amenity values negatively;
- lead to excess resource extraction, i.e. depletion;
- cause harmful residual flows beyond the assimilative capacity of biological systems;
- reduce the regenerative capacity of life support systems.

External effects can also be positive, such as the nutrient effect of airborne nitrate in stimulating crop growth, but, on balance, the evidence suggests that the positive effects are of relatively minor importance as compared to the negative ones (cf. Holland et al. 1999).

In order to be able to estimate the optimal level of environmental controls, not only do the costs of intervention need to be known, but also some idea of the order of magnitude of the external effects to be reduced is needed. For this purpose, some estimates of the values of environmental goods are required as well as a good quantification of the environmental consequences of marginal changes in economic activity. The accounting of external effects requires a life cycle assessment (LCA)-based approach in order to take full account of the complex pathways involved. It also needs to be based on a valuation of environmental goods, preferably on revealing individual preferences for such goods by means of indirect or direct methods. It could be argued that a circular economy will turn negative external effects into positive ones by con- necting waste streams to possible beneficiaries. How- ever, in order to assess the benefits of this approach we would still need to account for the effects separately as
well as for the direct costs involved.

IV. Market Prices Reflecting External Costs

Once reasonable estimates are available for the external costs, it would be possible to internalise these in market transactions by introducing relevant environmental taxes and charges.

There are four main reasons why such an approach would be preferable.

First and from the purely economic perspective, the externality tax approach secures that the marginal costs of the external effects will be reflected in market prices, so that market actors will take account of these in their mutual transactions. The allocative efficiency will be improved if the environment is not a free commodity but has a price tag. Some external effects will persist, but as a price tag is now attached, the benefits of economic activity will need to exceed the social costs imposed. Producers may choose to employ more labour and ''less environment'' by, for example, promoting recycling and reuse activities.

Secondly, externality taxation will help improve abatement efficiency. Existing environmental regulations are often technology-oriented and prescribe uniform technological measures for all polluters, regardless of the specific opportunities for cost-effec- tive abatement in various industrial sectors and companies. If prices reflect the external costs, polluters will abate where measures can be introduced which are more cost-effective than paying the tax; conversely, they will choose to pay the tax where measures are too expensive.

Thirdly, externality taxation will often provide a continual incentive to develop new and cleaner technologies, which can in turn reduce impacts cost-effectively and lower the marginal abatement costs. Being

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granted a permit on the basis of administrative standards is a conventional negotiation process, whereas externality taxation embodies a dynamic market-based process. The relative success of Japan in sulphur abatement in the 1970s compared with other industrialised countries was caused not only by stringent standards but also by the health compensation levy, which provided an economic incentive akin to an externality tax (Matsuno and Ueta 2000).

Finally, the externality taxation approach allows for flexible adjustment. The individual company has more freedom to find its own solution, which can promote highly individualised solutions as recommended within the industrial symbiosis approach of the circular economy.

It is of course possible to introduce environmental taxes merely as an incentive to reduce pollution, but the crucial question remains how to justify the exact rates of such taxes. Baumol and Oates (1971) once suggested setting the rates of environmental taxes at a level sufficient to ensure the agreed standards accord- ing to the ''standard-pricing'' approach. However, the problem remains that it is far from certain that stan- dards will lead to a socio-economically efficient level of abatement. Standards are partly the result of a political process and may have been set either too low or too high from an environmental economic perspective. Baumol and Oates (1988) put forward their proposal in the absence of externality estimates and, in fact, did not include the standard-pricing approach in their subsequent textbook on environmental economics.

V. How to Account for External Costs

It follows from the above, that techniques to account for external costs will be needed to provide the right economic incentives to internalise the use of the environment in the economic system.

In recent years considerable advances have been made in developing methods to account for external effects. These advances have taken place primarily in the context of the Extern E research project series, financed by the European Union's Research Programmes. To begin with, these efforts were undertaken in cooperation between U.S. and EU research programmes, but since 1995 the efforts have been financed entirely by the EU.

ExternE has addressed the externalities of energy production and transport and has primarily focused on the effects related to the use of the environment as a waste repository for air pollution. Comprehensive progress has been accomplished in quantifying the impacts of air pollution on crops, forests, building materials as well as on human health. ExternE uses the impact pathway approach to trace the specific impacts of pollutants.

The main methodological challenge in accounting for external costs is that it is necessary to know the marginal contribution of a particular economic activity to the state of the environment. In the case of air pollution, one needs to know the contribution of, say, a particular power plant's emissions to the air pollutant concentrations in a particular area. Such changes in air pollution concentrations, and in subsequent exposures, can in fact be calculated by combining local and regional air pollution models. This is the first step in the impact pathway methodology of ExternE (Fig. 4).

Once the marginal changes in concentrations are known, the second step in the impact pathway is to calculate the number of people exposed. Geographical information systems (GIS) are used here to keep record of land-use and population densities, so that, for example, the number of persons exposed to air pollution is matched directly with the changes in air pollution exposure in specific parts of the geographical grid. In this way the analysis can capture the significance of potentially high exposures in areas with high population densities. The method is highly site specific in its accounting of the external effects, as both the emissions and the exposures are calculated according to the specific site in question.

The third step in the impact pathway assessment involves a screening of the scientific literature for dose- response functions of the effect endpoints. Dose- response functions describe how various entities will react to changes in exposures. Vegetation cover, for example, reacts to changes in air pollutant concentra- tions, as do humans. The medical literature is espe- cially rich on exposure-response functions. These functions are, at our current level of knowledge, often treated as linear, but there are important thresholds to consider, below which possibly no effects occur.

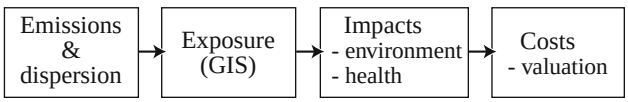


Fig. 4: The impact pathway chain (Holland et al. 1999). GIS Geographic Information System

The fourth and final step involves attaching unit values to the end-points of the impact pathway analysis. In the case of air pollution, the end-points comprise both mortality and morbidity effects for humans; the latter comprise work-loss days, cases of bronchitis, prevalence of asthma medication, hospital admittances, among others. The endpoints can be valued either with cost-of-illness figures or, if desired, with preference-based values based on contingent valuation surveys.

Table 1 provides an overview of figures for the externalities of air pollution arrived at in an analysis commissioned by the European Commission. The fig-

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ures differ between member states, not only because of differences in population densities but also because of differences in abatement technologies (e.g. in power plants). The difference between Belgium and Denmark for particulate matter smaller than 2.5 lm (PM2.5) is believed to reflect both of these factors.

It is important to emphasise that these figures are likely to increase if emissions occur in highly populated areas (e.g. in cities). In a city with 100,000 inhabitants, the externality estimate for PM2.5 is 33,000 €/t and for SO2, 6000 €/t. In a city with 0.5 million inhabitants, the estimates increase by a factor of 5. NOX remains constant as it is a regional pollutant with a greater dispersion than particulates and sulphates (the figures reflect European price levels and would differ for a region with other health sector costs and lower per capita income).

Table 1: Externality estimates for air pollutiona from stationary and mobile sources: background values (BeTa-tables, European Commission 2002)

Commission 2002				
€/tonne	SO_2	NO_x	PM2.5	VOCs
Austria	7,200	6,800	14,000	1,400
Belgium	7,900	4,700	22,000	3,000
Denmark	3,300	3,300	5,400	720
Finland	970	1,500	1,400	490
France	7,400	8,200	15,000	2,000
Germany	6,100	4,100	16,000	2,800
Greece	4,100	6,000	7,800	930
Ireland	2,600	2,800	4,100	1,300
Italy	5,000	7,100	12,000	2,800
Netherlands	7,000	4,000	18,000	2,400
Portugal	3,000	4,100	5,800	1,500
Spain	3,700	4,700	7,900	880
Sweden	1,700	2,600	1,700	680
UK	4,500	2,600	9,700	1,900
EU-15 average	5,200	4,200	14,000	2,100

a Values are expressed in lg/m³. NO_x, Nitric oxides; $PM_{2.5}$, particulate matter smaller than 2.5 lm; VOCs, volatile organic carbons

VI. Socio-Economic Analysis of the Circular Economy

The externality estimates can be used in the analysis of projects that are considered to improve the circular aspects of the economy. In the case of recycling, the potential benefits are basically comprised of three elements:

- the market value of the recycled materials;
- reduced burden from waste disposal (incineration or landfill);
- reduced burden due to reductions in extraction of virgin materials.

The two burdens will be site- and technology-spe- cific to some extent and can be assessed by means of the impact pathway method, taking into account the specific damages. It is necessary to take into account a wider set of emissions and environmental burdens than those mentioned in Table 1 as these are only examples of where methods exist to quantify externalities. In recent years, externality estimates have also been developed for heavy metals and certain toxic materials, whereas the main lacunae are for emissions related to water pollution.

In the case of aluminium cans, aluminium has a certain market value, and this is often sufficiently high to promote the collection and recycling of aluminium. However, there will be additional benefits to justify such a scheme, in terms of both reduced waste disposal and the reduced extraction of virgin materials. The costs of the aluminium-recycling scheme can be matched against the total benefits, always taking into account the uncertainties, as could any other scheme designed to recycle materials.

In the case of the circular economy, companies with residual waste streams may often be some distance from the market where they obtain the value of materials. As such, the waste products do not relate to their main area of activity and the companies may be forced to dump them at unfavourable prices to nearby plants that are willing to accept them. However, if the authorities institute a set of taxes on the key pollutants, any activity that will diminish the net environmental burden will become profitable for both the receiving and the disposing companies. Alternatively, the authorities may require a socio-economic analysis of the benefits of recycling, as outlined above.

VII. Conclusions

Significant advances in the pricing of externalities have been achieved in recent years by means of complex interdisciplinary analyses that attempt to account in detail for the environmental consequences. The mon- etary estimates reached as a result of such interdisci- plinary research are gradually being applied by the authorities to the economic analysis of environmental policy priorities. A prominent example was the assessment that emerged from the EU's 6th Environ- mental Action Programme (RIVM 2001). This assess- ment relied on the results of the ExternE project, and the economic analysis was based on the use of the National Institute for Public Health and the Environ- ment of the Netherlands' (RIVM) expertise and models for the natural scientific basis.

The challenge in accounting for external effects is very much related to the necessity to transcend disci-plinary orientations and to combine the knowledge and data available in various subfields. That environmental issues are complex has been acknowledged for dec-

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ades, and the resulting predominance of symbolic politics been deplored by many observers. Whether the insights obtained by combining natural science models with economic principles of accounting for external effects will lead to an environmental policy that is more rational and less sensitive to abuse by vested interests is perhaps to early to say, but we can at least hope that a more confined playing field for the clash of interests can be defined.

The establishment of a future trajectory for a circular economy will require that this approach be extended so that the broader issue of sustainability can be addressed more comprehensively. Whereas external effects relate mainly to the present generations, the sustainability issue implies a need to address the future generations as well when the implications of the envi- ornamental pressures are quantified. Although the available estimates for external effects provide only a partial and incomplete picture of the environmental costs at stake, they help support and expand on the analysis of the virtues of a more circular economy.

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