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SUSTAINABLE DEVELOPMENT AND ECONOMIC GROWTH IN THE MARKET ECONOMY

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Turku, May 2007

Teemu Haukioja

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Introduction to the Essays of Sustainable Development

1 OUTLINE OF THE STUDY

1.1 The emergence and relevance of the problem of sustainable development and economic growth in a market economy

History suggests that mankind has been living at the mercy of the natural forces. To a large extent people have struggled against everyday poverty, crop failure, epidemic disease, and famine. The Enlightenment and Industrial revolution brought about a change for the Western world. Nature is exploited intensively in order to create economic wealth and human progress. Even though development has been revolutionary, nature is still the ultimate scarce resource. Several environmental problems and other signs of limits to growth arose to the public concern after the World War II. (Crocker 1999) Sustainable development is a modern label for the common and largely agreed manifestation that the environment should be taken into account at all levels of human action. It seems that sustainable development is not a fashionable catchword that fades away, but it is here to stay. Many people think that development and progress go together with economic growth. For this reason the problems of sustainable development are always timely and comprehensive economic reasoning is more and more important.

According to Adam Smith (1723–1790), voluntary transactions at a market, division of labor, and free trade create wealth for nations. Countless economic actors who have self-interested private motives produce socially beneficial outcome as if it was guided by an invisible hand. However, classical political economists like David Ricardo (1766–1823) and Thomas Malthus (1766–1834) derived dismal conclusions about economic development. They saw that it is impossible to provide large human populations with wealth and prosperity. Despite of temporal progress, in the end we have to face a steady state economy beyond which no further progress can be achieved. Restricting factors are the ultimate form of capital 'land' and dynamics of population growth. Productivity of extra land is decreasing, because arable land is a scarce resource and quality of new land is poorer. Because of new farming, food production increases, but it cannot support population which grows exponentially. Also profits decrease, because in the end all investment opportunities will be exhausted. Consequently, the fate of large masses is to get stuck into the poverty trap and subsistence level. Free trade and investment activities can only postpone the inevitable state of affairs. At the time nature was understood to present the basic factor of food production and it defined the ultimate limits to growth and welfare. On the other hand, classical economists like John Stuart Mill (1806–1873) and Karl Marx (1818–1883) considered that the steady state economy does not mean misery, but it is the state of happiness that should be pursued. Technological progress, productivity growth in farming, and colonialism provide much more resources to wealth than reasoned by Malthus and Ricardo. In the steady state economy all basic needs are satisfied. The society's task is then to provide equal income distribution and to support individual aspirations to spiritual development without the threat of material shortage. (Perman, Ma, McGilvray and Common 1999, Chapter 1)

Economic interest moved from dismal classical long term scenarios to micro- and macroeconomic analyses where the environment or nature had actually no relevant role. Important exceptions to this were externality analysis made by Pigou (1877–1959), and optimal use of exhaustible resources by Hotelling (1895–1973). Economy was seen as a closed independent system where ecological functions were not interesting. Microeconomics was established to mean optimization of consumption and production. Macroeconomics was fixed to analyze business cycles, money, and financial and economic policies. The Solow growth model took the standing position in long-run growth analysis. After the World War II expansive industrialization took place and it brought along notable environmental problems. Interest to economic analysis of the environment arouse gradually. Nowadays the economics of the environment and resources has an impressive field of economic research tradition to offer.

1.2 The purpose of the study

Sustainable development is a relatively recent label for the old problem of progress under circumstances of scarce resources. It was popularized by the well-known Brundtland Commission report (WCED 1987). Because of the present state of production technology and expanding scales of economic activities the natural environment is forcefully affected; economies profoundly shape the current living conditions and future prospects of development. Due to this it is important to form a comprehensive and consistent picture of the key forces behind sustainable development. This thesis is one attempt to achieve this goal. For this purpose we explicate and apply the concept of sustainable development in economic terms. The focus is on modern democratic market economies. Thus, here we do not touch upon such important issues like poverty and developing countries. However, we believe that the main conclusions of the thesis are applicable also into the problems of economic development. We approach the general problem of sustainability by three angles: (1) the first essay is about moral philosophy. We explicate the market economy concept and propose moral principles that are consistent with the sustainable development in a market economy. (2) In the second essay we interpret essentials of sustainable development in the framework of endogenous growth theory. (3) In the next two essays we study empirically how selected environmental pressure indicators are affected by economic growth. These four papers are shortly motivated and outlined below. The headers differ from the essays in order to describe more generally the themes they touch upon.

1.3 Essay I: Sustainable development in a market economy

The first essay is about moral philosophy, ecological economics, and the evolution of a market economy. The ultimate purpose is to consider comprehensively whether the idea of sustainable development is consistent with the nature of a market economy as a moral order and cooperation system for its agents. In other words, the essay considers market economy as a social contract. We attempt to form a comprehensive picture of the social system where principles of individualism are strictly applied to all levels of ‘collective’ social system called market economy. The essay is meant to be in accordance with the tradition of political economy and moral philosophy. A value system that can justify sustainable development in society is constructed. Sustainable development is the general metaphor for the idea that present people and societies should feel and take serious responsibility on the state of nature, and well-being of current and future generations. Even though the concept of sustainable development is ambiguous, it anyhow expresses something about common worldwide concern of many.

Ecological economics emphasizes the importance of ecology in both economic analysis and real world economic affairs. It is seen that man-made economic and social systems are fundamentally subsystems of nature. The Earth provides the ultimate limits to natural system. Because nature has its limits, also material base of economic systems is limited. If critical natural and ecological processes are put under the excessive pressure, also vitality and existence of economic and social systems is in danger. Essentially, the natural system does not need human systems, but human systems are dependent on the natural systems. Consequently, the goal of sustainable development is not possible without explicit consideration of features and limits of natural systems. Nature provides consumers with services that cannot be substituted completely by man-made goods: life supporting systems (air, water), inputs to production (minerals, forests), waste management (landfill, assimilation), new resources (evolution, medicine), systemic resilience (catastrophes, variation), and experiences (spiritual values, adventure). Natural resources and the environment form a coherent entirety that cannot be displaced. Individual parts and subsystems of nature may be substitutable in some extent, but mainly the natural system is indispensable basic resource without which no economic system can survive.

Paradoxically, sustainable development is often understood to mean that something must be preserved as unchanged. In one extreme, it is required that natural environment, all parts of ecosystems, all flora and fauna must be kept intact and original, and all this must be transferred to the future generations. Everything must be preserved, and species must not be allowed to go to extinction. The principle 'leave it as you took it' is followed as a rule. However, the word 'development' means change – something becomes something else or new. The old is not the holy thing to be restored as such. Sustainable development can be understood to mean that a change is sustainable, that is, nature, human beings, and societies evolve continuously. In other words, what we should preserve are the forces that make continuous evolution possible and vital. The word 'development' also can be interpreted to mean that change makes things better, not worse, as compared to previous state of affairs.

Clearly, virgin nature does not need human intervention to its evolution process. On the other hand, mankind is the product of natural evolution. Evolution has led to the present situation where human beings are able to change directions of evolution dramatically. Before this time evolution was affected by natural catastrophes and random events. Evolution process is path-dependent, and a chance could have produced the world that looked distinctively different from the present one. Possible directions for evolution are infinite. From this fact we must conclude that the current nature is only one possible form of existence, and as such, this special form has no absolute or sacred value. Besides, natural evolution changes this form continuously; new species are born and old ones go to extinction even without human intervention.

Because of this, it seems that the most important task is to take care of vitality of evolutionary processes. Biodiversity and well functioning ecosystems seem to be crucial factors for natural evolution to be successful. Forces for successful social evolution are not so clear. We may claim that evolution has created a creature that is powerful enough to design evolution process itself. Because this is the result of evolution, we may conclude that human beings have a natural right to manipulate direction of evolution, but also a natural duty to manage it. The problem of manipulation and management leads to the basic question of sustainable development: ‘How can we balance both economic and social subsystems with the environmental total system so that all three systems survive and prosper in the long-run?’ This kind of social system is constructed in the paper.

1.4 Essay II: Sustainable development in an endogenous growth model

The second essay presents a simple model which is powerful enough to spell out some fundamental ideas behind sustainable development and economic growth. The model can be used to show the conditions for sustainable steady state economy, but also conditions for ever growing sustainable economy. Large disputation is taking place among scholars whether sustainable development requires zero growth economy or not. Simple structure of the model reveals that zero growth economy is only a special case of sustainability.

The Solow growth model has a constitutive role in growth theory. The main lines for taking into account the environmental dimension in the Solow model are the following. For natural resources the problem is how to allocate scarce resources optimally in order to maximize an intergenerational utility function. Criterion for sustainability is non-decreasing consumption path with infinite time horizon. Often perfect substitutability between different kinds of capital is assumed. For instance, decreasing natural capital can be substituted with man-made capital without decrease in utility. (Hanley, Shogren and White 1997, 426) In neoclassical growth model the steady state means that growth rates of relevant variables, like per capita output, capital and pollution are zero at optimal growth path. Introduction of new exogenous technology may raise the levels of variables, but diminishing returns on factors of production lead growth rates to converge back to zero.

We introduce basic features of AK model which is possibly the simplest case for endogenous growth models. In production function there are constant returns to scale. Balanced growth path implies positive growth rates for relevant variables, like output, capital, pollution and abatement.

Growth critics often call for zero growth economy, that is, a steady state economy. This means that growth rates of output, capital, and pollution must be zero. Also levels of output, capital and pollution must be constant, and they are not allowed to rise above some critical level. We modify the AK model to take those critics seriously. The modified AK model requires the constancy of capital and pollution. Naturally, this means that their growth rates are zero at balanced growth path. However, we demonstrate that growth rate of output can be positive if the ultimate engine of growth is human capital. As far as we know, this analysis has not been done elsewhere.

1.5 Essays III and IV: Sustainable development and the Environmental Kuznets Curve hypothesis

The last two essays are empirical investigations of relation between indicators of economic growth and the environment. The Environmental Kuznets Curve (EKC) hypothesis is used to discuss the real world development. Growth pessimists see that detrimental effects of economic growth override the benefits. There is some definite limit for economic growth and it should be settled down to a zero growth path. Growth optimists see that, because of technological progress and human ingenuity, limits to growth are not a permanent problem, and the environment is not at stake in the long-run. Empirical research is needed in order to get some idea about real world development. The Environmental Kuznets Curve hypothesis states that as economies develop the environmental stress (p) increases at the early stages of development, but due time per capita income (y) reaches the stage after which the environmental stress will decline to acceptable levels. This inverted U-relation is described in Figure 1.

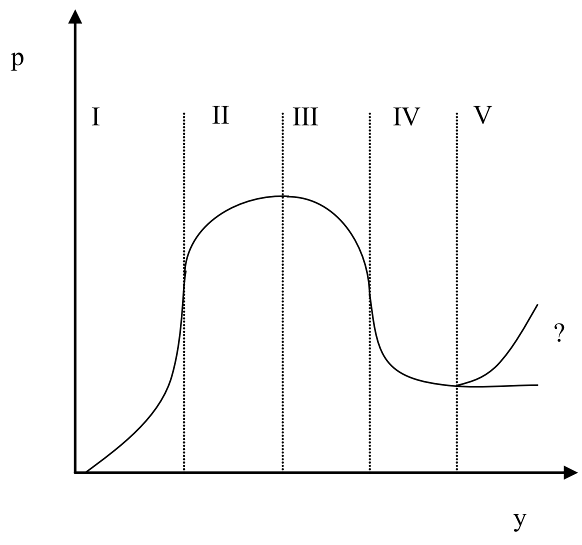

Figure 1 the Environmental Kuznets Curve

There are several explanations for the EKC behavior. As industrialization begins material intensity and use of natural resources is extensive causing lot of pressure to the environment (Phase I in Figure 1). As consumers get richer they step onto the higher level in hierarchy of needs. At that level environmental values become more important. Firms must respond to increasing demand of green products if they are going to survive in competition. Politicians can get votes by expressing their political ideas about the environment as environmental policy gets more emphasis in a society. The EKC becomes more gentle (Phase II) and turns downwards (Phase III). Due to growth of wealth, investment, and technological development, green consumption and production methods become economical and applicable. Development means structural change. Industrial society gradually proceeds toward service and information society, where material intensities of production and consumption decrease. As scarcity of the environment and natural resources becomes tangible relative prices go up. This gives incentives to search substitutes and more efficient technological solutions. Environmental policy can make harmful activities more costly. Environmental policy can correct prices of previously under priced goods, whose social value is not properly captured by market forces. Ideally, environmental pressure can be settled down even though an economy grows (Phase IV).

There are, however, many reasons why the EKC may fail. One reason is lack of democracy or its weaknesses. Opportunistic behavior is not uncommon to public authorities or politicians. Projects that benefit immediate self-interest are likely to displace in favor projects that produce often ambiguous public benefits that are hard to measure. Also in a democracy different interest groups have more or less social and economic influence. Rent-seeking or opportunistic behavior can be disguised and justified to present public interest by pleading of employment or national competitiveness. Also well-intended environmental policy may be inefficient, misdirected, wrongly weighted, or it creates unintended harmful incentives. Different policy sectors are often in contradiction with environmental goals. This inconsistency may exist for example between competition, trade, and agricultural policies.

Technological development does not always mean decrease in total environmental pressure even though it may decline in relative terms. For example, because of technological development production of some good may become more efficient, inputs are required less, and new applications are discovered. Decrease in price, easiness of use, and spread of applicability may change the demand structure so that total environmental pressure increases; change in quantity displaces change in quality. Mostly, environmental issues are not among the first priorities in business interests of firms. Business firms want to give consumers good image of themselves and in order to attract green consumers they may exaggerate their environmental qualities or give disinformation more or less intentionally. Developing countries may get struck into a poverty trap where totalitarianism, unequal income distribution, and protectionism hinder the development process to take off. Even though domestic environmental policy might be satisfactory, in case of global environmental problems (climate change) the free-rider problem is a potential threat.

The EKC hypothesis is often tested by reduced form statistical models where some environmental indicator is explained by different forms of gross domestic product and variables that describe structural features of economies. In a seminal paper Grossman and Krueger (1991) find an inverted U-curve for sulfur dioxide and smoke. The EKC hypothesis is tested in several successive studies. The hypothesis gets statistical support in some cases, but evidence is mixed, since some studies suggest that the EKC hypothesis should be rejected, and the EKC is not a general pattern for economic growth and the environment. Also cases can be found where economic growth and environmental degradation have clear positive correlation. Also N-like behavior can be recognized for some indicators; after phase that produce the EKC relationship, further expansion of an economy implies increase in the environmental indicator again (Phase V in Figure 1). (de Bruyn and Heintz 1999) To conclude, empirical results about the effects of economic growth to the environment in the long-run are ambiguous. More research is needed in order to get more knowledge about empirical relations between economic growth and the environment.

1.6 Conclusions

Essay I: The purpose of the first paper is to apply contractarian moral philosophy to the problem of sustainable development in the market economy: ‘What kinds of rules are rational for society, and what kinds of rules would be derived by self interested men behind the veil of ignorance?’ The principles for the basic moral order of ecologically sustainable market economy are introduced. For this purpose we propose auxiliary concepts of the original self, dynamic social contract, social market economy, and intertemporal common property regime. It is argued that sustainable development is a possible, reasonable and self evident goal for a market economy whose basic value codes are based on individualistic contractarian doctrine.

Essay II: In the second paper we use the AK model framework for exposition of fundamental relations between sustainable development and economic growth. First, we present features of a basic AK model. It serves as a reference model. Second, we add pollution into the model. Third, we allow abatement technology. This is familiar from literature , and the basic result is that an economy can grow along sustainable development path if growth rate of pollution is zero while capital and abatement grow at the same positive constant rate. Next, we reconsider critics of the so-called steady state economy approach. According to it, growth rate of an economy should be zero, because of the laws of thermodynamics. Because throughput in a steady state economy should be constant, we require that physical capital and pollution must have some allowable upper limit. In that case the only engine of growth is human capital which is assumed to be non-polluting and whose use does not increase entropy. We conclude that, in theory at least, positive economic growth and sustainable development can be consistent goals even though there were definite upper limits to energy and material flows in an economy.

Essay III: This study analyses the Environmental Kuznets Curve hypothesis with material use data for the USA, Germany, Japan, the Netherlands and Finland. The EKC hypothesis has not been widely tested with direct material flow data. In this paper, we test the EKC hypothesis via direct material flows. The results of the empirical hypothesis tests conducted indicate that the EKC hypothesis does not hold for industrialised countries such as Germany, Japan, the USA, the Netherlands and Finland. This is the main result of the paper.

Essay IV: Our purpose in this paper is to get comprehensive picture of CO_2 emissions in the EU-15 and the USA. CO_2 emissions are measured from three different angles: efficiency, human effect, and total environmental stress. CO_2 per GDP measures improvements in technical efficiency. For the EU the EKC seems strongly to be present indicating technical efficiency. This means that the EU is able to create more wealth with decreasing CO_2 emissions per output. For the USA it seems that the once materialized EKC has transformed into an N-curve. The picture becomes less optimistic as we measure CO_2 emissions in terms of per capita. In the EU-15 there may be the EKC relation present, but in the USA the EKC process does not get statistical support, on the contrary, per capita emissions are increasing. Models for total CO_2 emissions suggest that in the EU-15 the EKC may be present, but also Race to Bottom scenario is plausible. There is no EKC for the USA in total CO_2 emissions. To conclude, our experimentation highlights that the single piece of evidence for the EKC hypothesis does not mean that economic progress also promotes total welfare by reducing relative environmental stress.

The overall purpose of the study is to capture a comprehensive and consistent view on sustainable development in a market economy in economic terms. We approach this task by (1) explicating the nature of a market economy as a moral and cooperation system that is intended to create wealth and well-being to its current and future members, (2) using the framework of an endogenous growth theory in order to highlight the fundamental preconditions for sustainable development in a growing economy, and (3) making empirical research for certain environmental indicators in order to get information about the real world relations between economic growth and environmental pressure indicators in industrial countries.

The overall conclusion of the thesis is that the problem of sustainable development is, in fact, the essential ingredient of long term economic analysis. It can be incorporated fruitfully into the theoretical analysis of a market economy, economic theories of growth and development, and also to empirical studies in a consistent way.

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ESSAY I

Contractarian Justification for the Goal of Sustainable Development in the Market Economy

1 INTRODUCTION

The very elasticity of the concept of sustainability raises questions about what it is supposed to mean: the sustainability of what, for whom, for how long, and why? (O'Neill 2002, xiii).

The notion of sustainable development has established itself into every day language. In spite of that, it is not at all clear what does it actually mean in practice or what kinds of actions are needed to get it. As an illustration, consider common arguments and counter arguments concerning the construction of a nuclear power plant, or desirability of economic growth. Whether you are for or against the two above, you can make an appeal to sustainable development, and your arguments seem to be reasonable in many respects.

The Brundtland commission's (1987) notion for sustainable development is often referred as a working definition for further analysis: "*Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (WCED, 1987, 43). We adopt this, admittedly elusive, notion also here. It will do for our purposes, and we try not to develop strict and exhaustive definition for sustainable development.[1] In the following we give one interpretation for sustainable development: 'what should it mean in a market economy the principles of which are based on just social contract?' Our method is contractarian reasoning, where we lock ourselves into the original position of a social contract theory in order to derive basic principles for a just society that takes advantage of the forces of the market economy. This paper examines what kinds of socio-economic rules and principles, if any, are required in order to achieve sustainable development in the market economy. To this end it is necessary to clarify the fundamental nature of a market system in order to find out, how the market economy should be designed[2], if we want it to be

[1] For further discussion see Amundsen and Asheim (1991), Beckerman (1994, 1995), Daly (1995), Dobson (1996), Jacobs (1995), Tisdell (1992, 1994).

[2] Designing a market system leads us to the delicate field of value driven normative economics, and we have to ask 'how it should be' –questions, like 'what should be designed, by whom, how, and why?' Market economies may take various forms with different outcomes depending on prevailing social institutions that are human creations. What follows is one attempt to figure out proper general principles for designing sustainable market economy.

sustainable[3]. The sustainability of any socio-economic system requires that fundamental building blocks, rules and principles of that system are respected both by individuals[4] and government.

We have to confess that even though we recognized some fundamental rules for sustainability, we still could not give exhaustive solutions in every individual case to such practical questions as whether or not to construct a nuclear power plant. This does not mean, however, that considerations and evaluations about guiding principles of sustainable development would be useless. On the contrary, if we are able to consider practical issues with deep understanding about the key factors that make a socio-economic system just and sustainable, our statements and policy actions are based on consistent and careful process of reasoning. Then, one may expect that socially good decisions and results will follow.

The organization of the study is as follows. In chapter two idealized features of the market economy are outlined. We use contractarian approach to construct a basic moral order for the market economy as a just social cooperative system. We ask what kinds of principles should prevail in such a system. A market economy is one possible way to organize production and allocation of scarce resources in a society. The market economy can be considered as a moral system, since it defines the procedures and rules for individual and social action in a society. The contractarian concepts of the original position and veil of ignorance are introduced. These concepts are explicated and used for the derivation of the basic moral order of the market economy.

Rationality of the goal of sustainable development is scrutinized in chapter three. We ask if sustainable development is a rational choice for decision makers in the original position. We conclude that men in veil of ignorance desire the goal of sustainable development. In chapter four basic principles for the ecologically sustainable market economy are proposed. The core elements of environmental economics, like externalities and social costs are discussed in context with the ideas of the sustainable market economy. We also discuss some principles for ecologically sustainable economic growth. We find that both some established contractarian and neoclassical conclusions about sustainability in the market economy are not so self evident after all. Chapter five concludes.

[3] We will argue that, if we share the values of individualism, freedom, and equal justice, its logical implication is strict commitment to sustainable development.

[4] We take the value judgement that, basically, all people are equal (this choice also can be justified with the original position, where people don not know who they are). It does not matter what is his or her sex, age, race, religion, political view, or other individual conditions or features. Consequently, we use the pronouns he and she interchangeably to refer any person.

2 CONTRACT THEORY AND MARKET ORDER

"... the continuing question of social order: How can we live together in peace, prosperity, and harmony, while retaining our liberties as autonomous individuals who can, and must, create our own values?" (Buchanan 1987d, 313).

If markets were perfect they would be able to discover solutions to all relevant socio-economic problems. All information about individual preferences, choices, and values would be reflected in prices of all goods, both tangible and intangible. In reality there exist many unavoidable obstacles to the frictionless functioning of markets. Thus, we have to consider: How much public intervention is needed in a market economy? What kind of intervention do we need? Is it possible to find guidelines that imply which decisions should be left to markets or submitted to collective or public decision making? One method by the help of which we may try to find out answers to these questions is the contractarian tool called the original position.

2.1 The original position reconsidered

2.1.1 The original position

The original position refers to an imaginary construction where all members of a society come together to set rules that are neutral or fair with respect to the chances that each member might face. Thus, the ultimate purpose is to choose just principles to a society. (Rawls 1999.) A necessary condition for a social contract to become a just one is the requirement that decision makers do not know their own personal attributes, social positions, tastes, income, wealth etc. in a society where they are supposed to live. All private information that might bias decision makers' choice is denied; it is said that they are behind the veil of ignorance. There must not be any limitations on common knowledge or general information which describe natural laws, economics, social theories, and the like. The properties of the systems of social cooperation and natural laws must be taken into account if institutions, as human creations, are going to control social and economic behavior fairly and efficiently. (Rawls 1999, 118–123.) This kind of veil of ignorance implies that all decision makers are equal and ultimately homogenous in their reasoning. Thus, it does not make any difference whether there are millions of decision makers or only one. Equality in original position leads to a unanimous social contract anyhow[5] (cf. Rawls 1999, 120, 232–233.)

Principles that were selected in the original position, should fulfill at least the following properties: (1) the principles should be general by their nature, (2) they should be universal in application, (3) they should present a public conception of justice, (4) they should impose a desirable ordering on conflicting claims, and (5) they should present finality and conclusiveness (Rawls 1999, 112–118). John Rawls argues that the following two principles for a just social contract would be chosen in the original position. He presents a first statement which is a preliminary one. After thorough and extensive reasoning he gives a statement that he considers as final.

(i) The first statement for the two principles of justice:

First principle:

"*First: each person is to have an equal right to the most extensive scheme of equal basic liberties compatible with a similar scheme of liberties for others*" (Rawls 1999, 53).

Second principle:

"*Second: social and economic inequalities are to be arranged so that they are both (a) reasonably expected to be to everyone's advantage, and (b) attached to positions and offices open to all*" (Rawls 1999, 53).

Rawls develops these two principles further, and the second principle gets the form that is known as the maximin principle.

(ii) The final statement for the two principles of justice:

First principle:

"*Each person is to have an equal right to the most extensive total system of equal basic liberties compatible with a similar system of liberty for all*" (Rawls 1999, 220, 266).

Second principle:

"*Social and economic inequalities are to be arranged so that they are both: (a) to the greatest benefit of the least advantaged, consistent with the just savings principle, and (b) attached to offices and positions open to all under conditions of fair equality of opportunity*" (Rawls 1999, 266).

[5] Our approach to the original position is less restrictive than Rawls's contribution. Barry's (1996) explication of Rawls's system is instructive.

We do not adopt the maximin principle, because it is not at all clear that it would be selected in the original position (see Mueller 1989, 408–423). Our disagreement with the maximin principle is due to the following obscurities: From the economic point of view, the requisite 'the greatest benefit of the least advantaged' poses a maximization problem. Strictly, it means that all social variables, that is, the policy, ought to be selected 'optimally' so that 'utility, welfare, benefit expectations' or other such objective in an objective function of the least advantaged was maximized (see Rawls 1999, 175). In other words, the main criterion for all social and public projects is that the benefits of the least advantaged are to be maximized. Then, any beneficial project that would produce the greatest benefits to all, should be rejected, if there is an other project with only modest social benefits, but where the share of the benefits of the least advantaged group would be greater than in the former project. Consider for example economic growth and development. The maximin principle might lead to the situation where the overall welfare producing growth would be modest in comparison to an alternative, but in relative terms the least advantaged group would get maximal benefits in a *contemporary* society[6]. In the long-run however, another optional policy, which is not restricted by the maximin principle, might produce much more benefits.

The maximization problem of one special objective always subordinates other reasonable goals to it. Maybe more important requirement for just social institutions would be that the least advantaged should have a potential escape from the group of the least advantaged. Then, the requirement that expectations of the least group should not be negative was sufficient. It could be that the least advantaged group may gradually vanish due the course of time, and then there is no point in trying to artificially support its existence by trying to maximize its expectations. The point is that maximization of the expectations of the least advantaged sets unnecessary restrictions to evolutionary processes of society. It may favor old structures of society and retard progress that is superior in the long-run. The 'original' second principle gives more policy choices to societies. We argue that the strict maximization form would not be adopted in the original position as the final and universal

[6] For intertemporal optimization problems with exhaustible natural resources Dasgupta and Heal (1979, chapters 9 and 10) discuss extensively about possible consequences that different ethical choices may cause. The main points are as follows. Application of the maximin principle leads to equal division. This means among other things that for the sake of fairness economic progress should not be allowed because it unjustly favors the future over the present. The maximin principle indicates that consumption per head should be the same for all generations. (Solow 1974, Dasgupta and Heal 1979, 289).
In fact, Rawls himself did not require that maximin strategy should be followed in choosing intertemporal consumption sequence. Maximin principle is reserved to intragenerational comparisons. Some authors argue that he ought to do that because extreme risk aversion is postulated elsewhere in Rawls' book. (Solow 1974, Dasgupta and Heal 1979, 275)

rule, because it has same kinds of problems than maximization of utility as a primary rule for social projects.[7]

Even though we do not adopt the final version of the second principle, and the first statement version of it may be too general, we do not either try to produce or propose the rival 'final' second principle. It would take us too far away from the main purpose of this study. Instead, we content with the first version of the second principle and proceed by taking advantage of it. However, we give a working proposal of the second principle in the next section. We will not go here into the details of utility theory and its comparisons to contractarianism.[8] Utility maximization is powerful and useful tool for understanding rational economic behavior. Contract theory, however, gives it only secondary, but still important, role in public design of society. The primary issues for human social arrangements are those of equal liberty, integrity of an individual, human dignity, equal individual rights with corresponding duties, and freedom of choice.

Human-being is the ultimate decision making unit. She is closest to the issues that concern her interests. It is quite natural since she is always present to herself. Consequently, she is the obvious or prominent person to make decisions about her personal affairs. Even though she voluntarily joined some human community, because of advantages of social cooperation, she would prefer the greatest possible freedom of choice and judgmental power about her life and belongings. The only allowable restrictions to these rights are due to the respect of equal liberties of other individuals in a community.

In individualism the principle of liberty is thought to be so prominent that it should precede all the other principles. Other principles may be adopted only if they are subordinate to the first principle of liberty. Thus, it should be possible to arrange principles in hierarchical, serial, or lexicographical order. Even though the principle of utility is powerful and useful, it cannot be the highest in hierarchy, since its full adoption would otiose all subsequent criteria, including the principle of individual liberty. (Rawls 1999, 37–39, 53–54, 220, 257.)

[7] In utilitarianism everything is subordinated to the utility maximization. In Rawls's maximin criterion issues of justice must first be fulfilled, and after that the utility maximization of the least advantaged displaces all other prospects.

[8] An excellent study about relations between utilitarianism, Rawls' theory of justice, and normative economics is presented in Mäkinen (2004, Dissertation in Finnish). Mäkinen argues that Rawlsian system has not been interpreted accurately (e.g. maximin criterion) and applied with its full potential in economics.

2.1.2 Critics, further explication and the original self

Interpretation of Rawls' theory of justice is not at all unambiguous and straightforward. It is no wonder that it has raised much criticism. The main critics against the idea of unanimous social contract concern its operationality and plausibility. Transaction and information costs make it impossible to gather all members of a community together in order to make a social contract. Another dispute of controversy concerns the status quo for an agreement. Should the status quo be the state of anarchy, natural law system, or the prevailing structure of a society? (Vihanto 1999)

Utilitarian criticism reduces into the interpretation and applicability of difference principle. This criticism identifies the difference principle with a maximin decision rule. (Mäkinen 2004) In decision theory the maximin principle means that a decision making agent considers the worst consequences of each possible courses of action, and then she chooses the one that has the least harmful consequences. Thus, the decision making agent is extremely risk averse. If the maximin criterion is adopted as a general rule for all moral considerations, unwanted and counter intuitive results will follow. The maximin criterion is only one special case in utilitarian framework. (Arrow 1973, Dasgupta and Heal 1979, Solow 1974) Mäkinen (2004) argues that critisism is not quite justified, because Rawls's theory of justice does not reduce into the maximin principle and its application to all moral decision making situations. In order to overcome the essential critics and to avoid potential confusion, it is necessary to express the approach of the present study more explicitly; what is the basic idea behind the original position.

Mainstream approach to economic justice can be seen as average preference utilitarianism (Mäkinen 2004). According to it all moral decisions can be derived by performing per capita utility maximization calculations. Then, the maximin decision rule is only a special case for special purposes. Originally, Rawlsian system for justice is meant to replace utilitarian approach only in considerations of the basic structure of just institutions in liberal and democratic society. For many other purposes he sees that utility analysis is fruitful. In other words, Rawls sees that utility analysis is useful and informative as such, but it is not well suited for designing just and stable basic institutions for society. Even though mainstream economics has not adopted the Rawlsian system, it is not completely abolished either. Among others Sen (1985, 1990) sees that Rawls's approach has some merits for welfare economics and there are good reasons to take it seriously and to explicate it further. Sen also shares the view that utility analysis is very useful for many purposes, but it is not adequate for all purposes. We do not adopt Rawlsian system as such, but use its basic ideas for consideration of the problem of sustainable development in the market economy.

In our approach utilitarianism is seen as a significant auxiliary tool for analyses of efficient allocations of scarce economic resources. But as we consider institutional basic structure for a just society, we have to respect rights of free and equal individuals. This indicates that requirements for justice must precede utility evaluations. The original position is meant to give a justification for selected views of justice. As we reconsider the original position, we may recognize some pros and cons of both utilitarianism and Rawlsian principles. Utilitarian approach is useful in the original position, because it promotes efficiency, i.e. dissipation must be avoided. More utility is also preferred to less utility. Main problems come from the fact that there are no unambiguous guidelines that restrict public or private actions that are unjust or unanticipated for free and equal individuals.

Rawls concludes that rational decision makers in the original position want to secure that life prospects of people in the least fortunate group are still positive. In other words, just institutions must somehow take care of those who are socially or economically most disadvantaged. It is plausible that people in the original position want that institutions provide them with some kind of safety nest which favor expectations of less fortunate. However, it is not at all evident that rational decision makers want to *maximize* the expectations of the less fortunate as Rawls's Second principle in part (a) manifests. Because of Rawls's ponderous and extensive reasoning process, it should not be too surprising that this kind of formulation easily can be interpreted to mean the maximin decision rule.

Because the formulation is confusing and ambiguous, we do not adopt it as such, but prefer the first preliminary formulation. Because Rawls's first formulation for the Second principle in part (a) may be thought to be too general, we suggest for our purposes a version of a possible principle that is something between Rawls's preliminary and the final statement. This version must be understood to be very preliminary one only, because our purpose of the study is not to reconsider derivation and formulation of difference principle. That would be an independent and demanding research problem as such.

A working proposal for a Part (a) of the Second principle:

'Social and economic inequalities are to be arranged so that they are reasonably expected to be to everyone's advantage, but special attention must be called to the life prospects and capabilities of the least advantaged as a socio-economic group.'[9]

At this stage it is an open question whether it possible to say anything more specific about this general principle. The merit is that it recognizes the special attention to the least advantaged group. It also allows considerations whether the special needs of the least advantaged group should be specified using absolute or relative terms. There is no requirement for maximization, which has seemed to cause much confusion. Overall, there may not be any need for maximization of anything for principles that are meant to be somehow basic and universal in all reasonable states of the world. It can be thought that if a unanimous agreement about just principles can first be accomplished, then at later stages utilitarian maximization framework can be used to guarantee efficient (and just) solutions for different cases. This kind of reasoning suggests that utilitarian framework is important and essential, but subordinate to the principles of justice.

Next we give some specific features for the original position as a methodological reasoning tool. Let us put up the following imaginary construction: The omnipotent souls are going to play the role game called life in the planet Earth. They come together to make the rules for the game, and to agree maintenance responsibilities for the playground. Maybe there are many rounds for the game. After setting the rules of the game, they enter into the real world using lottery to order the entry. We could develop even more ambitious construction: Suppose that there exists only one omnipotent soul who divides itself into countless separate persons in different times and places (cf. Rawls, 166–167). That is, in the original position there exists only one 'self' who decides to divide itself into many different persons into the planet Earth for varying positions, times, and places. Let us call her as '*the original self*.' Why should we make this kind of imaginary assumption? The original position is only a theoretical thinking tool, not the state of the real world that should be tried to accomplish. This kind of imaginary construction strives for the most purity of common view to the rules of just society. The original self can be understood as a methodological thinking device that helps reasoning based on introspection (Vihanto 1999). It is totally irrelevant whether this story has any links to the mystery of life or reality. The main point is that everybody would agree that playing field must be maintained and there must be favorable conditions for the players, or different realizations of 'myselfs' to exist.

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[9] Amartya Sen (1985, 1990) gives convincing reasoning and justification for the necessity to take into account capabilities in considerations of social and economic justice. Without going into the details here, we suggest as a preliminary idea that capabilities could possibly be expressed as a part of the difference principle.

It may be necessary to justify the concept of the original self more profoundly. The main reason for the introduction of this concept is that it can at best reduce some potential controversy and define relevant issues from irrelevant ones with more precision. It also strengthens the common view approach, introspection and sympathy against different people and socio-economic groups. Some confusion can be derived from the obscure state of affairs whether many decision makers are required or just one. If only one decision maker is required, the methodological use of the original position may be easier. The introduction of the original self is consistent with the claim that only one decision maker is required in the original position where just socio-economic institutions for the sustainable market economy are derived.

Rawls compares moral calculation of utilitarianism with the two principles of justice in chapter 30 of his book. This discussion is also referred by Dasgupta and Heal (1979, 264–265). It may be instructive first to quote Rawls and then discuss about interpretations that might lead to the adoption of the concept of the original self:

"*A rational and impartial sympathetic spectator is a person who takes a general perspective: he assumes a position where his own interests are not at stake and he possesses all the requisite information and powers of reasoning... Thus he imagines himself in the place of each person in turn... imagined pains cancel out sympathetically imagined pleasures, and the final intensity of approval corresponds to the net sum of positive feeling... The principle of rational choice for one man is taken as the principle of social choice as well.*" (Rawls 1999, 163)

"*The approvals of the impartial sympathetic spectator are adopted as the standard of justice, and this results in impersonality, in the conflation of all desires into one system of desire.*" (Rawls 1999, 164)

"*In the classical conception one chooses as if one will for certain live through the experiences of each individual, seriatim as Lewis says, and then sum up the result. The idea of taking a change on which person one will turn out to be does not arise... Instead of defining impartiality from the standpoint of a sympathetic observer, we define impartiality from the standpoint of the litigants themselves.*" (Rawls 1999, 165)

"*We might try out here the idea that a benevolent person is to guided by the principles someone would choose if he knew that he is to split, so to speak, into the many members of society... Since a single individual is literally to become many persons, there is no question of guessing which one...*" (Rawls 1999, 166)

Rawls also discuss about literature where one impartial decision maker is adopted as the standard of justice (Rawls 1999, 164, footnote 37). Clearly, there are merits for the assumption that critical moral decisions could be derived as if they were made by one representative agent. Thus, it may not be artificial to adopt the concept of the original self who makes the basic moral decisions about just institutions in the original position. Several remarks are now possible. Obviously, if there is only one original self in the original position, there is no bargaining over just institutions; only reasoning. There is no point in disputing with oneself. The relevant constraint for the original position is that it can take place continuously at the instant time. Even though the original position takes place 'now' the original self knows that she is taking decisions that concern her today and in the future; she lives all contemporary and future lives successively.

There are differences between 'benevolent impartial spectator' and the original self. The impartial spectator is an outsider and the original self is an insider in the sense that the latter will for sure live through all the consequences of her decisions. Thus, her own interests are at stake. She probably does not want to follow the maximin rule, but it is at her interest to insist that no group will be treated unfairly in order to maximize benefits of the whole. Consequently, maximization of total or average utility can not be the overwhelming decision rule for the moral considerations of the basic institutions. Sympathetic spectator gets all relevant information from all the agents. However, she has not to live all positions, but only sum up the net result. Thus, he has no special interest for the life prospects of the least advantaged or any other group. The original self is at the same time self-interested and altruistic. She is self-interested, because she wants to be as free as possible to pursue at her own ends that are important to her particular realization. She is altruistic, because she wants to be as equal as possible with everybody else despite her particular realization.

It is now interesting to reflect the implications that the adoption of the original self might cause against the critics that Arrow (1973) presents against the original position. Arrow (1973, 255) writes "*But empirical knowledge is after all uncertain, and even in the original position individuals may disagree about the facts and laws of the universe.*" The original self knows that she does not now everything. She knows what she knows and she has to come along with that knowledge. It is reasonable to assume that she is not schizophrenic, so that she is able to make consistent decisions.

"*But suppose that he replies that in fact Catholicism is the true religion, that it is part of the knowledge which all sensible people are supposed to have in the original position, and that he insists on it for the salvation of all mankind. How could this be refuted?*" Arrow (1973, 255) The original self knows that in reality she will be Catholic, Protestant, Jew, Muslim, Agnostic, or whatever. In fact she is indifferent between religions. Besides, if any special religion will lead to salvation, she is saved, because she lives through all the available religions.

"*I feel I know that Marxism (or laissez-faire) is the truth; therefore, in the original position, I would have supported suppressing other positions. Even Rawls permits suppression of those who do not believe in freedom.*" Arrow (1973, 255) Again, the original self wants to secure as much as freedom and equality for her realizations. Then, she has no problem in resolving this issue. It is irrelevant what her realizations will believe at their live times. Every realization is free to believe whatever she or he wants. The original self knows that her realizations will believe in different things. Those special beliefs do not enter in the original position, because its purpose is to find just institutions that guarantee equal justice for everybody, and for all beliefs.

"*There is another kind of knowledge problem in the original position: that about social preferences... But why should there not be views of benevolence (or envy) even in the original position?... But if these are admitted, then there can be disagreement over the degree of benevolence or malevolence, and the happy assumption, that there are no disagreements in the original position, disappears.*" Arrow (1973, 255) It is reasonable to assume that the original self is benevolent to herself and she does not envy herself. Thus, there cannot be any disagreement in the original position, because you cannot disagree with yourself.

To sum up, people in the original position are reduced to the original self. The original self is rational, but she knows that in the real world she is only limitedly rational. Further, she knows that in the real world she has feelings and other human 'frailties' which affect her behavior and sense of justice. She also understands that in the real world government is limitedly rational and it is used for selfish intentions by different interest groups. This does not, however, preclude her to try to find out moral rules that provide normative general guidelines to just liberal society. By observing possible decisions of the rational original self, limitedly rational agents may learn something fundamental about just society.

In conclusion we propose evolutionary solution to status quo and path dependencies that are seen to be problematic in contract theory. Figure 1 expresses the idea.

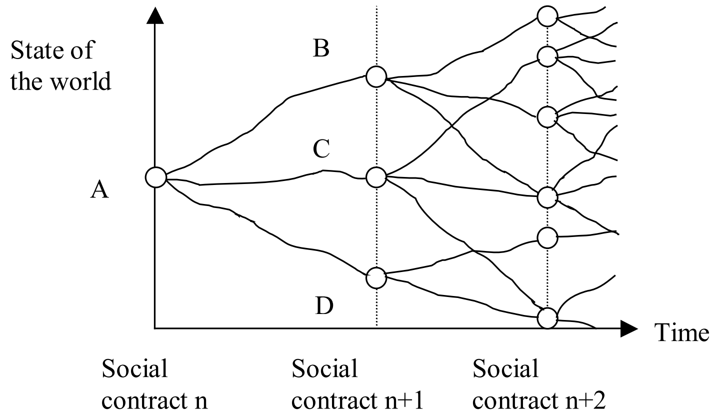

Figure 1 Path dependency and status quo in evolutionary process of social contracting

Vertical axis measures state of the world however measured. Horizontal axis presents time. Node A describes the present status quo at time moment ‘n’. Evolution (history) has brought us to this specific state of the world. We now may consider just social contract using all general information that we have in this state (A) of the world: we may recognize the development path that has taken us here, and we may know our phase of development. Despite of this, we still may use reasoning based on natural law. That is, we respect the idea that every individual has some obvious fundamental rights. Then we may revise the justice of our principles and institutions, and then move on. Evolution may lead us to one of nodes like B, C, or D at time n+1. Let us suppose that evolution takes us to node B. There again we may take advantage of the new general knowledge (which possibly was not available in A), and make a new revision, and so on. The original self recognizes her history, new knowledge, and she knows that she will live all lives of the node B and all successive lives in the following time periods. Obviously, she has to be interested about sustainability and development.

2.2 Principles for a market economy

Under due circumstances democratic capitalism may constitute a just social moral order (Machan 1999). This is especially so if the principles of the market system are derived from the original position. The market economy and democracy may be designed to be consistent with the two principles of Rawls (see Buchanan 1987b, Rawls 1999, 240–241, Vihanto 1991). If the two principles are satisfied, each person's basic liberties are secured and benefits of social coordination can be realized (Rawls 1999, 154). We call a social market economy to be such that it is both just and democratic. If a society is just, it should also be democratic, because in no other system do citizens have an equal potential opportunity to take part in political decision making process. If an economy is democratic, it may or may not be just. Democratic system has potential weaknesses that are vested in potential opportunistic majority dictatorship or informational asymmetries. Below we argue that a social market economy also should respect requirement of sustainable development.

2.2.1 Individual and rights

An economy forms an institutional structure that, more or less explicitly, defines rights and duties of its members. While considering fundamental elements of socio-economic order, one cannot avoid value judgments about a good society. The fundamental assumption concerns the role of individual in a society. In individualistic approach it is thought that an individual is fundamentally free and he or she has some basic rights that must be respected by others. The very basic right says that an individual has a full user-right to her own body and mind. This requirement enables intentional and purposeful action.

Just rules of conduct are the elements of a just society. Because individuals are basically egoistic, it is natural that every now and then individuals come into conflict with each other. One of the most important tasks of a socio-economic coordinative cooperation system is to define which individuals have rights and correlated duties when private or collective interests are in conflict.

According to an individualistic approach a membership in a society should be seen as a voluntary agreement between an individual and the rest of a society. Free individuals come together in order to form a community or society because they see that cooperation can provide every individual with benefits that cannot be achieved in isolation. A just agreement in a society is presumed to acknowledge this principle. On the other hand, a well functioning cooperation with others means that one individual cannot take any actions she wants without restrictions, because also other individuals' similar basic rights should be respected. The market economy is typically characterized as a system where decisions concerning the allocation of scarce resources are made by voluntary interactions between individual buyers and sellers. The market economy is a social constellation that requires established rules of ownership and property rights.

The classical theory of rights sees the system of private property rights to be a system of equal rights. In theoretically ideal construction, all resources are privately owned by someone, and everyone is free to use her own property in whichever way she wants, with the restriction that she does not by so doing violate the equal rights of other individuals to use their property. While an individual has an unbroken right into her person and property, she is not allowed to enter on somebody else's person and property without the latter's consent. As these principles are followed, all individuals or interest groups in a society have a right to pursue whatever goals they like, but belongings of others must be respected, i.e. life, freedom, and property. (Pilon 1982). The classical liberal system is based on three rules (Pilon 1987): (1) The market participants must not take anything that belongs to someone else. (2) Arrangements must be followed. (3) If an agent fails in either one or two rules above, she must give back in full extent what she has wrongly taken or withheld.

2.2.2 The role of the government

In mainstream economics efficiency is an overwhelming decision making criterion. It does not matter whether we are considering the private or public decision making problem. According to this reasoning the government's task is to find market failures, i.e. cases where markets don't work, and then correct them. The contractarian doctrine, however, emphasizes that in collective decision making the issues of rights and justice always precede the criterion of economic efficiency (Rawls 1999, 230–231, 266–267).

From contractarian point of view the fundamental function of the government is to secure basic rights of individuals against illegal aggressions of other individuals or public authorities. Also the government must be tied to the basic moral order (Buchanan 1987c), and it should not be allowed to use arbitrary decisions or to set individuals into unequal positions (Vihanto 1991). Thus, according to contractarian approach the ultimate duty of the government is to implement institutions and a coercive authority system that supports the basic moral order.

The individualistic approach suggests that the role of the government is to secure every individual's property rights on life, freedom, and property. Daniel Bromley (1991, 15) defines a right as *"a capacity to call upon a collective to stand one's claim to a benefit stream"* that a property produces. Rights only have meaning in the context of some authority system that defends a rights' holder's interests against the others. Rights must be understood as a common consent between an individual actor and other actors with respect to some object. Rights can only exist when there is a social mechanism that gives a right to one economic actor, and requires correlated duties from other actors, and further, uses its coercive power to implement these rights and duties in the case of misconduct. (Bromley 1991, 41.)

A society needs an authority system that guarantees that individual members of a society follow the rules of social cooperation. The government should secure individual rights, and control that correlated duties are not neglected. Because well defined and established property rights are seen to be fundamental to the proper functioning of a market economy, conflicts in a society should always be resolved via consideration of whose rights should be protected and who is an obligate on the ground of the basic moral order.

3 SOCIAL CONTRACT AND SUSTAINABLE DEVELOPMENT

> "*...what rights and obligations there must be if society is to be sustained and the security or freedom of the individual preserved*" *(Kukathas [1989, 125] on Friedrich A. Hayek, quoted in McCann [2002, endnote 68]).*

3.1 Justice between generations

Originally, Rawls's theory is meant for purposes of intragenerational justice. Consequently, Rawls's treatment of the problem of justice between generations is complex and difficult to interpret (see also Mäkinen 2004, 189–202). For example, he argues that "*The persons in the original position have no information as to which generation they belong*" (Rawls 1999, 118). In the same section he claims that "*Since the persons in the original position know that they are contemporaries (taking the present time of entry interpretation), they can favor their generation by refusing to make any sacrifices at all for their successors...*" (Rawls 1999, 121). Later he writes "*Now when the parties consider this problem they do not know to which generation they belong or, what comes to the same thing, the stage of civilization of their society. They have no way of telling whether it is poor or relatively wealthy, largely agricultural or already industrialized, and so on. The veil of ignorance is complete in these respects. But since we take the present time of entry interpretation of the original position (§24), the parties know that they are contemporaries; and so unless we modify our initial assumptions, there is no reason for them to agree to any saving whatever. Earlier generations will have either saved or not; there is nothing the parties can do affect that. So to convince a reasonable result, we assume first, that the parties represent family lines, say who care at least about their more immediate descendants; and second that the principle adopted must be such that they wish all earlier generations to have followed it (§22). These constraints, together with the veil of ignorance, are to insure that any one generation looks out for all.*" (Rawls 1999, 254–255) For Rawls (1999, 153) "*...the original agreement is final and made perpetuity, there is no second chance.*"

For Rawls persons in the original position are contemporaries, information and knowledge is not allowed to differ at different times, and conclusions would also be the same at any time. Rawls's assumptions may be reasonable for the derivation of the very basic institutions, but if we want to reconsider comprehensively the issues of sustainable development and intergenerational justice, these assumptions must be revised. Rawls himself modifies his initial assumptions in order to achieve reasonable results (Rawls 1999, 254–255). Thus, we believe that Rawlsian system is meant to be revisable and adjustable to contingencies.

If we adopt the original self, we more or less abandon Rawls's descriptions for persons and available information in the original position. The original self knows that she is contemporary, but she also knows that she belongs to all possible generations. There are no strictly conflicting interests between different generations. The common view is perfect, and we insist that a social contract has to be consistent with sustainable development. Because our approach to the original position, veil of ignorance, and persons in the original position differs distinctively from Rawls assumption, we may call our modification as a dynamic social contract. It should be a universal requirement for all generations, but contrary to Rawls, it is revisable as Figure 1 suggests. In our proposal the state of development and new general knowledge must be allowed for considerations of intergenerational justice.

There are two general principles that most likely were chosen by rational individuals behind the veil of ignorance: requirement of sustainable development and obligation for government to secure it. Argument of Kneese and Schulze (1985, 203) is consistent with our interpretation: "*... the present generation does not have a right to deplete the opportunities afforded by the resource base since it does not "own" it. This is not to say that the resource base, including environmental resources, must be held physically intact, but when there is depletion, is must be compensated for by technological development or capital investment.*" Evidently people in the original position have a mutual interest to guarantee somehow that the preceding generation does not destroy the possibilities of later generations for raising their standards of living and welfare. Rawls's original position "*links all generations together with a common perspective*" (Kneese and Schulze 1985, 204). This means that just principles of saving and stewardship of natural, man-made, and human capital must be formulated. "*Justice does not require that early generations save so that later ones are simply more wealthy*" (Rawls 1999, 257). Contemporaries have no obligation to make successors better off. Instead, it is unjust to make them worse off. (Barry 1996, O'Neill 2002.) Justice requires that due resources are handed down to posterity in order to make continuous progress and higher levels of well-being possible also in the future.

Irremediable injuries to the welfare of future generations, and irreversible damages for the environment must be avoided (Rawls 1999, 239). The following principle is consistent with the requirements of the original position.

'*The sustainability principle*: Every generation should respect the idea of sustainable development. Natural resources are common property of all generations. One generation or one economic agent can own, use and manage natural resources, but it has no exclusive right to exhaust the potential opportunities that resources might give.'

Sustainable development indicates that there should be certain constraints for the use of exhaustible natural resources (renewable and nonrenewable). The resources that the Earth provides belong to all generations and not to someone particularly. The single possessor is not allowed to extract them exclusively so that there would not be anything left after her exit, at least not without a due compensation. One quite obvious implication of this principle is that unreasonable, uncompensated intertemporal costs should not be transferred to later generations.

This proposition is in line with Rawls's first and second principles as well as with our reformulation. The consistency with the first principle is trivial. We may interpret the second principle to mean that generations may differ with their preferences and aspirations, but sustainability criterion says that inequalities, say in resource use, should somehow to be advantageous also to the following generations, and open possibilities for other kinds of preferences and time bounded unknown goals should be secured.

Rational men behind the veil of ignorance would choose this principle, because they wanted to secure the proper resource base also to their generation. The private property regime is useful for careful stewardship and for efficient and due care of scarce resources, but this means only usufruct for these resources. After the prior owner's exit or abandonment there will be somebody else that owns and takes care of this resource, and enjoys the benefit streams it produces as compensation for due care. Consequently, the just government should restrict user's rights on private property.

'*The sustainability principle for the government*: The government is a representative agent for the present and future generations. It has to guarantee adequate resource base that is required for sustainable development. It has an obligation to secure equal rights and interests of the present and the future. The resource base consists of viable ecology, balanced man-made capital, human capital, and just institutions. The balanced resource base and just institutions promote long-term progress and well-being which mean sustainable development.'

The government should be a representative agent for future generations that do not exist yet, and thus, cannot negotiate with the present. This is to say that basic equal rights both for the future and present individuals should be respected in contemporary decision making. It is not required or even desirable that the present generation maintains the resource base intact, at the same composition or even at the same total size as it was left by the previous generation. There may be some contingencies according to which some variability in the resource base may be allowed. The most important requirement for the resource base is that it is able to provide continuous progress and well-being also in the future.

3.2 Time preference and discounting

The logical conclusion for intergenerational justice is that a society should maintain just institutions as a heritage to later generations (Rawls 1999, 255). The time preference problem is controversial issue. The use and justification of time preference in decision making has an important role in intertemporal justice, because strong emphasis on the present is a potential threat to the interests of the future (Pittel 2002, 81). Large literature can be found concerning the justice or injustice of time preference (see for example Portney and Weyant [1999]). Frank Ramsey's (1928) argument that on equality basis the time preference should be zero has been very influential. Also Rawls (1999, 259) assumes that in choosing a principle of savings the persons in the original position have no pure time preference, because according to him from a moral point of view there are no grounds for discounting future well-being on the basis of pure time preference (Rawls 1999, 253). It is reasonable to assume that people do not have pure time preference in the original position. They may live in what ever relevant time instant, and as rational decision makers, they want to be sure that they have proper conditions for development and progress in their, yet unknown, life time.

It may be a reasonable assumption that the decision makers in the original positions have no pure time preference, because they are making fundamental decisions for immortal evolving society. On the other hand, they also should know that mortal people in the real world will value the present against the future, and for good reasons. Our treatment is somewhat distinctive from Rawls. We comment these differences after the following quotation. "*As with rational prudence, the rejection of pure time preference is not incompatible with taking uncertainties and changing circumstances into account; nor does it rule out an interest rate (in either a socialist or a private-property economy) to ration limited funds for investment. The restriction is rather that in first principles of justice we are not allowed to treat generations differently solely on the grounds that they are earlier or later in time. The original position is so* *defined that it leads to the correct principle in this respect. In the case of individual, pure time preference is irrational: it means that he is not viewing all moments as equally parts of one life. In the case of society, pure time preference is unjust: it means (in the more common instance when the future is discounted) that the living take advantage of their position in time to favor their own interests. The contract view agrees, then, with Sidgwick in rejecting time preference as a grounds of social choice.*" (Rawls 1999, 260)

The first distinction comes from the different definition of the original position. As we previously argued, Rawls's assumptions about the general knowledge in the original position may be valid for the derivation of the basic principles for a just society. While we are considering more concrete problems, it is necessary to revise the assumptions. Rawls does this himself as he considers the problem of the just savings principle. Our proposal for the modification of the original position and veil of ignorance for considerations of sustainable development is presented in Figure 1. From the point of view of the original self the generations must not be put unequal positions. This, however, does not mean that pure time preference should be denied from actual societies or individuals. If there are proper safety rules that prevent irreversible damage to be caused for the future generations, there should not be any reason why the use of pure time preference should be denied. After all, pure time preference is a simple device for taking account in uncertainty and expectations about rising income that are intertwined to the passage of time.

The second difference concerns rationality of individual time preference. The original self understands that mortal individuals weight the present and near future time in their lives. Individual life prospects and plans are always conditional to contingencies that may be drastic, fatal or unforeseen. It is not irrational to view different time moments at different weights.

Third, pure time preference is not unjust to society if requirements for sustainable development are guaranteed. It is natural that contemporary societies give weight to their generation. Every generation has an equal right to take advantage of their position in time to favor their own interests.

Fourth, for these reasons it is not self evident that contract view should reject time preference as a ground of social choice.

On the other hand, people in the original position also know that in the real world they will want to give an emphasis to their own life span. Is there really a contradiction? We argue that the absence of pure time preference in the original position does not mean that also in the real world time preference should be zero. Counterarguments can be found which state that it may well be fair and just to use positive time preference with caution. According to weaker difference principle the use of positive time preference is compatible with intergenerational justice if it is supposed to benefit all subsequent generations, or at least, its use does not restrict equal opportunities of later generations for development and progress. This is an extremely important argument, because adoption of strict difference principle (maximin rule) would mean that rising welfare would practically be impossible (Pittel 2002, 15–16). If the well-being of the worst-off generation, in the case of continuous progress that is the current generation, should be maximized, the steady state, zero growth, economy should be reached by all means as soon as possible, so that the current level of the state of affairs would prevail forever. According to the more general difference principle this outcome would be a result of unjust conduct.

Impatience, capital productivity, raising income, and uncertainty about the future are the main reasons for the use of discounting. Rawls among others sees that uncertainty does not justify positive time preference (Rawls 1999, 259). We disagree, because the present generation should make sure that continuous development is potentially possible. Then, it has a right to use positive time preference with due care. We may expect that if growth and development meet sustainability requirements, the future generations are always better off than the present one. The contemporaries have a right to use positive discounting, but of course, not without restrictions. It is their obligation to leave potential possibilities for sustainable economic growth, welfare, and development. The due use of discounting is in no contradiction with the weaker or modified form of the difference principle. Examples of deliberated discount rates are given by Gollier (2002) and Weitzman (2001) who provide reasons to use social discount rates that are declining through time.

For fundamental decisions to be made, it is reasonable to assume that all individuals live only once under genuine uncertainty. Thus, they must have an equal right to give some emphasis on their current affairs. Also societies are in different development positions at different times. Different time moments are not equivalent: every time instant has a unique state of the world that must be taken into consideration. The values of time moments are constructed by changing contingencies of the states of the world. Individuals may be young, old, healthy, sick, etc. Also societies are in unequal positions because of different stages of development and states of nature. This means that every time moment is unique and such thing as pure time preference has no relevance for reality. Every time instant just describes different states of the world. The problem then, is not a positive time preference as such, but the recognition of the proper, or just, discount factor to each relevant case. Development and progress mean increasing well-being. On the ideal time path of sustainable development societies get more prosperous, and there is no reason why time preference should be set as zero under such conditions.

Further, it is consistent with a compensation principle to use discounting, if decisions of contemporaries also make future generations better off in general terms. This means, of course, that it is unjust to transfer costs to later generations without due compensation.

As a simple example, consider the case of two generations. The present generation is implementing the project that generates great benefits for them with minor costs for next 50 years. For a reason or another, the real costs of the projects will be realized only, say, after 100 years meaning that the next generation faces only huge costs. The use of positive discounting suggests that the project is beneficial for the present generation. If not the both generations benefit, the project is unjust. The project violates the compensation principle. This might be the case with nuclear power or greenhouse effect. Yet, it is possible that in some cases the project is beneficial for both generations even though the next generation bears the most of direct costs of the project. If the project is able to produce indirect benefits, like considerable progress in human capital and well-being which exceed or at minimum compensate direct costs, the project may well be a fair one, after all.

The adoption of the strict difference principle leads to many unsettled problems. Rawls (1999, 121, 254) recognizes that problems of saving and justice between generations are not easily resolved without further assumptions and constraints. Instead, if we adopt the weaker or modified form of the difference principle and we assume that the decision maker in the original position is the original self, we need no auxiliary assumptions or constraints. This means that the time issue as such is irrelevant: the original self knows that she will live in every time in forms of different persons, that is, she is living every life of every individual. Then, whether the decision maker is contemporary or not does not matter. There is only one decision maker who has many successive and contemporary lives. There is no bargaining problem between different generations, only the problem of rational reasoning.

Because of the nature of linear time, "*[t]here is no way for later generations to help the situation of the least fortunate earlier generation*" (Rawls, 1999 254.) This is only a problem for the strong form of the second principle. If the weaker or modified form of the second principle is adopted, there is no need for the maximization of the least advantaged previous generation. This is also one possible escape from the difficulties of the maximin criterion that can be interpreted to mean that there should not be any economic growth and progress. The justification of the use time preference allows many extensions. It gives more room for analyzes of intertemporal justice and saving in various cases. We might expect that intergenerational justice requires different kinds of practices and principles for different kinds of capital, like human-made, social, natural, human, biotic, land, labor, etc. Also whether a decision maker is private or public actor makes a difference, because of differing time horizons: we should assume mortal individuals living in immortal societies. A public representative agent for an immortal society should have distinctive perspective for parameters of decision making than a mortal individual. Typically, the social rate of time preference and discounting should differ downwards from individual or private rates of time preference (Caplin and Leahy 2004, Pittel 2002, 119).

To conclude, the main question is: 'What is critical for sustainability?' To Robert Lind (1999) and Thomas Schelling (1999) discounting is of only a minor concern, because the fundamental choice to be made is whether the current generation transfers resources or costs to generations living in the distant future. To our view, if the present generation is saving for the future, it also has a right to use positive time preference with caution. The original self wants that in every instant of time when she lives (in forms of many separate persons), she has full potentials for freedom of choice and meaningful life. Also Brian Barry (1996, 1997) concludes that the relevant concept of justice between generations is justice as equal opportunity. Every person has a unique life time, thus it is natural that the instant of time 'right now' must be allowed to be the most important for her. It is always uncertain whether the next time moment or period will be realized for her. Consequently, she has to have a right to give more emphasis for her own time compared to time of others, but she is obliged to recognize that all others in different times have an equal right which must be respected. Her valuation of the present must not mean that she deprives the future generations' freedom of choice to develop and make progress[10].

[10] A further argument for non-zero discounting can be found from studies, which show that the total effects of zero or positive discounting on the environment may be ambiguous depending on structural factors behind propensities to invest on nature or capital (Pittel 2002, 82).

4 SOCIAL MARKET ECONOMY AND SUSTAINABLE DEVELOPMENT

Our approach to the market system is based on individualism, contractarianism, and liberalism, but our views about the market economy are refined into what we call as a social market economy. Thus, our basic premise is that the market system should be consistent with the logic of the original position. People in the original position want the market system that is just social cooperation system that is able to produce benefits to all individuals. This requirement reinforces the market order to be a strict moral system for social cooperation. If we accept this, we may proceed to consider how natural resources and the environment should be managed in a social market economy. It is important to differentiate between different kinds of economic goods including environmental goods. Different kinds of goods require different kinds of governance structures under the regime of sustainable development. General sustainability principles for the use of renewable and nonrenewable resources are introduced.

4.1 Externalities and social costs

Externalities, social costs, and Pigouvian taxes are central concepts in environmental economics. Next we reconsider these classical topics once again from our contractarian perspective. We see that our conclusions differ somewhat both from neoclassical utilitarianism and mainstream contractarianism. We do not go into details and multiple properties of these concepts, but we briefly define them in a way that is sufficient for our purposes: A negative harmful externality or external cost is present as some economic unit takes an action which causes costs that are transferred onto other economic units. She does not make her economic decisions in order to cause costs on others purposefully, but in her decision making she takes only account private costs of her action, and she ignores the costs that fell on others. Pollution is a classical example.

To be more precise we may use the definitions by Baumol and Oates (1988): *"An externality is present whenever some individual's (say A's) utility or production relationships include real (that is, nonmonetary) variables, whose values are chosen by others (persons, corporations, governments)* *without particular attention to the effects on A's welfare."* (Baumol and Oates 1988, 17) This definition classifies externalities to technological and pecuniary ones. Technological externalities are relevant for the environmental economics and issues of sustainability while pecuniary ones are not. Technological externalities enter utility or production functions as independent variables. This means that they shift the production possibilities frontiers or utility functions. Consequently, they cause divergence between social and private marginal rates of transformation or social and private marginal rates of substitution. Pecuniary externalities do not cause shifts in functions and they do not cause divergence between social and private marginal rates of transformation or substitution. (See Baumol and Oates 1988, 29–31)

Social costs are due to summation of private and external costs. Pigouvian taxes provide a theoretical solution to the externality problem. Pigouvian tax is set equal to marginal external costs. This internalizes an externality which ensures that total benefits of an action are maximized. (see Grafton et al. 2001, 98, 257, 214 Markandya et al. 2001, 94, 167, 150).

4.1.1 Rights

According to individualism men are basically free and they have some fundamental rights[11]. One of such rights says that she is a prominent and autonomous decision maker concerning her own body, mind, and life. We may immediately take a step further and ask: 'what are the necessities for a human life to exist?' In order to stay alive, and to decide of her own body, mind, and life, an individual needs clean air to breathe, healthy food to eat, clean water to drink etc. Man is not an isolated and independent unit that can survive without environmental services, but she is a subsystem of nature, and if she has no access to vital environmental goods and services she cannot survive.

'*The property rights principle for the environment*: Every individual, in every generation, has a right to the basic services that the environment can provide.'

Property rights to privacy, healthy food, clean air, fresh water, etc. should be declared as fundamental rights of every individual. Ezra Mishan (1993, 31-33) calls rights that should have a legal recognition as amenity rights. This principle is in no contradiction with Rawls's first and second principles. In

[11] As Rawls suggests people in the original position value liberty and equality as primacy of justice. They are needed for to maintain self respect of individuals and to implement meaningful individual life prospects. In order to promote liberty and equality, it is necessary that people have some publicly recognized inviolable rights that make meaningful life prospects possible to reach for. We may call such rights as fundamental rights.

fact, he claims that distributive justice implies that unreasonable externalities should be eliminated (Rawls 1999, 245). Polluters under this principle always would become liable for environmental damage they have created. Thus, the polluter pays principle is consistent with the individualistic logic of the social market economy, and it is a logical consequence of the property rights principle stated above.

The polluter pays principle is not a prominent principle in utilitarianism or mainstream contractarianism: The Coase Theorem says that harmful external effects, like pollution, are reciprocal by their nature: *"To avoid the harm to B would inflict harm on A"* (Coase 1960, 2). Furthermore, if property rights are well defined, it is irrelevant whether a polluter has a right to pollute or whether an opponent has a right to clean environment, because bargaining leads to an efficient outcome anyhow, with the assumption of zero transaction costs. Our approach, on the contrary, suggests that we should recognize who has a fundamental right[12] to the object under consideration. Strict liability would reduce excessive polluting activity close to socially optimal levels[13]. Consequently, polluters would have economic incentives to seek technical or other ways to reduce externalities in order to avoid excessive or potential liability costs.

Thus, individuals have a fundamental right, for example, to clean air. Pollution without consent or permission of an affected person is a violation of her individual rights (Machan 1991). In reality some concessions must be made if people want to benefit from social cooperation in full extent. People in the original position understand this. Maybe we should propose that individuals have a right to some 'reasonable' quality of clean air. Reasonable quality should be defined through social, ecological, and health criteria. Within these criteria a polluter may buy or redeem a right from a society, i.e. the government[14] whose task is to represent its individuals in these kinds of matters, to pollute moderately. (Rawls 1999, 237.) A public authority should act as an ultimate guarantor, and to observe the quality of the environment, to

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[12] The fundamental right that is derived from the original position may be in contradiction with the current (unjust) law and legal praxis.

[13] If we require that the concept of social cost should include the issues of justice, the rights of future generations, and preservation of ecological functions or biodiversity, we have extended the concept of social cost from its traditional meaning.

[14] Free market libertarian would ask: 'Why government? Why not to leave the bargaining process to markets?' We do not touch this issue here any further. We only refer to well-known problems that are due to high transaction costs. These cost justify a government as an agent that is able to diminish transaction costs effectively for both the current and future generations. A government is also able to create pseudo markets for environmental goods through pollution taxes or tradable pollution permits. That is, it creates a pricing device for goods that have value, but the values of which are practically impossible to be catched by prices or free markets without the public agent. (See e.g. Fisher 1981, 179–184).

impose taxes, fees, and other controls on polluters so that sustainable development is not at stake.

4.1.2 Intertemporal externalities

Intertemporal externalities are asymmetrical in the sense that only the preceding generation is able to push unwanted costs to the offspring. Further, the problem of intertemporal externalities cannot be solved through markets since there are no real markets present where the unborn might reveal their preferences through market transactions (Bromley 1991, 87). Intertemporal externalities are crucial for justice between generations. Especially irreversible damages caused by the present generation may be seen as grave offenses against other generations (Rawls 1999, 261). Earlier we concluded that there are no definite answers to the questions like how much to save for future generations, for instance. "*It does not follow, however that certain bounds that impose significant ethical constraints cannot be formulated*" (Rawls 1999, 253).

The present generation is able to act without regard to the interests of the future. If the present generation ignores the long-run environmental consequences, the present takes privileges and gives no rights to the future, which is in contradiction to our approach that suggests that the current generation has an obligation to respect equal rights of the future generations. Uncontrolled market economy is prone to produce lot of intergenerational externalities, because infinite transaction costs hinder future generations to reveal their preferences at markets; it is not possible to negotiate with the unborn (Bromley, 1991, 85-86). Yet the interests of the future can be reflected in contemporary policy choices. Of course, we can never be sure about the preferences and needs of the future, but it is possible to leave them more or less possibilities to make free choices. Whenever some actions of the current generation lead to extinction of some resource, there is at least one choice determinant less for the future.

4.1.3 Dispute

Next we give some illustrative examples of dispute between different approaches. Because there is no general consensus about these matters, and because our intention is to propose a complementary approach (or even a synthesis) to the existing ones, it is necessary to further clarify the main ideas behind our reasoning. The approach developed in this essay differs with all the mainstream doctrines. Our approach is not completely Rawlsian in the sense that we do not slavishly adopt and apply Rawls's theory, it is not utilitarian in the sense that we do not accept universality and omnipotence of utilitarianism, it is not libertarian in the sense that pure chance and status quo of current affairs in socio-economic relations are not accepted without reservations to be a reference point according to which institutional revisions and allocation decisions should be made. Our approach is Rawlsian in the sense that we apply Rawlsian contractarian method of the original position, our approach is utilitarian in the sense that we see that utility analysis is a main tool of economics by the help of which we can derive efficient and consistent solutions to many socio-economic problems, our approach is libertarian in the sense that freedom, individualism and individual rights are seen to be such basic values of humanity that must be respected.

Before we turn to examples, we have to raise some questions. Laws of thermodynamics imply that if we are going to have production and consumption (i.e. economy) we cannot avoid high entropy waste (pollution) (see for example Daly 1974). In other words, it is not possible to have zero pollution. Knowing this, we have to get some idea about the question how much pollution must be accepted as a natural unavoidable phenomenon and how strictly we should apply the polluter pays principle, or should we even have a victim pays principle. Externality is defined as in Baumol and Oates (1988, 17) (Condition 1. in their definition). This means that any positive amount of pollution can be counted as a harmful externality. It is irrelevant whether it is compensated or not (c.f. Condition 2. in Baumol and Oates 1988, 17–18). It is very likely that people in the original position have to consider issues like what is right or wrong, good or bad, what is wanted and what is not wanted. Even though they could not get any definite or precise solutions, they can form general guidelines and principles for these kinds of issues.

Considerations of production-pollution trade-off in context of justice might include some kind of classifications about actions that are socially recommendable or unwanted. We can consider production-pollution problem as an inseparable optimization problem. In practice such policy evaluations are extremely important for the sake of efficiency. All rational environmental policy analyses must be based more or less on such trade-off evaluations. However, theory of justice can be used to restrict the set of acceptable solutions. Theory of justice may disqualify such solutions that are acceptable for utilitarian or libertarian, because these solutions are calculated to maximize the net benefits in a current economy with certain (unjust) policy actions or prevailing (unjust) socio-economic structures. For our purposes it is necessary to divide production-pollution problem to separate but interrelated sub-problems; production as such and pollution as such. Let us imagine that people in the original position make some lists about socially wanted and unwanted issues. They also have to make distinctions between socially preferable and avoidable actions.

If there were lists of socially wanted and unwanted things, we might find that socially wanted items are cooperation, trade, production, etc. Socially unwanted items could correspondingly be anarchy, stealing, pollution, etc. A pair of questions emerges: do people have an equal right to take socially preferable actions, and do people have an equal right to take socially harmful actions? An answer to the first part is obviously ‘yes’, but the second part is more problematic. We may try to figure out a list of fundamental rights. These rights get their justification from the fact that they are socially preferable. We also have to ask, can people have a fundamental right to make socially harmful things, for example, ‘do people have an equal right to kill anyone they like?’ Obviously the answer is ‘no’. List for fundamental rights might include an equal right to establish an enterprise and to start goods production. This means that firms and entrepreneurship are seen as socially desirable matters as such. A society should encourage entrepreneurship by proper incentive mechanisms.

Very likely this list of fundamental rights would not include socially harmful activities like killing, stealing, fraud, or causation of any other harm to others like emitting pollution. They may be unavoidable in some more or less exceptional real world cases, but they cannot be fundamental rights of anybody. Thus, basic principles are not against entrepreneurship, on the contrary. The point is that harmful activities as such (like pollution) should be discouraged by socio-economic institutions (even though they were side-effects of some desirable actions). Because of technological progress, production-pollution trade-off is not a zero-sum game, but economic incentive structures can affect to the composition of production (wanted)-pollution (unwanted) ratio. If people have no fundamental right to pollute, clean production methods are systematically favored against dirtier ones. The polluter pays principle is more consistent with sustainable development than the victim pays principle.

An externality producer is an (active) agent who causes harm to others. A victim of an externality is an (passive) agent who is used as a ‘tool’ to raise somebody else’s utility. If people had an equal right to pollute, it would be morally justifiable to establish a factory whose only purpose is to produce as much noise and dirty as possible. The business idea could be to collect payments from victims in exchange of causing less pollution. It would be possible to find an optimal solution to this problem (in the spirit of Coasian bargaining where it is irrelevant who has rights to whatever as long as property rights are well defined), but we should ask whether we want such a problem to exist at all. Analogously the right to pollution in more realistic cases with real production has this basic feature. If people have an equal right to produce but not to pollute, it implies polluter pays principle and liability to compensate harmful externalities at least in principle. In the real world cases this liability may not become real or to be compensated in full, but potential liability remains. This potential liability has concrete consequences.

Very often contractarian approaches disqualify utilitarian Pigouvian tax as a general solution. Calculation of benefits and costs case by case violates such contractarian principles like individual rights, liberty, strict Pareto improvement, strict compensation, unanimity, and justice (Buchanan and Stubblebine 1987, Rawls 1999). Utilitarian solutions are allowable only if contractarian principles are first fulfilled. We should notice that our reasoning does not represent mainstream liberal contractarian view about externalities. For example James Buchanan (1960) uses a classical example of smoking chimney. Assume that economic policy action is called for a correction of externality that is caused by smoke. According to Buchanan full compensation principle requires that previously-damaged individuals, who gain from a policy change, should pay some tax because of bettering their position. Also the owners of the firm should be compensated for the capital loss that will result. Because neglected external costs will tend to offset neglected external benefits both in market bargaining and democratic voting process, Pigouvian marginal divergences between private and social costs or benefits disappear. Due to this, it follows that there are no grounds for organizational or institutional changes. (Buchanan 1987a).

Our solution to this example by Buchanan is quite distinctive. First, there are no fundamental reasons why previously-damaged individuals who gain from a policy change should pay some tax because of bettering their position, on the contrary. According to our approach the unfair status quo situation has been corrected. Also the owners of the firm should not be compensated for capital loss that will result. They have unjustly benefited from unjust status quo in times where their potential liability has not been activated. Consequently, also Buchanan’s conclusion that there is no organizational or institutional change in the very beginning disappears. On the contrary, for the sake of justice, a policy change is necessary.

Another illustration of differences between approaches can be revealed from an example presented by Buchanan. He argues: “*Consider, for a real-world example, the closing of the Saltville, Virginia, plant of the Olin Corporation in the early 1970s as a result of governmentally imposed water-quality standards. Local residents were left unemployed; long-term contractual agreements between these persons and Olin were terminated, clearly a restriction on liberties. Presumably, defense of this governmental action was based on the alleged benefits of improved water quality to the* *general population of the whole country. It does not seem possible to stretch Rawls's principle of equal liberty to cover such instances. The liberties of some persons were restricted for the alleged benefits of others, and without compensation. There was no trade-off with other liberties, as Rawls might have required; the defense could only have been made advanced on utilitarian-efficiency grounds. To Rawls, this governmental action could only be classified as "unjust"*". (Buchanan 1987b, 261).

Contractarian approach developed in this paper provides distinctive reasoning and consequently, divergent conclusions for this case are derived: Because of the closing of the plant, local residents were left unemployed, and contracts between employees and the employer were terminated. However, this does not mean that equal liberties of contractual parties were intervened unjustly. In fact, they have no fundamental right to deteriorate the quality of water that belongs to the whole population. If they do, they violate the fundamental rights of all individuals to the good-quality water. Thus, interest groups of the plant had from the very beginning the potential liability for damages they had caused to others' fundamental property. The status quo, where they had escaped the liability was unjust, and they had no privilege to free use of water as a waste sink. On the contrary, they should compensate the rest of society. Compensation could have been implemented in the form of environmental taxes, fees, tradable permits, etc.

Defense of governmental action undoubtedly can be viewed as consideration of public benefits. Interestingly, it seems that in this special case a solution to the problem indicates that dynamic social contract approach is closer to utilitarianism than to liberal contractarianism. This is a coincidence only, since reasoning is quite distinctive. The dynamic social approach may take the advantage of benefit-cost –analysis, if only issues of rights and justice are first fulfilled. This may lead to distinctive solutions with utilitarianism.

For our perspective it seems that it is possible to stretch Rawls's principle of equal liberty to cover these kinds of issues after all. A dynamic social contract approach might argue that the unjustified liberties of some persons were restricted without compensation for the sake of justice. There was a trade-off between justified and unjustified liberties. Consequently, this governmental action could be classified as just, even though it accidentally was derived by the unjustified concern of public interests.

Thus, Buchanan's conclusions are just opposite to our view, even though both are based on contractarian doctrine. We come to different conclusions, because in our view an imaginary construction of the original position is emphasized, while Buchanan emphasizes democratic status quo political decision making process where the criterion of unanimity is hard to put into the practical use. In our view, the chimney owners, in the previous example, have no fundamental right to cause externalities to others; instead they are potentially liable for damages caused. If status quo institutions are unfair, it does not entitle to any compensation to polluters who have avoided so far their liability to the public, that is, to other individuals. Of course, some temporal subsidies for structural changes can be a matter of discretion because of contingent social, political, and economic reasons, but those options are not self-evident.

4.2 Nature and management of environmental goods

4.2.1 Goods

Different kinds of private property may be used with varying degrees of freedom. Depending on the properties of the natural resource, the owner is allowed to use it whichever way she wants, or she has a right to use it only in a particular way, or for a particular purpose. Properties of market and environmental goods are well-known.

For example, William Nordhaus (1992) puts it as follows: "*'Market goods' are goods for which the social costs and benefits are captured in market transaction - that is, those without significant externalities in consumption or production. For market goods, it is generally assumed that market prices properly measure both the marginal cost to producers and marginal valuation to consumers. Thus we can look to the changes in market process to place a value on the impact of rising scarcity.*" (Nordhaus 1992, 30-31.) *"'Environmental goods' designate goods for which the social costs and benefits are not captured in market transaction, or those with significant externalities in consumption or production"* (Nordhaus (1992, 34).

Consider first renewable natural resources. If there are no controls over markets, extinction of some renewable resources will likely occur. We may observe this as a historical fact. Most likely, the full social value of these resources, for the current or future generations, has not been captured by market prices. Renewable resources have complex relationships inside ecosystems, and whether they have substitutes is extremely uncertain.

Consider next nonrenewable resources. First, sustainable use of these resources is not possible, since their supplies are limited physically. They have no capacity to regenerate themselves. Secondly, the substitution of these resources has been proved to be possible. At least in theory, price dynamics for them follows the Hotelling rule i.e. their scarcity is captured by a market price (Nordhaus 1992). If some given resource has viable substitutes, it may resemble a market good in the sense expressed above. Many environmental goods could be treated like market goods, if only intratemporal and intertemporal externalities were internalized.

4.2.2 Regimes

Well functioning markets have a property to approach equilibrium, where individual actors' uncoordinated plans will be coordinated efficiently according to preferences of private actors. But as economic analysis shows, a private optimum differs from a social optimum whenever externalities are present. While markets may be superior for a few goods, they may be disastrous in the management of natural resources (Bromley 1991, 39). Markets are potentially superior when (1) factors of production and outputs are clearly divisible, (2) there are no public goods, (3) there are no externalities, (4) there are no irreversibilities, and (5) the structure of property rights is unambiguous, precise, and strictly covers all aspects of social intercourse. Because environmental goods do not meet these criteria market processes favor such private optima that diverge from social ones. It is questionable, whether spontaneous market evolution could ever find its ways to approach social optimum, which is a prerequisite for sustainable solutions. Involvement of public design is potentially superior in cases where (1) indivisibilities, (2) public goods, (3) externalities, (4) irreversibilities, or (5) unclear property rights are present. (Bromley 1991, 19-21.)

Institutions and property rights practices are human creations. How these systems are implemented, affects the use of all resources. According to Bromley (1991, 23-30), there are four possible resource management regimes, namely: (1) state property, (2) private property, (3) common property, and (4) non-property i.e. open access regimes.

Open access and common property regimes are not equivalent although they are sometimes used interchangeably. The open access regime allows a resource to be free for all without any duties. In a common property regime, however, behavioral rules are specified, more or less strictly, for a group of relevant actors. That is, there should be institutional checks, rules, and sanctions that define and guide the relationships of economic actors to one another with respect to the environmental resource.

State property regimes may vary from direct control and management to state-owned natural resources to leasing contracts with individual economic actors. In the latter case individuals do not own a resource, but these contracts give them some defined usufruct rights and ownership rights to benefit streams that the resource might produce. (Bromley 1991, 23.)

A private property regime is socially compelling as long as the interests of the owner are in accordance with the common interests of the public. The case for private property regimes, as with all property regimes, ultimately rests on judgments concerning its social desirability[15]. Private property regimes have well-known incentive, learning, and knowledge properties that make an owner to consider carefully her economic decisions about the use of a given resource. She has incentives to make decisions that serve her own best interests. When a social dimension is present, only few owners are completely free to use their property as they wish (Burrows 1979, 47).

Common property is private property for the group of co-owners. In a common property regime the individuals in the group have insider rights and duties against each other. Further, non-owners are excluded, so a common property regime has something very much in common with private property or state property regimes. The property-owning groups are economic or social units with some common interests, with some shared norms, and with some established authority system. These groups might consist of families, firms, organizations, municipalities, states, or ultimately the whole mankind including the future generations. The recognition of the rights of the individuals in the last group allows us to make a distinction to the traditional meaning of a common property regime. We may call it as an *intertemporal common property regime*.

'*The principle of property rights regimes*: An intertemporal common property regime says that ultimately all natural resources are owned by all people in all generations. An intertemporal common property regime dominates and includes all the other regimes in the sustainable market economy. It sets restrictions to the implementations of state property, private property, common property, and open access regimes.'

This may be derived from the original position where people behind the veil of ignorance require that no generation or economic actor is entitled to have an exclusive right to exhaust any natural resources without consent of others. The reasoning by a decision maker behind the veil of ignorance might go like this: 'Whatever is my generation, I want to be sure that I have enough good quality basic resources that are available for me for my unknown aspirations to develop myself and to increase my welfare according to my preferences.'

[15] It should be evident by now that social desirability in our approach means the full respect of equal rights of individuals. For instance, case by case maximization of social utility, where rights of some individuals are violated for the sake of public interest, is not approved.

If we use the original self, it is trivial for her to ask who owns resources; she owns them. As she divides herself into countless of realizations in different generations it is evident that there cannot be a single (mortal) realization who has an unrestricted right to use resources whatever ways he wants, because basically he is not the only owner of any resources. Intertemporal common property regime can be said to present the same idea that Arrow (1973) calls as 'asset egalitarianism.' It means that "*all the assets of society... are available as a common pool for whatever distribution justice calls for... It must be said... that asset egalitarianism is certainly an implication of the "original position" contract*" (Arrow 1973, 248).

This result is consistent with Rawls's principles, because it is rational to vest mortal people with temporal and restricted rights to the resources that are meant to serve all individuals, in all generations, on equal basis, and provide also future people with equal possibilities to make choices that they prefer in an immortal evolving society. That is, all the resources must be common property of mankind in some sense: (1) A private property regime may be implemented under an intertemporal common property regime by a society. An intertemporal common property regime sets rules – rights and duties – for the use of the private property. (2) A state property regime may be implemented under an intertemporal common property regime by a society. It tells that some economic actors or all the citizens have privileges, rights, or duties in respect to some resource. (3) An open access regime may be implemented under an intertemporal common property regime by a society. In this case a community sets no restrictions for the use of a given resource. (4) A common property regime may be implemented under an intertemporal common property regime by a society. It defines privileges, rights, or duties of the club members in respect to some resource.

Interestingly, we have derived the situation where methodological individualism has led us to the conclusions that may sound odd to libertarians and which sound like collectivism or altruism to many. We have got here by using liberal theory of justice where individuals have inalienable rights, which are balanced with social responsibilities. Thus, one might argue that individualism may give us instructions that look very social indeed. Also Charles McCann (2002, 6) strongly sees social aspects in liberalism: "*...[Friedrich A.] Hayek's brand of liberalism is more akin to one variant of modern communitarianism that it is akin to the libertarian strain of liberal though.*" Even though Hayek is often held as one of the most conservative libertarians, McCann demonstrates that Hayek's social philosophy presents, in fact, communitarian liberalism. Thus, we began from needs and rights of an individual and ended up with rules that benefit the whole social entity. An important point is that in individualism the standard of good is not some foredoomed social goal as such, which might require violation of some individual's rights, but the respect for individual wants and freedom in equal terms in relation to the rest of individual actors who constitute a society. It is a strict interpretation of equal rights and equal duties to social problems that makes individualism to be a very social approach after all.

4.3 The use of natural resources

Let us now consider some principles that should be followed in the use of natural resources in order to get ecological sustainability in the market system. Earlier, it was proposed that people in the original position would require sustainable development. What kind of rules these people would insist on for the use of renewable resources? Owing to uncertainty, decision makers behind the veil of ignorance are not able to attain unanimity about specific uses of natural resources. In fact, there is no need to accomplish a detailed contract about the use of resources. It is obvious that decision makers allow every generation to use renewable resources, but they do not allow a complete depletion of these resources, because all the potential benefits of them and associated biodiversity are unknown, and they may be revealed only due time and progress of science and knowledge. In ecology, harvesting of renewable resources is sustainable only to the point where the rate of natural reproduction is not exceeded. Because economic actors maximize the value, not the quantity of harvest, just institutions are needed to make predatory harvesting uneconomical.

'*Sustainability principle for renewable resources*: The original position indicates that no generation or interest group has an exclusive right to exhaust any of renewable resources. Every generation has an obligation to maintain the viability of the total stock of renewable resources.'

The aim of this principle is to secure biodiversity and genetic banks whose real value may be revealed only due the progression of knowledge. Therefore, there must be some rules in a just society that guarantee sustainability of renewable resources, but also rules that guarantee private profits or benefits for those who manage them with due care. In many cases the 'tragedy of commons' has emerged because of the open access regime. The open access regime gives an exclusive right to that economic actor who gets a catch. In this case, she or anybody else doesn't have to take any responsibility to secure the sustainability of the resource. Thus, some kind of an intertemporal common property regime is called for where the members of the management group have a right to their individual catches and profits but also duties with respect to use rates and maintenance of the asset. Because of natural evolution, new species emerge and old ones vanish. There must not be any responsibility for the current generation to try to change this natural law, and try to save all living species. The point, however, is that the current generation is not allowed to extract some given renewable resource in excess so that its genetic bank or intertwined ecosystem is lost forever. The current generation also may wish to destroy some biotic plague. It is possible that this might increase the well-being of the present, but also the future generations. However, genetic information of those 'harmful' populations should not be lost, since they may have some very useful properties that only wait their discovery.

What about nonrenewable resources? If these resources are used, then they will be used up sooner or later. It is clear that it is impossible to share nonrenewable natural resources equally between generations since we cannot know how many generations there will be and what the preferences of each generation are.

'*Sustainability principle for nonrenewable resources:* For nonrenewable resources the restricted finder's keepers is the only principle that is possible and consistent with the market system. Despite of that, every generation has an obligation to maintain viable total capital stock (man-made, social, human, and natural capital) which is able to create wealth and progress also in the future.'

Applications of Hartwick's rule may be relevant for these cases. Because of factor substitutability, it should not be a serious problem even if one or two of these resources are used up (Solow 1974). In other words, technological development or capital investments are able to compensate loss in these resources (Kneese and Schulze 1985). The use of nonrenewable resources is not a threat to sustainable development if (1) the resource is not indispensable for life of species, or (2) it does not create uninternalized external costs while it is used.

Sustainability analyses often are based on basic assumptions or beliefs about weak or strong sustainability (Grafton et al. 2001, Beckerman 1994 and 1995, Daly 1995, Jacobs 1995, Markandya et al. 2001, Neumeyer 1999). According to weak sustainability natural capital can be replaced in full extent by different kinds of man-made capital. Sustainability only requires that the total value of capital does not diminish. Strong sustainability argues that it is not possible to substitute all natural capital by man-made capital, but sustainability requires that natural capital must not decrease, because natural capital provides critical life supporting system to all human activities. Our approach does not get much out of this division of sustainability concepts (see O'Neill 2002, xxx–xxxi). Instead, we propose that the potential vitality of natural capital should not be destroyed. That is, the capacity to provide the full range of environmental services and goods should be maintained. (Daly 1995, Jacobs 1995). Now we can get a criterion to sustainability: whenever using environmental resources maintain the life supporting ecosystem, biodiversity, and the potential possibility to restore an environmental service or good at hand. Man-made and natural capital may be substitutes in some extent, but basically, they should be treated as complements. Barry (1996) argues that equality of opportunity means that if irreversible damage to the environment has been done, new opportunities must be created. Our approach strengthens Barry's view further, because here we may recognize just conduct of compensation principle which is an important principle in contract theory.

4.4 Economic growth

Economic growth and sustainable development are issues both for the present and the future. The crucial question is: 'is it possible to get both sustainability and continuing growth for indeterminate future?' In the following we describe some conditions that are required for co-existence of sustainable development and economic growth from the viewpoint of dynamic contractarian approach. Broadly speaking, there exist two contradictory views concerning desirability of economic growth and its effects on sustainable development: The first claim is that economic growth must come to the end, because economic growth irrevocably causes environmental stress that the environment cannot stand in the long-run. Growth will eventually lead to the collapse of the environmental system, and consequently, also to the collapse of the world economy. According to opposite views, economies can afford to environmental protection only if economic growth is strong enough. Thus, the protection of the environment requires economic growth. To aggravate, growth pessimists require minimization of economic growth toward zero or less, and growth optimists require growth maximization. Without doubt, growth pessimistic view is able to guarantee ecological sustainability, because zero growth steady state economy keeps the environmental pressure as constant or decreasing. In growth optimistic view problems that are related to strong economic growth are seen to be only temporary by their nature. Ecological sustainability is potentially endangered, because a belief that maximization of economic growth will solve all relevant problems in the end may be fallacious. Instead, contractarian paradigm suggests that growth must not be maximized or minimized; rather it should be optimal subject to relevant constraints that express principles of justice, liberty, and welfare. This is in accordance with welfare economics according to which welfare maximization requires that economic growth is optimal, not too low or too high. Thus, very likely optimal growth lies somewhere between the two extremes.

According to our interpretation of contractarianism, the problem is that growing economic activity may exhaust scarce renewable resources, and create pollution, which are a threat to the ecological system, and to the health and well-being of current and future generations. Economic growth as such cannot be a problem but mainly uncontrolled growth that is more than optimal, and a laissez-faire economy that has no societal or environmental checks.

It is possible to present the idea behind technological escape from limits to growth in terms of simple model of perfect competition: Assume that production creates pollution. Goods and associated costs are valued by market prices. The demand is derived from marginal benefits, and supply is derived from private marginal costs. Market participants find a private equilibrium at point where supply equals demand. The price level and quantity produced find equilibrium values by simultaneous maximization of consumers' utilities and firms' profits. This is not, however, a social optimum, because it does not take into account social costs. External costs of pollution may be shifted on to third parties, who do not necessarily take part in market exchange of the good at all. Social costs include external cost in traditional meaning, but if we consider sustainable development and sustainable economic growth, we should also include all potential costs on future generations. Only if we take into account all externalities, intratemporal and intertemporal, we are able to make conclusions that are consistent with sustainability requirements. Assume that social costs describe all relevant costs that sustainable development requires. Then, with given technology, if we internalize externalities, we reach an equilibrium where we should produce less and pay more, i.e. the proper price, of the commodity. However, development of technology may alleviate social costs. The new sustainable equilibrium can be found where price level is less and we are allowed to produce more without adding environmental stress.

Simon Kutznets set a hypothesis according to which inequality in the distribution of income and economic growth have an inverted U-shape relationship (Kuznets 1955). His hypothesis has been adopted into the environmental and natural resource economics, and it is known as the Environmental Kuznets Curve hypothesis (EKC). According to the hypothesis environmental stress will strengthen at low incomes, but due economic progress and wealth there will be a certain point after which environmental stress will decline even though economic development will continue. The environment is not at a high priority level in poor economies, because people are more interested in their every day subsistence. While economies get wealthier people are more interested also about other values. If necessities are satisfied other aspects like spiritual values, experience, adventure, health, and affection become more important. Citizens and consumers demand environmental goods more, and they insist environmental policy, and green products by firms. Also because technological development and economic progress go hand in hand, it becomes possible to adopt eco-efficient solutions into production and consumption.

The most important lesson of empirical research on the EKC is that it reveals that the coexistence of positive economic growth and the better environment must not be in contradiction. On the other hand, it also reveals that economic growth and environmental degradation may occur also in the long-term. (Agras and Chapman 1999, Dasgupta et al. 2002, de Bruyn et al. 1998, Ekins 1997, Grossman and Krueger 1995, Kaufmann et al. 1998, Mason and Swanson 2003, Munasinghe 1996, Roberts and Grimes 1997, Selden and Song 1994, Stern and et al. 1996).

Efficiency improvements mean that more output can be extracted from less input. Normally this would mean less environmental pressure. However, it is possible that efficiency improvement causes an increase in total resource use, because inputs become cheaper and much more attractive in relative terms. This phenomenon is known as rebound effect, or Jevons paradox. (Binswanger 2001).

With given technology, there exist physical boundaries for material throughput that the environment is able to take without collapse (Daly 1974). Throughput should be controlled using indicators, checks, and designing socio-economic institutions that would reflect the true value of the environment as accurately as possible. Some of Herman Daly's principles and ideas are straightforward and easy to adopt to our contractarian social market economy approach: Institutions should provide social controls for the goal of sustainable development. This should be done with minimum sacrifice of personal freedom, promoting microeconomic resilience and variability, and macroeconomic stability. There should be a safety slack between environmental stress and carrying capacity, and throughput should be kept below ecological limits. Daly's detailed program about control of population, physical wealth, and income distribution does not get support from contractarian approach without reserves, because individual rights are at stake, and we do not consider them here. Daly's approach does not give weight to the stock of human capital either (Hanley et al. 2001, 138).

Introduction of human capital and new growth theory give much more optimistic views about possibilities to get sustainable development with positive and sustainable economic growth. Rawls's second principle suggests some taxation and fair equality in education (Rawls 1999, 247). Even though free market liberalism often sees taxation as unjustified coercive action, we also have seen that liberal individualistic contractarian approach may justify, and even require the use of taxation for purposes that support fair and just individualistic plans in well-ordered society. We claim that a polluter pays principle is consistent with contractarianism. This simply means that all economic units that create harmful externalities should be liable at least in principle. Laissez-faire growth is in contradiction with the fundamental principles of individualism and contractarianism: While polluting freely, and shifting involuntary costs on others, polluters are violating equal individual rights. So the polluter pays principle should be honored in every stage of activity. If this was publicly recognized, economic actors would know that they have a potential duty to compensate the damage they have done, for instance in the form of environmental taxes. It is apparent that they would have to take into account the potential liability in their decisions from the very beginning. Also Daly's (1974) principle that institutions should support the possibility to tighten constraints gradually when necessary is consistent with this reasoning. The sources for economic growth and development may be found from technology and individual discoveries. Progress of knowledge and technology may allow growth to happen even though fixed constraints for material throughput have been set according to environmental facts. Theoretical research on endogenous growth reveals that environmental taxation may, in fact, give a new growth impetus to economy (Hettich 2000). To conclude, sustainable development means ecological sustainability, human progress and economic growth. Ecological sustainability is of the first importance, because it ultimately enables also human progress and economic welfare. Then, the crucial question is: 'are there any limits for accumulation of human capital?'

5 CONCLUSIONS

The purpose of this paper is to apply contractarian moral philosophy to the problem of sustainable development in the market economy: ‘What kind of rules would be derived for society by rational and self interested men behind the veil of ignorance?’ The principles for the basic moral order of ecologically sustainable market economy are introduced. For this purpose we propose auxiliary concepts of the original self, dynamic social contract, social market economy, and intertemporal common property regime. It is argued that sustainable development is a possible and reasonable goal for the market economy. In fact, we claim that this goal should be self evident in individualistic contractarian doctrine.

Few general principles for a sustainable market economy are recognized. They imply among others the following: The government should guarantee the fundamental equal rights and duties of present and future generations. The goal of sustainable development is inseparable part of the system of the market economy. Everyone has a right to clean environment and life supporting functions, and for example, polluter pays principle and environmental taxes are consistent with the basic moral order of ecologically sustainable market economy. This is a result that may seem odd to mainstream libertarians. Dynamic social contract obliges that the present generation does not transfer unreasonable costs to the future without due compensation. Renewable resources are critical to sustainable development, not nonrenewable resources. Biodiversity and large gene base should be maintained. In short, a society has an obligation to leave just institutions and natural resource base that potentially enable to satisfy necessities, and make possible individual and social development and progress. The adoption of sustainability principles suggest that the efficient functioning of the market economy is not violated in the long-run. On the contrary, it might even be the only rational choice that can be made in order to maintain successful features of the market economy. In the short-run competitiveness and employment may decline at least in those industries or fields of activities that cannot meet green requirements. However, the whole idea behind sustainable development is to change socio-economic structure toward sustainable basis.

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ESSAY II
Sustainable Development in a Simple Endogenous Growth Model

1 INTRODUCTION

Progress in technology and knowledge in less than one hundred years has been so immense that mankind has now tools to change the state of the world dramatically. It seems apparent that economic systems, social networks, behavioral codes, and the environmental change are more intertwined than ever. Even thought this is largely recognized among scholars, politicians, and public, there is disagreement about the desirability or direction of the current development and the role of economic growth in it. Globalization, liberalization of world trade, and economic growth divide opinions. For growth pessimists these phenomena mean ecological crisis, cultural disaster, and social inequality. For growth optimists these same tendencies mean possibility to limitless wealth creation, increasing welfare, proliferation of democracy, and more resources to environmental protection. Both these scenarios can be defended by reasonable arguments. The essence of the problem is not to discover the absolute truth that reveals the inevitable path either to misery or cornucopia. The more important question is whether it is possible to recognize the available choice set facing society, and to design such institutional basic structures that support balanced co-evolution of economic progress, social cohesion, and ecological sustainability.

The purpose of this essay is to show that the simple AK model structure is able to capture essential features of sustainable development. That is, we describe both conditions for a steady-state economy (stationary economy) (Daly 1974), i.e. ecologically sustainable economy with zero growth, and conditions for ecologically sustainable economy with positive economic growth. We also explicate effects of technology and human capital in sustainable growth process. The basic AK model can describe sustained economic growth. As we introduce pollution into the model, we get mixed results. Sustained economic growth may or may not be optimal depending on assumptions we make. If we assume that productivity is able to overcome disutility of pollution, it implies continuous economic growth. If we set a restriction on pollution growth, it leads to a steady-state economy. However, with pollution abatement technology the AK model can describe more plausible conditions for sustained economic growth. Many ecological economists think that this is still against the laws of thermodynamics, because material throughput is increasing with increasing capital. Such a solution to a pollution problem may be in contradiction with sustainable development according to steady-state economics. Yet, we can take one more step forward with the AK framework. We are to show that the AK model can produce ecologically sustainable development with a stricter assumption about thermodynamic throughput constraint. In this solution human capital becomes the ultimate engine of growth.

The essay is organized as follows. In chapter 1 we shortly review economics of sustainable development. In chapter 2 the basic AK model is introduced. In chapter 3 the effects of pollution are introduced. This chapter also discusses how pollution effects can be mitigated through abatement technology. In chapter 4 we reconstruct the AK model in order to emphasize the importance of human capital in sustainable development, in case where material throughput and ecology set the critical limits to growth process. As far as we know, this interpretation for the AK model has not been given elsewhere. Chapter 5 concludes.

1.1 A review on economics of sustainability and growth

In this section we provide a short review on economics of sustainable development. The purpose is to recognize the fundamental factors behind sustainability. An extensive evaluation of the state of the art with emphasis on measurement issues of sustainability is presented by Pezzey and Toman (2002). There are at least three economic forces that may offset limits to growth even though the given exhaustible resource is essential in production: technical change, the substitution of man-made capital for the exhaustible resource, and returns to scale. These basic results in presence of essential exhaustible resources to production are presented in three papers by Dasgupta and Heal (1974), Solow (1974), and Stiglitz (1974). In the first paper Dasgupta and Heal (1974) incorporate a substitute product (e.g. the sun) into the treatment of the optimal depletion of exhaustive resources. They demonstrate that the elasticity of substitution between reproducible inputs and exhaustible resources plays a crucial role in optimal extraction of exhaustible resources. Solow (1974) shows that an economy is able to achieve and maintain a constant level of consumption per capita. Earlier generations are entitled to extract exhaustible resources as long as they add the stock of productive capital according to the Hotelling efficiency rule. With exogenous technical change it is possible to find a path along which aggregate output does not decline. If technical progress is strong enough in comparison to a discount rate, positive and constant growth rates of consumption per capita are feasible, as is shown by Stiglitz (1974).

A contemporary paper by Daly (1974) argues for the necessity of the steady-state economy. In a steady-state economy physical stocks and population are constant, and material throughput should be as low as possible. Tahvonen and Kuuluvainen (1991) analyze neoclassical growth in the presence of stock pollution. The production is featured by substitution possibilities between capital and emissions. The existence of stock pollution decreases the optimal steady state level of capital and consumption. Beltratti, Chichilnisky and Heal (1993) extend the model of Dasgupta and Heal (1974) by adding a regeneration process for the natural resource. The growth model obeys the so-called Chichilnisky welfare criterion, where the utility function gives weight both on the sequence over finite periods and on the very long run. Utility is a function of consumption and the stock of environmental asset. The stock of resource is also an argument of the production function. Ecological dynamics for the environmental asset is described, and ecology is affected by economic activity. Selden and Song (1995) reexamine Forster's (1973) model to demonstrate theoretical basis for J curve for abatement and an inverted U curve for pollution.

Neoclassical growth theory implies that level of technology is an important factor in economic growth. Technology is, however, exogenous to the neoclassical growth model and reasons for and implications of technological progress are not analyzed profoundly. Endogenous growth theory[1] is an attempt to fill this gap. There are two ways to endogenize technological progress: breaking the assumption of diminishing marginal returns to capital, and making the rate of knowledge creation dependent on decision variables. Human capital is seen to be the essential engine of continuous growth. Human capital can raise productivity of other capital goods, like physical and social capital, but it also can be used to raise its own level and productivity.

Smulders (1999) highlights the essential features of environmental analysis in endogenous growth theory. The idea is that human capital is essential source of economic growth in the world where natural capital of the Earth is limited. Sustainable economic growth and development are possible only if energy and material flows can be managed so that critical ecological functions are not endangered. In other words, precondition for sustainable development is that energy and material flows do not exceed critical constant levels. Human capital can be used to get more out of these constant flows.

Endogenous environmental-economic growth models may contain functions for production technology, the environment (pollution, ecology or natural resources), and preferences. The environment can be taken into

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[1] It is generally recognized that Romer (1986) and Lucas (1988) launched the expansion in the new growth theory research.

account several ways in every function. Ecology can be described by biological population growth functions (forestry, fishery) where the use of the environment and the state of nature are combined. Because of regeneration they can, in principle, produce infinite flows of environmental services, if only they are managed with due care. Reserves for nonrenewable resources (oil, ores) decline by use, but they are not vital for ecology, and often substitutes can be found. Pollution can be combined into production, natural resources, ecology, and utility. Technology can be described in production function which may include national income, human capital, and consumption. Productivity may be affected by the state of nature, i.e. quality and availability of inputs, and health of labor. Preference function captures wants and needs of consumers who are supposed to live infinitely; sustainability requires that the society is viable to unforeseen future. Higher levels of consumption are preferred to lower levels, but also environmental and natural goods are valued.

In paper by Smulders (1995) it is analyzed how environmental policy affects welfare, consumption, and production if the quality of environmental asset is initially too low. He argues that even though physical limits (the laws of thermodynamics in extreme case) are taken into account, economic growth is possible in the long run. Sustainability is described as the condition where economic variables grow but natural variables remain constant in the long run. Knowledge is thought to be in the key role in creating economic value in the long run sustainable development. Knowledge is not constraint by entropy laws, but it is an inexhaustible resource. Smulders (1995) shows that if the environment is necessary input in the production process, improvements in initially too low environmental quality may boost economic growth.

In the model by Smuders and Gradus (1996) pollution is a byproduct of economic activity but it can be reduced by devoting some fraction of total output to abatement activities. The environment is seen to be essential for production and welfare. They conclude that positive economic growth can be sustainable if abatement activities grow fast enough in relation to capital accumulation. Thus, pollution stays constant or it may even fall if growing economy is able to produce a growing amount of abatement technology.

Bovenberg and Smulders (1996) compute analytically the effects of tightening environmental policy in the model where the environment is a renewable resource which is a public consumption good and a public input into production. Technological progress takes place in abatement technology, which is a stock variable. They conclude that stricter environmental policy may cause a decline both in the growth rate and the level of output as a first short-run effect, but in the longer term the growth of income may improve.

Stokey (1998) constructs three models of pollution which generate an inverse U-shape relationship between per capita income and environmental quality: a static model, an AK growth model with endogenous technology, and a growth model with exogenous technology. She finds that even though positive growth rate of consumption is possible, it is not optimal in the presence of pollution. Rate of capital accumulation decreases and finally it approaches zero, because ever stricter environmental standards reduce the rate of return on capital.

Elíasson and Turnovsky (2004) introduce a small economy model with a renewable resource sector. The renewable resource is used to purchase imports goods. The problem is how to optimally allocate labor between a natural resource and the final output sectors. The paper shows that a renewable resource sector of limited size can coexists with a growing sector with traditional capital.

Ramirez, Khanna and Zilberman (2005) present an endogenous growth model where ineffective input-use causes pollution. They examine conditions where balanced growth path is achieved while the environment is preserved thought investment in conservation capital. Conservation capital has a property that it both increases productivity of input-use and reduces pollution per unit of input and output. Conservation capital is private rival good which also has public pollution-reducing properties. Thus, there exist private incentives to invest in it at some extent.

In an extension of the Uzawa-Lucas –type endogenous growth model by Hartman and Kwon (2005) production of physical output generates pollution, human capital is produced by clean technology and physical capital can be used for pollution control. They find that in the long run it is optimal for human capital to grow more rapidly than physical capital, output and consumption. This indicates that pollution declines in the long run.

Endogenous growth theory has many interesting applications: how firms and consumers react to different economic and environmental policies, how environmental policy affects other policy sectors, how the environment is affected by different economic policies, what are the welfare effects in the short-run, middle-term, and in the long-run (Hettich, 2000, Pittell 2002). Endogenous growth theory seems to be suitable to analyze the conditions that are fundamental to sustainable development. Economic growth can be said to follow a path of sustainable development if both ecological viability is preserved and consumption is not decreasing in the long-run.

1.2 The meaning of sustainable development

The meaning of sustainable development may be ambiguous, but a general idea, as spelled in the report of Brundtland Commission, is clear enough:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987, 43). Below we explicate the meaning of sustainable development in this essay. We are not concerned here about intragenerational equity, but only about intergenerational aspects of environmental and man-made capital. It is quite generally held that there are potential contradictions between intertemporal efficiency and equity. Economic efficiency is not a sufficient condition for sustainability. If there are conflicts, many environmental economists see that equity overrides efficiency in considerations of sustainable development. (Hanley, Shogren and White 1997, Chapter 14) However, in a recent paper by Endress, Roumasset and Zhoun (2005) it is argued that optimal and intertemporally neutral growth is sustainable apart from whether resources are renewable or non-renewable. Ecological economics emphasizes the importance of environmental capital, especially ecosystems. In intergenerational context it means that all generations should have an access to the viable environmental resource base provided by ecosystems. The emphasis is thus different from earlier neoclassical treatments where intertemporal efficiency and non-declining consumption over time are of primary concern. Presently maximization of the non-declining utility function is often seen as an objective. In practice this means that utility function also includes environmental aspects, because people derive utility also from environmental services. In ecological economics also environmental conservation constraints are important. Their task is to secure some critical level of environmental capital in order to guarantee healthy functioning of the ecosystems, and transferring of potential environmental resource base to future generations. In this study sustainable development takes place if intertemporal utility can be sustained for infinity. In the present simple model framework it means that economic growth and critical ecological functions are sustainable. Sustainability of economic growth means non-declining growth, preferably positive rate of growth. Ecological sustainability means that environmental pressure stays constant or is declining; it does not permanently deteriorate critical ecosystems in the long-run.

1.3 Modeling scheme

We discuss and analyze four versions of the AK models. The purpose is to recognize critical conditions behind sustainable development. By sustainable development we mean that intergenerational utility is non-decreasing and economic growth is not a threat to ecological sustainability. In these kinds of models utility is derived from consumption which is derived from income that is generated by production which uses capital as input. Consequently, economic growth means utility growth as soon as disutility of pollution does not override benefits from growth.

The first model is the basic AK model. Utility is a function of consumption. Production follows AK technology. Income is used for consumption and investment. A control variable is consumption, and a state variable is physical capital. We discuss general features of these types of models. The purpose is to use it as a reference model to growth models where environmental pollution is taken into account. The basic model abstracts the ideal model where sustainable economic growth prevails. Capital is understood in broad terms, i.e. it includes human capital. This justifies constant returns to scale in production. In this kind of economy there exist no distortions to growth process. The problem is to select consumption path that maximizes intergenerational utility function. The basic model reveals that perpetual economic growth is possible along balanced growth path. There is no steady state where growth rates of capital or production were zero, but growth rates are positive and constant.

The second model is the basic AK model with pollution. Utility is affected by consumption and pollution. Production follows AK technology. Income can be used to consumption and investment. Pollution is a function of capital. A control variable is consumption and a state variable is capital. The purpose is to figure out optimal consumption path in presence of pollution. The model reveals that perpetual economic growth is optimal if productivity can overcome disutility of pollution, depreciation and time preference. On the other hand, with a strict ecological constraint continuous economic growth is cut down to zero. This result is in accordance with Stokey (1998). In this case, growth rates of capital and output are zero on balanced growth path, thus we have a steady-state economy.

Next the model is augmented with pollution abatement technology. Income can be used for consumption, investment and abatement. Pollution is a function of capital and abatement, control variables are consumption and abatement, and a state variable is capital. This model indicates that in ecologically sustainable economy, sustainable economic growth can only take place if the growth rate of abatement is strong enough. That is, perpetual economic growth is possible along a balanced growth path. This requires that growth rates of capital and abatement activities are the same.

The fourth model is a one sector model with man-made capital, pollution and human capital. We use this model structure to analyze the general case where human capital provides an engine for growth that does not pollute. Utility is a function of pollution and consumption. Production is a function of polluting physical capital and clean human capital. The new feature which makes difference to the prevailing AK models is that capital is now seen as an indicator of material throughput, and it is required to get a constant level in the long run. It is not allowed to be augmented infinitely because of laws of thermodynamics. Both capital inputs are essential to production. Income can be used for consumption and investments in human capital. Control variable is consumption. State variable is human capital. This model describes the ultimate conditions for sustainable development in case where ecological limits to growth are binding. In the previous AK models human capital to man-made capital ratio is constant along a balanced growth path. Even though the production technology obeys constant returns to scale for both human and man-made capital, the relative importance of human capital grows and relative importance of man-made capital will decline to zero. This result is consistent with Hartman and Kwon (2005). We are able to show that the simple AK structure is capable to capture this feature. Increasing human capital (knowledge) combined with a constant flow of capital services is able to produce sustainable economic growth with sustainable ecology; this means sustainable development as we define it. This is a new interpretation for the AK model. All other AK models suggest that sustained economic growth requires increasing man-made capital. To conclude, the model suggests that in the very long run human capital is essential for balanced economic progress and viable ecology; that is, sustainable development.

2 THE BASIC AK MODEL

The neoclassical model of Solow is generally considered to present a benchmark model of economic growth. The essential feature of growth dynamics is that the long run economic growth rate must eventually cease to zero. An exogenous technology shock can cause positive growth rates but they are only temporary. Neoclassical growth model reveals that technological progress is a key to sustained positive growth rates, but it stays exogenous to the model.

Papers by Romer (1986) and Lucas (1988) are considered as most influential to the boost of new growth theory research. The message of endogenous growth theory is that positive constant long run growth rates can be reached. In other words, the long-run steady-state growth rate must not converge to zero but it may stay at some positive constant. Also, economic growth may dependent on policy and other decision making variables of a model. (Grossman 1996)

Mainly there are three approaches to endogenous growth models. Sustained growth may be due to 1) the properties of the aggregate production function, 2) positive externalities between economic actors, and 3) investments in knowledge. In the AK model the production function is linear, and sustainable positive growth is achieved by the requirement that constant returns to capital stay over the subjective discount rate. Jones and Manuelli (1990) and Rebelo (1991) have made the AK models familiar as a simple approach to endogenous growth analyses. (Grossman 1996)

We use the AK framework to describe relations between sustainable development and economic growth. We closely follow Hettich (2000) and Aghion and Howitt (1998) for exposition, and Barro and Sala-i-Martin (1995) for studying the properties of the AK model. The following simple structure is used as a benchmark for later modifications.

2.1 Production

One specific form for neoclassical production function with diminishing marginal returns to factors of production can be expressed as

(1) $Y(t) = A(t)K(t)^{\alpha} L(t)^{1-\alpha}$, $0 < \alpha < 1$, where t is continuous time, $Y(t)$ is production, $A(t)$ is the level of technology, $K(t)$ is capital, $L(t)$ is labor, and α is the intensity coefficient of the relevant factor of production. From this we can derive the AK production function simply by setting $\alpha = 1$:

(2) $Y(t) = A(t)K(t)$,

where capital must be understood in broad terms. That is, capital includes both physical and human capital, which justifies constant returns to capital. K includes both physical man-made capital and human capital which highlights the importance of knowledge in the production process and welfare. Because technological progress and use of capital are tightly intertwined, it is theoretically possible to avoid diminishing returns. Also labor and population are included. This can be seen if we express the production function slightly differently. As explained below the productivity factor A is taken to grow with constant terms with physical capital. A simple formulation $Y(t) = A(t)K(t)$ is a special case of a more general form

(3) $Y = \overline{A} K^{\alpha} L^{1-\alpha}$,

where $\overline{A}$ is a common scale technology factor of an economy, L is labor, and α is the share of capital in final production.[2] It is assumed that $\overline{A}$ is a function of capital-labor ratio:

(4) $\overline{A} = A(K/L)^{\beta}$.

Substituting (4) in (3) we get

(5) $Y = AK^{\alpha+\beta} L^{1-\alpha-\beta}$.

A case of constant returns to broad capital, $\alpha + \beta = 1$, again produces $Y = AK$. Growth rate of output is determined by

(6) $\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + \frac{\dot{K}}{K}$.

The resource constraint for an economy is

(7) $Y(t) = C(t) + I(t)$.

where $C(t)$ is consumption, and $I(t)$ is gross investment. Capital accumulation follows the simple form:

(8) $\dot{K} = I - \delta K$,

where δ is depreciation rate of capital. In equilibrium investment equals savings

[2] From now on time indices are not presented explicitly in equations (if no ambiguity results) except at the first introduction of a variable or if we want to emphasize time dependency for some reason.

(9) $sY = I$**,**

which leads to

(10) $\frac{\dot{K}}{K} = sA - \delta$**.**

Growth of output is then

(11) $\frac{\dot{Y}}{Y} = \frac{\dot{A}}{A} + sA - \delta$**.**

The growth rate of output depends on both the growth rate of technology and also its level. Steady state growth requires that *A* is not increasing, because it would lead to explosive behavior. For this reason the level effect *A* is constant, and the steady state growth rate consistent with the AK model is

(12) $\left(\frac{\dot{Y}}{Y}\right)^{SS} = sA - \delta$**.**

Firms maximize profits *π(t)* by choosing optimal amount of capital *K* which is owned by households. Firms pay compensation *r* for use of capital. Profit function is then

(13) $\pi = AK - rK$**.**

From the maximization problem we get the first order optimality condition:

(14) $\frac{\partial \pi}{\partial K} = A - r = 0$**.**

Thus, interest rate equals with the real marginal product of capital. Households get capital income, *r*, which equals with productivity, *A*. Below we prefer to use *A* in a budget constraint for households.

2.2 Consumers

Consumers maximize utility, *U(t)*, by choosing consumption, *C(t)*, ($U_C>0$). The intertemporal utility function of representative consumer takes the following constant intertemporal elasticity of substitution (CES) form. It is also called the constant intertemporal elasticity of substitution (CIES) utility or constant relative risk aversion (CRRA) function:

(15) $U = \frac{C^{1-\theta} - 1}{1-\theta}$**,**

where θ is the inverse of the intertemporal elasticity of substitution between the current and future consumption, and $\theta \neq 1$. If $\theta = 1$ utility function takes logarithmic form:

(16) $U = \ln(C)$ **.**

(Barro and Sala-i-Martin (1995, 64–65) CES-utility function is able to produce steady-state growths paths with positive growth rates.

The budget constraint for an economy is

(17) $Y = C + I$ **.**

Income can be used to consumption and investment in capital.

2.3 The optimal solution

The optimal growth path is one that maximizes the present value of the intertemporal utility levels subject to the constraint that consumption plus investment must equal aggregate output. With the above structure the utility maximization problem for $\theta \neq 1$ becomes

(18) $$\max_{C} U = \int_0^{\infty} \frac{C^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt$$

subject to

(19) $\dot{K} = AK - C - \delta K$ **,**

(20) $K(0) = K_0 > 0$ **,**

(K_0 given),

(21) $\lim_{t \to \infty} K(t) \geq 0$ **.**

A, θ>0, θ≠1, ρ >0 is exogenous rate of time preference.

Because

(22) $U'(C) = C^{-\theta} > 0$ **,**

$U''(C) = -\theta C^{-(\theta+1)} < 0$,

U(C) is concave in *C*, thus the maximum of Hamiltonian with respect to *C* will occur as an interior solution. If $\theta = 1$ we have:

(23) $U'(C) = \frac{1}{C} > 0$ **,**

$U''(C) = -\frac{1}{C^2} < 0$.

The current-value Hamiltonian is

(24) $H = \frac{C^{1-\theta} - 1}{1-\theta} + \lambda(\ (A - \delta)K - C\ )$**.**

The first order necessary conditions for optimality are:

(25) $\frac{\partial H}{\partial C} = C^{-\theta} - \lambda = 0$,

(26) $\frac{\partial H}{\partial K} = \lambda(A - \delta) = \rho\lambda - \dot{\lambda}$,

(27) $\frac{\partial H}{\partial \lambda} = (A - \delta)K - C = \dot{K}$.

From (26) we get $\dot{\lambda} + (A - \rho - \delta)\lambda = 0$, which is homogenous linear first-order differential equation with a constant coefficient. The general solution to this differential equation is

(28) $\lambda(t) = \lambda_0 e^{-(A-\rho-\delta)t}$,

where λ_0 is undetermined constant.

According to (25) $\lambda(t) = C(t)^{-\theta} \Leftrightarrow C(t) = \lambda(t)^{-\frac{1}{\theta}}$, which can be used to find a general solution to an optimal consumption path:

(29) $C(t) = C_0 e^{\frac{1}{\theta}(A-\delta-\rho)t}$.

Because $C(0) = \lambda_0 * 1$, we may define $C(0) \equiv C_0$.
After taking logarithms of equation (29), deriving it through time, and rearranging, we are able to find the optimal growth rate of consumption:

(30) $\frac{\dot{C}}{C} = \frac{1}{\theta}(A - \delta - \rho)$.

In order to have positive growth rate we must require that productivity exceeds the sum of the rates of capital depreciation and time preference:

(31) $A > \delta + \rho$.

We also need a restriction for utility function in order to avoid unbounded utility. If we substitute consumption path (29) into the utility function (18) we get:

(32) $\frac{1}{1-\theta}\int_0^\infty e^{-\rho t}\left[C_0^{1-\theta} e^{[(1-\theta)/\theta](A-\delta-\rho)t} - 1\right]dt$.

This integral goes to infinity unless

(33) $\rho > [(1-\theta)/\theta](A - \delta - \rho)$.

Thus, restriction that ensures positive growth rate and bounded utility is

(34) $A > \delta + \rho > [(1-\theta)/\theta](A - \delta - \rho) + \delta > 0$.

To find time path for capital, substitute *C(t)* from (29) into $\dot{K}(t)$ in (19). This yields the following differential equation

(35) $$\dot{K}-(A-\delta)K=-C_0 e^{\frac{1}{\theta}(A-\delta-\rho)t}.$$

Multiplying by integrating factor $e^{-(A-\delta)t}$ and integrating the differential equation takes the form:

(36) $$\int \frac{d}{dt}\left[e^{-(A-\delta)t}K(t)+b_0\right]dt=-C_0\int e^{-\gamma t}dt,$$

where b_0 is some unknown constant of integration, and

(37) $$\gamma\equiv\frac{1}{\theta}(A-\delta-\rho)-(A-\delta)=(A-\delta)(\frac{\theta-1}{\theta})+\frac{\rho}{\theta}>0.$$

Solving (36) produces a general solution to *K(t)*:

(38) $$K(t)=\left[CONSTANT\right]e^{(A-\delta)t}+\frac{C_0}{\gamma}e^{\frac{1}{\theta}(A-\delta-\rho)t}.$$

To find the definite solution, we have to use a terminal condition:

(39) $$\lim_{t\to\infty}\left[e^{-\rho t}\lambda^*(t)K^*(t)\right]=0,$$

where λ^* and K^* are at optimum. Using (25), (29), and (38) in terminal condition(39) we get:

(40) $$\lim_{t\to\infty}\left\{\left[CONSTANT\right]+\frac{C_0^{1-\theta}}{\gamma}e^{-\gamma t}\right\}=0.$$

Because $\gamma>0$ the second term in brackets goes to zero. Thus, constant in equation (38) must be zero. Using (38) for *K(t)*, and the boundary condition $K(0)=K_0$ we get:

(41) $$K(0)=\frac{C_0}{\gamma}=K_0.$$

Thus, definite solution to *K(t)* is

(42) $$K^*(t)=K_0 e^{\frac{1}{\theta}(A-\delta-\rho)t}.$$

Using relation (41) we may express definite solution to optimal consumption path:

(43) $$C^*(t)=\gamma K^*(t).$$

The growth rate of consumption is constant as expressed in (30). Let us define this constant as

(44) $g \equiv \frac{\dot{C}}{C}$.

From the production function we may derive the equilibrium condition:

(45) $\frac{\dot{Y}}{Y} = \frac{\dot{K}}{K}$.

Because the production function is linear, we may conclude that also this equilibrium relation of production and capital is constant. From the resource constraint of an economy we may derive the long-run equilibrium condition for production and consumption:

(46) $\frac{\dot{Y}}{Y} = \frac{\dot{C}}{C}$.

Combine the above results to get

(47) $\frac{\dot{Y}}{Y} = \frac{\dot{C}}{C} = \frac{\dot{K}}{K} \equiv g$.

Using (27), (30), and (47) we find that growth rate of an economy and consumption to capital ratio are

(48) $g = \frac{1}{\theta}(A - \delta - \rho)$,

(49) $\frac{C}{K} = A - \delta - \frac{1}{\theta}(A - \delta - \rho)$.

Alternatively equation (49) can also be derived by using definition (37) and relation (43). Because there is no government, taxes, or externalities, the market solution and the socially optimal solution are the same.[3] The growth rate of an economy depends on A, δ, ρ, and θ as follows:

$$\frac{\partial g}{\partial A} > 0, \; \frac{\partial g}{\partial \delta} < 0, \; \frac{\partial g}{\partial \rho} < 0, \; \frac{\partial g}{\partial \theta} < 0.$$

Increase in productivity or level of technology, A, increases growth rate of an economy, while increase in δ, ρ, or θ lowers it.

If $A > \delta + \rho$ then $g > 0$; In an equilibrium path economic growth takes place if level of technology exceeds the sum of depreciation rate and rate of time preference. Correspondingly, if $A < \delta + \rho$ then $g < 0$. Lastly, if $A = \delta + \rho$ then $g = 0$, which is condition for the zero growth steady state economy.

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[3] We prefer the term 'socially optimal solution' to the 'central planner solution', because the latter may falsely give the impression that the centrally planned economies are superior to market economies in allocating resources efficiently.

There are no transitional dynamics in this model. The variables start at initial values of

(50) $K(0) = K_0$,

$C(0) = \gamma K_0$,

$Y(0) = AK_0$.

After which they continue at constant positive rate of growth, *g* (Figure 1).

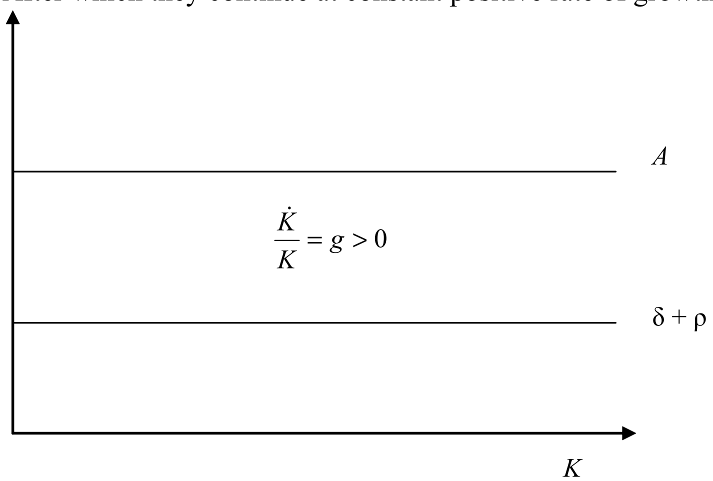

Figure 1 Growth dynamics of an AK economy

According to Mangasarian sufficiency theorem the conditions for the maximum principle are also sufficient for global maximization in this model. This is so, because *U(C)* is concave in *C* and $\dot{K}$ is linear in *C* and *K*. (Chiang 1992, 83–90, 214–217)

For $\theta \neq 1$:

$U_C = \frac{1}{C^{\theta}} > 0$, and $U_{CC} = -\theta \frac{1}{C^{1+\theta}} < 0$.

For $\theta = 1$:

$U_C = \frac{1}{C} > 0$, $U_{CC} = -\frac{1}{C^2} < 0$.

Thus, the utility is maximized rather than minimized. The basic AK model presents one of the simplest possible endogenous growth models. Endogenous growth is achieved because of constant returns to scale in production. Constant returns to scale can be justified if capital is understood in broad terms, i.e. capital includes also human capital. The model produces a long run balanced growth path along which growth rates of capital and output are positive and constant. If an economy is free of distortions the model can be said to present sustainable development in its simplest meaning.

3 AK MODEL WITH POLLUTION

3.1 Pollution function

Now we introduce environmental stress as a pollution function in the basic AK model. There are many ways to handle the use of the environment in growth models as discussed in the introduction. Several studies argue that relevant qualitative features do not change whether pollution is expressed as a stock or flow variable (e.g. Bovenberg and deMooij 1997, Smulders and Gradus 1996, Stokey 1998). We treat pollution as a flow variable. In principle, pollution flows may originate from a few different sources in the present AK model. In general we may express that pollution is some function of overall level of production, consumption, or use of capital:

(51) $P(t) = P[Y(t), C(t), K(t)]$.

Economic activity, *Y(t)*, in per capita terms, in absolute terms, or in terms of rate of growth, is often at the center of macroeconomic controversy about relationship between environmental and economic development. However, behavioral assumptions or specific forms of pollution function may be quite problematic if we want to capture controversial effects of economic growth on the environment. Controversy about the existence or generality of the Environmental Kuznets Curve is an example. Steady state economics suggests that increasing economic product (income) irrevocably increases environmental pressure and there are some definite limits to growth that must be met sooner or later. Contrary to this growth optimists claim that only higher income (economic product) makes it possible to take care of the environment and in practice there are no limits to economic growth. Because *Y(t)* is an aggregate measure of economic activity, its composition (qualitative and structural) is likely to change continuously. Economic product/income may be too rough an indicator to have a fixed relation to the environmental pressure at least in the long run analysis. If *Y(t)* were used as an originator of pollution, it should be decomposed.

Consumption, *C(t)*, is also known to cause environmental pressures in many ways. Consumption however may not also be the best candidate for a long run analysis, because consumption bundles, habits, tastes and fashion may change quite often and drastically. It is quite possible that environmental pressure will decline even though overall consumption expenses grow. This may be due to the change in a consumption bundle that includes less ‘dirty’ commodities and more ‘clean’ commodities. As is a case for economic product/income also *C(t)* should be decomposed.

Capital *K(t)* is used as an input to production. Use of capital creates income which is used for consumption. Because capital is the original source for production, income and consumption, it may be a suitable candidate for the main cause of pollution. Use of capital in production processes is in common parlance held as a main cause of an externality problem to exist and its pollution intensity is relatively high. In principle, externalities caused by production processes are relatively easy to identify and also polluter pays principle is applicable. Accumulated capital is the result of long run investments. Capital accumulation obeys relatively stable processes and production capacity does not vary as much as other economic fundamentals. Even though it is possible to decompose capital goods, it is not necessary in order to conduct reasonable analysis of interaction between economic activity and the environment. We adopt a simple, one to one relation between man-made capital and the flow of pollution. It is not unreasonable to assume that in general and in the long run it is true that increasing capital implies increasing environmental pressure. This assumption is also consistent with the established view that in fact pollution is an input to production (Cropper and Oates 1992). Also thermodynamic arguments support this point of view. In our analysis pollutions flows result from capital stock in one to one linear relationship:

(52) $P(t) = K(t)$.

3.2 Utility function

Utility is now supposed to be some function of consumption and flow of pollution:

(53) $U = U(C, P)$.

A specific utility function is assumed to have the CES structure:

(54) $U = \dfrac{(CP^{-\eta})^{1-\theta} - 1}{1-\theta}$,

where $\theta > 0$ and $0 < \eta < 1$ reveal that marginal utility of pollution flow is negative. This functional form enables that growth rates of consumption and pollution will be constant in equilibrium (see for example Barro and Sala-i-Martin 1995, 326–327).

(i) Case $\theta = 1$:

The utility function is $U = \ln(C) - \eta \ln(P)$.

The utility function reflects the standard properties that increase in consumption increases welfare, and increase in pollution decreases welfare.

$U_C = \frac{1}{C} > 0$, $U_P = -\frac{\eta}{P} < 0$, $U_{CC} = -\frac{1}{C^2} < 0$, $U_{PP} = \frac{\eta}{P^2} > 0$, and $U_{CP} = U_{CP} = 0$.

The determinant of the utility function is:

$$D = \begin{vmatrix} U_{PP} & U_{PC} \\ U_{CP} & U_{CC} \end{vmatrix} = \begin{vmatrix} \frac{\eta}{P^2} & 0 \\ 0 & -\frac{1}{C^2} \end{vmatrix}.$$

Define principal minors as

$|D_1| \equiv |U_{PP}|$, and $|D_2| \equiv \begin{vmatrix} U_{PP} & U_{PC} \\ U_{CP} & U_{CC} \end{vmatrix}$, where $|D_1| > 0$ and $|D_2| < 0$. It follows that the utility function is not strictly concave or convex.

Because of our requirements for sustainable development, we want to have a steady-state solution in which $\dot{C} > 0$ (possibly constant), and $\dot{P} = 0$, i.e. *P* is some constant. In order to maximize the utility function we have to require that $U = \ln(C) - \eta \ln(P) > 0$, which implies that $\frac{\dot{C}}{C} > \eta \frac{\dot{P}}{P}$ and $C > P^{\eta}$. Taking the total differential gives $\dot{U} = \frac{\dot{C}}{C} - \eta \frac{\dot{P}}{P} > 0$. If we differentiate with respect to time once more and apply the above restrictions, we get $\ddot{U} = -\frac{\dot{C}}{C^2}\dot{C} + \frac{\ddot{C}}{C} < 0$, because $\dot{C} > 0$ and $\ddot{C} \leq 0$ (zero if $\dot{C}$ is constant). This confirms concavity of the utility function with the above (sustainability) restrictions. Consequently, because the constraint $\dot{K}(=\dot{P})$ is linear in *C* and $K(=P)$, the maximum principle provides sufficient conditions for a local maximum.

(ii) Case $\theta \neq 1$:

Properties of the utility function are the following:

$U_C = C^{-\theta} P^{-\eta(1-\theta)} > 0$, $U_{CC} = -\theta C^{-\theta-1} P^{-\eta(1-\theta)} < 0$, $U_P = -\eta C^{1-\theta} P^{-\eta(1-\theta)-1} < 0$.

Signs of U_{PP} and $U_{CP} = U_{PC}$ are not as evident:

(55) $U_{PP} = -\eta C^{1-\theta} P^{-\eta(1-\theta)-2} [-\eta(1-\theta) - 1]$,

$U_{CP} = U_{CP} = -\eta(1-\theta) C^{-\theta} P^{-\eta(1-\theta)}$.

In order to guarantee that a solution is at maximum we must require that the utility function is jointly concave in *C* and *P*. That is, the determinant matrix has to be negative definite or negative semidefinite. The determinant is negative definite if the first principal minor is $|D_1| = U_{PP} < 0$ and the second principal minor is $|D_2| = U_{PP}U_{CC} - U_{PC}U_{CP} > 0$. From condition (55) we see that $U_{PP} \leq 0$ if $\theta \geq 1 + \frac{1}{\eta}$. Consequently, $U_{CP} = U_{PC} > 0$. With these restrictions together with linear constraint the maximum is guaranteed.

3.3 The market solution

The problem is to maximize the utility:

(56) $$\max_{C} \int_0^\infty \frac{(CP^{-\eta})^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt$$

subject to
$\dot{K} = Y - \delta K - C$
$K(0) = K_0 > 0$ (K_0 given).

Markets are not able to properly take into account the effects of pollution to total welfare. Pollution causes a negative welfare effect which is not taken into account in private production and consumption decisions. Market equilibrium is derived by choosing consumption. Pollution is an aggregate that a decision maker takes as given. Pollution affects utility, but consumers have no control over it. By choosing consumption we also get a time path for capital stock which produces a time path for a flow of pollution. The current-value Hamiltonian takes the form:

(57) $$H = \frac{(CP^{-\eta})^{1-\theta} - 1}{1-\theta} + \lambda[(A-\delta)K - C].$$

The first order conditions for optimality are:

(58) $$\frac{\partial H}{\partial C} = P^{-\eta(1-\theta)}C^{-\theta} - \lambda = 0,$$

(59) $$\frac{\partial H}{\partial K} = (A-\delta)\lambda = \lambda\rho - \dot{\lambda},$$

(60) $$\frac{\partial H}{\partial \lambda} = (A-\delta)K - C = \dot{K}.$$

Using the first order conditions (58) and (59) we can get the expression for the equilibrium growth rate of consumption:

(61) $$\frac{\dot{C}}{C} = \frac{1}{\theta}(A - \delta - \rho) + \eta(1 - \frac{1}{\theta})\frac{\dot{P}}{P}.$$

By using (2), (9), (52) and a budget constraint of a representative household in (56) we may derive the equilibrium condition for the growth path according to which:

(62) $$g \equiv \frac{\dot{Y}}{Y} = \frac{\dot{C}}{C} = \frac{\dot{K}}{K} = \frac{\dot{P}}{P}.$$

We see that growth rate of pollution is always positive, if the growth rate of an economy is positive.
Using equations (61) and (62) we can write economic growth rate as:

(63) $$g = \frac{\frac{1}{\theta}(A - \delta - \rho)}{1 + \eta(\frac{1}{\theta} - 1)}.$$

Using (62) and resource constraint of an economy we get

(64) $$\frac{C}{K} = A - \delta - \frac{\frac{1}{\theta}(A - \delta - \rho)}{1 + \eta(\frac{1}{\theta} - 1)}.$$

We may now compare this result to the basic AK model which represents the ideal case without any environmental problems or other distortions. Economic growth rate in (63), growth rate of consumption in (61) and consumption in (64) are identical with the basic model if the denominator is equal to one. Denominator equals to one either if $\eta = 0$ or $\theta = 1$. The first case is ruled out because it is assumed that $\eta > 0$. In the latter case the utility function approaches the form:

(65) $$U(t) = \ln C(t) - \eta \ln P(t).$$

We are interested in a case where $\theta > 1$. Then we see from (61) that positive growth rate of consumption always implies positive growth rate of pollution; according to (63) economic rate of growth is excessive compared to the ideal case, and (64) reveals that consumption to capital ratio is less than in the basic model.

3.4 Socially optimal solution

In finding socially optimal path to consumption we must fully take into account the effects of pollution through capital on utility. The current-value Hamiltonian to the maximization problem is the following:

(66) $$H = \frac{(CP^{-\eta})^{1-\theta} - 1}{1 - \theta} + \lambda[(A - \delta)K - C].$$

The first order conditions are

(67) $$\frac{\partial H}{\partial C} = P^{-\eta(1-\theta)}C^{-\theta} - \lambda = 0\,,$$

(68) $$\frac{\partial H}{\partial K} = -\dot{\lambda} = (A-\delta-\rho)\lambda - \eta C^{1-\theta}P^{-\eta(1-\theta)}K^{-1}\,,$$

(69) $$\frac{\partial H}{\partial \lambda} = (A-\delta)K - C = \dot{K}\,.$$

From above conditions (67) and (68) we can derive optimal rate of consumption, growth rate of an economy [(62), (69), and (70)], and consumption to capital ratio [(69), (71)]:

(70) $$\frac{\dot{C}}{C} = \frac{1}{\theta}(A - \eta\frac{C}{K} - \delta - \rho) + \eta(1-\frac{1}{\theta})\frac{\dot{P}}{P}\,,$$

(71) $$g = \frac{1}{\theta}\left(A - \frac{\eta\rho}{1-\eta} - \delta - \rho\right),$$

(72) $$\frac{C}{K} = A - \delta - \frac{1}{\theta}\left(A - \frac{\eta\rho}{1-\eta} - \delta - \rho\right).$$

We may now compare this result to the basic AK model which is our ideal economy without distortions. Pollution is an externality which decreases welfare. Denote market solution as 'ms' and socially optimal solution as 'sos.' In case where $\theta > 1$ we clearly see from (61) and(70) that $\left(\frac{\dot{C}}{C}\right)_{ms} > \left(\frac{\dot{C}}{C}\right)_{sos}$, $g_{ms} > g_{sos}$ [(63), (71)], and $\left(\frac{C}{K}\right)_{ms} < \left(\frac{C}{K}\right)_{sos}$ [(64), (72)]. That is, in unregulated market economy growth rates of consumption and production are higher than is socially desirable. Also consumption to capital ratio is less than is socially preferable.

Formula (48) in the basic AK model suggests that at the equilibrium growth path pollution growth rate should be zero in an undistorted economy. From pollution function (52) we see that

(73) $$\frac{\dot{P}}{P} = \frac{\dot{K}}{K}\,.$$

This together with the equilibrium condition (62) implies that growth rate of an economy should be zero. However, this requirement means that we have a steady state economy. In the present model only zero growth rate of capital can ensure constant environmental pressure.[4] In principle, there is nothing in the present model that forces economic growth rate to approach zero in the long run. The growth formula (71) allows perpetual positive economic growth as long as productivity is able to cover rates of externality, depreciation and time preference. Thus, the basic feature is that economic growth always means growth of environmental pressure. If we want to set an upper limit to environmental pollution, we also set an upper limit to economic activity. We can visualize these solutions by the following diagrams.

From (52) and (56) we get the phase line for $\dot{K}$. In Figure 2 we have a phase diagram for the AK model with constant positive growth rate. An economy starts from initial values K_0 and C_0 and then grows at constant rate along the $\dot{K} = \dot{P} > 0$ trajectory which lies below the phase line. As the phase diagram reveals there is no transition dynamics.

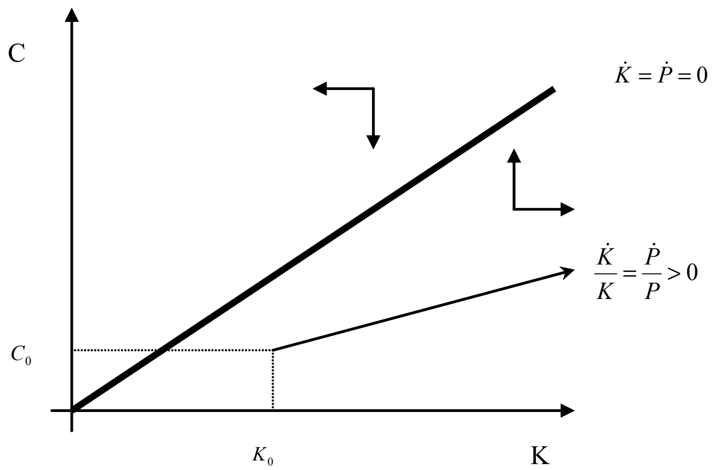

Figure 2 Phase diagram for g > 0

Figure 3 describes the case where a policy authority decides that there must be some upper limit for environmental pressure. An upper limit for the level of pollution, $\overline{P}$, presents also the upper limit for capital, $\overline{K}$, in this model. As an economy reaches its highest allowed value for pollution its growth rate is zero. Equilibrium is achieved at the point where $\overline{K}$ and the phase line intersect. Consequently, we have a steady state economy with constant flow of pollution and zero economic growth.

[4] Stokey (1998) constructs the AK model where sustained economic growth is not optimal in social planner's solution in the presence of pollution. Her analysis reveals that although sustained economic growth is possible it is not optimal. She has environmental policy in her model which explains this result.

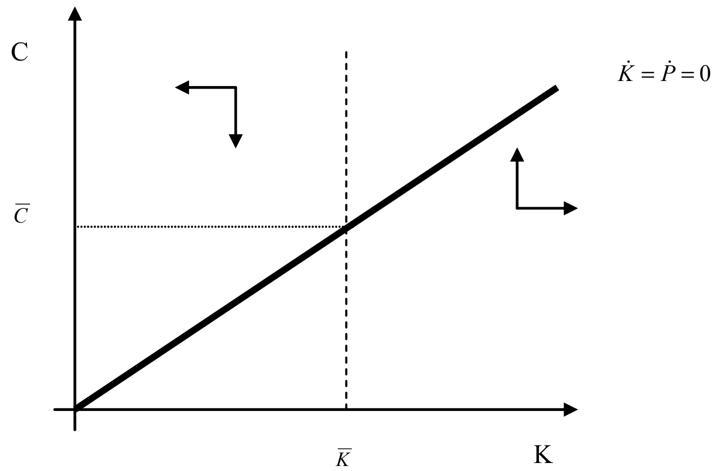

Figure 3 Phase diagram for g = 0

Pollution flow is assumed to be generated linearly by the use of capital stock in one to ratio (52). Thus, the relation between the growth rate of pollution and economic growth is also linear, $\frac{\dot{P}}{P} = g$. Equality of growth rates imply that income and pollution increase by the same fixed amount each time period. If there are ecological limits to growth the present AK model is not consistent with sustainable development. Because we are interested in the potential threat that economic growth may cause to sustainable development, we ignore the case where economic growth is decreasing, i.e. $g<0$. In a social solution development of technology factor A may raise growth rate temporarily, and consumption level (constant) permanently, but sustainability would still require the steady state zero growth economy. However, a steady-state economy may not be necessary for ecological sustainability if we introduce abatement technology into the model. This is done next.

3.5 AK model with pollution abatement technology

In order to reach for both ecological sustainability and economic growth the model can be augmented with abatement activity that reduces pollution flows. The AK approach is redundant to describe both sustainability and non-sustainability. Environmental policy can be analyzed conveniently in the AK approach but for our purposes it is sufficient to include only pollution flows and abatement technology into the socially optimal solution. By using the framework of Hettich (2000) and simple modifications we are able to show that sustainable development may be an achievable goal in the market economy, i.e. the simultaneous existence of balanced economic growth and pollution control is possible at least in theory.

Production technology is the same as above. Instead, the resource constraint of economy is slightly changed by the introduction of abatement activities, *Z*. The composite commodity can be allocated to consumption, investment and abatement of pollution flow.

(74) $Y = C + \dot{K} + \delta K + Z$ **.**

Abatement activities are treated in pollution function as follows:

(75) $P = \frac{K}{Z}$ **.**

Pollution flow results from the use of capital, and abatement technology can mitigate this flow; $\frac{\partial P}{\partial K} > 0$, $\frac{\partial P}{\partial Z} < 0$.

As previously we assume that consumers own factors of production. In socially optimal solution social designer takes into account harmful effects of pollution. Consequently, the problem is to choose optimal paths for consumption and abatement.

The problem is to maximize the utility:

$$\max_{C,Z} \int_0^\infty \frac{(CP^{-\eta})^{1-\theta} - 1}{1-\theta} e^{-\rho t} dt$$

subject to

$\dot{K} = Y - \delta K - C - Z$

$K(0) = K_0 > 0$ (K_0 given).

The current-value Hamiltonian is

(76) $H = \frac{(CP^{-\eta})^{1-\theta} - 1}{1-\theta} + \lambda[(A-\delta)K - C - Z]$**.**

The first order conditions are

(77) $\frac{\partial H}{\partial C} = C^{-\theta} K^{-\eta(1-\theta)} Z^{\eta(1-\theta)} - \lambda = 0$**,**

(78) $\frac{\partial H}{\partial Z} = \eta C^{1-\theta} K^{-\eta(1-\theta)} Z^{\eta(1-\theta)-1} - \lambda = 0$**,**

(79) $\frac{\partial H}{\partial \lambda} = (A-\delta)K - C - Z = \dot{K}$ **,**

(80) $$\frac{\partial H}{\partial K} = -\eta C^{1-\theta} K^{-\eta(1-\theta)-1} Z^{\eta(1-\theta)} + (A-\delta)\lambda = \lambda\rho - \dot{\lambda}.$$

With this information we can derive the Keynes-Ramsey rule for optimal growth rate of consumption:

(81) $$\frac{\dot{C}}{C} = \frac{1}{\theta}\left(A - \frac{Z}{K} - \delta - \rho\right) + \eta(1-\frac{1}{\theta})\frac{\dot{P}}{P}.$$

Marginal damage of capital use, Z/K, reduces growth rate of consumption. From production function we get $\dot{Y}/Y = \dot{K}/K$. From (77) and (78) we get the relation between marginal benefit and marginal cost of capital use:

(82) $$\frac{C}{K} = \frac{1}{\eta}\frac{Z}{K},$$

which implies that growth rates of consumption and abatement are equal; $\dot{C}/C = \dot{Z}/Z$. From resource constraint of an economy and from (82) we can derive that also growth rates of income and consumption must be equal; $\dot{Y}/Y = \dot{C}/C$. Now we can conclude that on an equilibrium path it must be true that growth rates of income, consumption, capital and abatement are equal and constant.

(83) $$\frac{\dot{Y}}{Y} = \frac{\dot{C}}{C} = \frac{\dot{K}}{K} = \frac{\dot{Z}}{Z} \equiv g.$$

On the other hand, from pollution function we get

(84) $$\frac{\dot{P}}{P} = \frac{\dot{K}}{K} - \frac{\dot{Z}}{Z}.$$

Because $\frac{\dot{K}}{K} = \frac{\dot{Z}}{Z}$ it must be true that along the balanced growth path growth rate of pollution is zero;

(85) $$\frac{\dot{P}}{P} = 0.$$

Thus, growth rate of abatement activity matches with the growth rate of capital, and nullifies pollution affluence of capital. Pollution emission flows stay constant. This result is consistent with positive economic growth and constant flow of pollution, i.e. a necessary condition for sustainable development, as we understand it, is fulfilled. Few remarks about the result can be noted. If $\dot{P}/P > 0$, then $\frac{\dot{K}}{K} > \frac{\dot{Z}}{Z}$; growth rate of polluting capital exceeds the growth rate of abatement activity, and pollution emission flows are increasing. This state of affairs, which mostly seems to be prevailing in contemporary economies, is not sustainable in the long run, and economic growth may be out of balance. If there is some upper limit for pollution flows, positive growth rate of pollution is not in contradiction with sustainable development as long as pollution flows stay below the ecological upper limit (or safe limit [see Munasinghe 2002]). In the long run, however, as ecological upper limit for pollution flows has been reached, sustainable development is not possible with positive growth rates of pollution, but growth rate of pollution must decline to zero. If $\dot{P}/P < 0$, then $\frac{\dot{K}}{K} < \frac{\dot{Z}}{Z}$; growth rate of abatement activity exceeds the growth rate of polluting capital. This case can describe the situation where restrictions to the environment become binding in the economy (due to strict environmental policy). The economy is out of equilibrium and pollution is excessive. Growth rate of pollution declines until it gets its long-run sustainability path where growth rate of pollution is zero. It is quite evident that declining growth rate of pollution must be consistent with ecological sustainability. Thus, in the long-run growth rate of pollution can be zero even though economic growth rate is positive as we may observe from (83) and (84).

It is worth to note here one important feature of the Environmental Kuznets Curve (EKC), which is an inverted a U-shaped relation between environmental degradation and per capita income. The curve suggests that environmental degradation first increases, reaches a turning point, and then declines as an economy becomes wealthier. It is common to measure the EKC by environmental impact per capita or per GDP. As Common (1995, 100–105) clearly illustrates this approach is vulnerable to incorrect conclusions about sustainability even though the EKC could be found to hold. If environmental impact per unit of income has some low positive limit, in the long run the total environmental impact will eventually grow without limit. In the AK model this means that $\dot{P}/P > 0$ and $\frac{\dot{K}}{K} > \frac{\dot{Z}}{Z}$. This is true, because every extra unit of production always produces an extra unit of pollution in net terms. In the present model we can see this by writing the long run relation so that environmental impact per unit of income is a positive constant; $\frac{P}{Y} = \varepsilon > 0$, in which ε is some (possibly small) constant. From this relation we can derive the condition $\dot{P}/P = \dot{Y}/Y > 0$, which is against the long run (sustainable) balanced growth path. Alternatively, we may write $\frac{K}{Z} = \varepsilon Y$. This relation implies that $\frac{\dot{K}}{K} - \frac{\dot{Z}}{Z} = \frac{\dot{Y}}{Y} > 0$, which is also against the long run balanced growth path. Sustainability requires that the total environmental impact has to have some upper critical limit that must not be exceeded in the long run so that $\frac{\dot{P}}{P} = 0$ holds.

To conclude, zero growth steady state economy is not needed in order to get sustainable development. Economic growth can be positive, but ecological upper limit for pollution must not be exceeded. Technological development can be used to convey environmental stress to the optimal level. In this model abatement technology makes sustainable development possible.

4 STEADY-STATE ECONOMY, AK MODEL AND SUSTAINABLE DEVELOPMENT

The above considerations of the AK models suggest a few insights about sustainable development. In the first model man-made capital causes pollution and there is no abatement technology available. According to the model perpetual growth is possible if productivity exceeds disutility of pollution, depreciation, and time preference. If we insist that there must be some ecological upper limit for pollution, the model produces a steady-state economy; maximization of intergenerational utility is restricted by a requirement that growth rate of pollution becomes zero, which is inevitable in order to avoid excessive marginal disutility of pollution. This means that also economic growth rate becomes zero. In order to escape stationary economy abatement technology was included. Abatement technology, which is a creation of man-made capital, is able to mitigate pollution so that sustainable development with constant positive growth rates is possible if only abatement and polluting activities grow at the same rate. This means that there is in no contradiction with sustainable development; polluting man-made capital can grow without limit if only capital is able to create new abatement at the pace which keeps environmental pressure constant. In short, growing man-made capital is able to clean its own dirty. Thus, according to this model also abatement technology can develop without restrictions. We should ask whether this is a realistic option for sustainable development in the real world. In the AK models capital is understood in broad terms, which means that also human capital is included into productive capital, K. It is a useful demonstration to reconsider the problem of sustainability from a different angle where emphasis is more explicitly on human capital, and the use of physical capital causes considerable environmental costs. This is done next.

4.1 Requirements for a steady-state economy reconsidered

Basically the AK model describes the economy which grows without limit. A steady-state economy requires that economic growth must become zero so that material throughput is constant. Thus, there seems to be a contradiction. The AK approach with abatement clearly provides an optimistic view on economic growth and technological progress. Formally, one can say that growth optimism relies on the balanced growth path condition: $\frac{\dot{K}}{K} = \frac{\dot{Z}}{Z} = g > 0$. Growth pessimists believe that on the balanced growth path condition $\frac{\dot{K}}{K} = \frac{\dot{Z}}{Z} = g = 0$ must hold, because it is more realistic to assume that abatement technology is not able to alleviate all relevant environmental stress in the long run. We consider man-made capital as a main source of pollution (throughput), and a constant rate of pollution as a requirement for ecological sustainability.

Ecological economics explicitly recognizes ecological limits. The paradigm of steady-state economics means development without growth (Daly 1999). According to ecological economics the macro economy is an open subsystem of the ecosystem (see Daly 1991, 1999). Man-made capital is created by using low-entropy matter-energy, and use of capital outflows high-entropy matter-energy. These flows define the scale or the total volume that affects the ecosystem. Abatement technology can be understood to be part of man-made capital. From this perspective, it is not plausible that man-made capital (whether productive or abatement capital) can grow without limit as in the previous model. Then, even though abatement technology is able to alleviate pollution there must be some upper limit for its use. On possible way to model this is to consider that the total man-made capital consists of dirty productive capital and less dirty abatement capital. Abatement expands the effective stock of capital, but it cannot keep throughput of growing capital constant in the long run. The total use of capital can be restricted to have some upper limit, i.e. the highest ecologically tolerable level of capital. Consequently, its growth rate can be hypothesized to cease to zero, and consequently, a balanced growth path implies that the growth rate of the total capital will decline to zero. This would imply that even though part of man-made capital can be used for abatement activities, its use cannot guarantee sustainability of economic growth. We are not analyzing this here, but next we perform a simpler demonstration where human capital is emphasized as the ultimate engine of growth. We put a strict steady-state economy restriction into the AK model in order to reconsider its implications for economic growth and sustainable development.

We partly follow Daly (1974) in requirements for a steady-state economy. However, we argue that requirement for a constant output may be misplaced. In a steady-state economy stocks of physical wealth or artifacts are constant. This can be interpreted to mean that man-made capital, K, must be constant and its growth rate is zero, $\dot{K} = 0$. Also population must stay at constant level. Thus, we may, as we have already done, to normalize its size to equal one. This implies that $\dot{L} = 0$. Throughput is the cost of maintaining stocks and it appears as pollution. Throughput is constant in the steady-state economy, $\dot{P} = 0$. According to Daly, progress in the steady state is due to increase in ultimate efficiency, *UE*.

(86) $$UE = \frac{Service}{Throughput} = \frac{Service}{Stock} * \frac{Stock}{Throughput}.$$

Using the same notation as above, this equation can be expressed as:

(87) $$UE = \frac{Y(t)}{\overline{P}} = \frac{Y(t)}{\overline{K}} * \frac{\overline{K}}{\overline{P}},$$

where $\overline{P}$ and $\overline{K}$ represent constant values for throughput (pollution flow) and capital stock. Stock of man-made capital causes pollution flow. Without capital there is no pollution. If growing capital inevitably means growing flow of pollution (throughput), as proponents of steady-state economy believe, we may justify the basic relation that we use. For the essential relation of throughput and capital in a steady-state economy, it may be redundant to assume the simple one to one relation to hold:

(88) $$K(t) = P(t).$$

Because we also require that this relation is constant in a steady-state economy, we can simplify the ultimate efficiency relation to be:

(89) $$UE = \frac{Y(t)}{\overline{K}}.$$

Because *K(t)* is the engine of growth in a steady-state economy, the constancy of capital means constant flow of services.

In the AK model this means that $\overline{Y} = A\overline{K}$ (constant) and $C(t) = \overline{C}$ (constant). For Daly (1974) progress in a steady-state economy means that ultimate efficiency can be increased either by maintaining stocks with less throughput, or getting more services from the same stock. These improvements are only temporary, because throughput will irrevocably increase in the long run due to gradual exhaustion of low entropy resources; Earth will dye sooner or later.

England (2000) presents a model that implies Daly's steady-state economy. The basic conditions are (i) relative scarcity of natural capital, (ii) general complementarity of human-made and natural capital in production, and (iii) exhaustion of opportunities to raise natural capital productivity through accumulation of technical knowledge. If these conditions are realized, a global steady-state economy will result. We briefly outline the model of England and then present alternative interpretation by preserving the AK structure. There should not be any confusion if we preserve England's original notation even though the interpretation is not quite the same. For England human-made capital, H (which does not denote human capital in our sense), is an aggregation of human population, L, and the value of human artifacts, K:

$H = K + \sigma L$, $\sigma > 0$.

It is hypothesized that human-made and natural capital are complementary in production:

(90) $Y = \min[AH, CN]$**,**

where N is the value of natural capital. A and C are positive coefficients (C is not consumption here). The model suggests that growth of human population ($\dot{L} > 0$), accumulation of produced capital goods ($\dot{K} > 0$), and labor saving innovation ($\dot{\sigma} > 0$) contribute the stock of human-made capital ($\dot{H} > 0$). Historic interpretation is that until the recent times H-capital was relatively scarce compared to N-capital:

$(H/N) < (C/A)$.

In other words, the production function has the form:

$Y = AH$.

In England's model the endogenous growth production function,

$Y = AK$,

is only a special case and not applicable to all time periods. Anyhow, this model is able to produce the same (endogenous growth) results as the previous AK models.

The nature and treatment of natural capital produces the difference, however. Natural capital stock is some function of the terrestrial stock of low-entropy energy and materials available for human use, M,

$N = N(M)$.

Because of the thermodynamic dissipation of energy and materials in economic use, a specific assumption is that:

(91) $\dot{M} = mY$**,** $m < 0$**.**

Any level of economic activity depletes the stock of natural capital sooner or later. Because $\dot{H} > 0$ and $\dot{N} < 0$, it is clear that there must be a moment when natural capital becomes relatively scarce and human-made capital becomes abundant. The scale of economic activity is constrained by the remaining stock of natural capital and its productivity. The condition $(H/N) > (C/A)$ holds, and the aggregate production function becomes

(92) $Y = CN$**.**

Under these conditions economic growth can only take place if $(\dot{C}/C) > 0$ or $(\dot{N}/N) > 0$. There is a dramatic change in a production technology; innovations are primarily due to natural capital. Basically, because C is constant, it is exogenous, and improvements in C can only be temporary. Obviously, it is not possible to augment natural capital without limit, non-renewable resources cannot regenerate themselves and growth dynamics of renewable resources imply that there are some limits for carrying capacities for biotic populations, and the size of the total ecosystem is restricted. Thus, no permanent positive economic growth can be achieved, but a steady-state economy is the ultimate result.

Human capital has no important role in a steady-state economy approach. If this neglect is unjustified, its explicit introduction changes a pessimistic view of a steady-state economy prominently. Production can be understood to be a function of both physical and human capital. Because a global economy is a subsystem of Earth, there are some physical limits to ecological and material systems that must be taken into account in designs of economic institutions. Progress in technology and human capital is capable to create more output from less input with less pressure. Steady-state economy proponents argue that this progress cannot be sustainable, because of growing entropy. Modern production is a mixed combination of physical capital, nonmaterial services, and new ideas. Even though there were strict limits to physical throughput, it is not at all clear, if there are any limits to new ideas. It is also less clear in what extent human capital can be a substitute to physical capital in the very long run. Currently, the knowledge content of production in industrial countries seems to be significant and increasing, which suggests that the same feature could hold also in the future. Consequently, new ideas could alleviate the problems. Also new ideas may some day find the way to harness efficiently the constant flow of solar energy in material and energy production. In that case the ultimate limiting factor for balanced economic growth on Earth is the age of the Sun. Steady-state economics approach suggests that because the input stock and throughput flow must be constant, also the flow of services must be constant. Next we reconsider the AK model so that throughput, stock limits, and human capital are taken into the consideration at the same time. We argue, contrary to the steady-state economy approach, that the service flow must not be constant along sustainable balanced growth path.

4.2 AK model and sustainability

In this section we reconsider the AK model, sustainability and a steady-sate economy. We adopt some steady-state principles, but retain the AK approach. Our treatment differs both from conventional steady-state economy and AK approaches. Growth of output is not fixed a priori as in the first approach, but population, capital, and pollution. Thermodynamic constraint is stricter than in the conventional AK approach. Human capital is more emphasized in our approach than in either of the conventional treatments. Even though the AK structure seems to be simple, human capital can be made more explicit. Before introducing steady-state economy requirements, we first represent some basic relations between inputs of production function. Output is produced by using two factors of production, capital *K* and labor *L*. The production function is

(93) $Y = K^{\alpha}(AL)^{1-\alpha}$,

where *A* represents efficiency or quality of labor. Because human capital is embedded in labor, we may write

(94) $H = AL$.

Thus, production can be expressed as a function of physical and human capital:

(95) $Y = K^{\alpha} H^{1-\alpha}$.

A proportion s_K of income is invested in physical capital. A proportion s_H of income is invested in human capital. The depreciation rates are δ_K and δ_H respectively. Accumulation of physical and human capital is then expressed as

(96) $\dot{K} = s_K Y - \delta_k K$,

(97) $\dot{H} = s_H Y - \delta_H H$.

We can find the equilibrium physical capital to human capital ratio by using the condition that both investments must yield the same rate of return.

Net marginal products for physical and human capital are:

(98) $\frac{\partial Y}{\partial K} = \alpha \left(\frac{H}{K} \right)^{1-\alpha} - \delta_K$,

(99) $\frac{\partial Y}{\partial H} = (1-\alpha) \left(\frac{K}{H} \right)^{\alpha} - \delta_H$.

In equilibrium net marginal products are equal. There may be more than one solution, but in a special case where depreciation rates are equal we get:

(100) $\frac{K}{H} = \frac{\alpha}{1-\alpha}$, which is constant.

With some manipulation we come back to the AK expression:

(101) $Y = K^{\alpha} H^{1-\alpha} = \left(\frac{H}{K} \right)^{1-\alpha} K = \left(\frac{1-\alpha}{\alpha} \right)^{1-\alpha} K$,

where $A = \left(\frac{1-\alpha}{\alpha} \right)^{1-\alpha}$.

Because the physical to human capital ratio is constant, both types of capital must grow at the same rate,

(102) $\frac{\dot{K}}{K}=\frac{\dot{H}}{H}$.

To conclude, human capital is the engine of growth in the AK model, but it is embedded into growing physical capital. At this stage we may reconsider Daly's relation of ultimate efficiency by introducing human capital into it:

(103) $UE=\frac{Y(t)}{\overline{P}_K}=\frac{Y(t)}{\overline{K}H(t)}*\frac{\overline{K}H(t)}{\overline{P}_K\overline{P}_H}$,

where $\overline{P}_H$ is normalized to one. In this relation output is produced by the combination of physical capital and human capital. The crucial assumption is that the presence of physical capital always creates flows of pollution and the throughput effect of the use of human capital is negligible ($\overline{P}_H$=1). There are no ecological limits to the use of human capital. This means that even though we keep physical capital and pollution flow constant, the output can be increased without throughput increase because of the properties of human capital.

If we require that the stock of capital must become constant in the long run, the above features of the AK model do not hold anymore. The physical to human capital ratio cannot stay at constant, because growth rate of physical capital is zero and growth rate of human capital is some positive constant. Even both capital goods are essential to production, the share of capital is diminishing and its relative share in production approaches zero.

Let us consider some features of the market solution. First we may derive some basic relations concerning the production function. The output is produced by using both physical and human capital, $Y=Y(K,H)$. We assume that both factors of production are necessary, i.e. $Y=Y(K,0)=Y(0,H)=0$. Under competitive conditions the marginal product of physical capital is the private rate of return, *r*, and the marginal product of human capital is the wage rate, *w*:

(104) $\frac{\partial Y}{\partial K}=r$, $\frac{\partial Y}{\partial H}=w$.

If we assume that production function is homogenous of degree unity in *K* and *H*, we have:

$Y=rK+wH$.

We assume that the specific form for the production function is Cobb-Douglas. Then the production function (95) can be presented as:

(105) $Y=AK^{\alpha}H^{\beta}$,

where constant term *A* is redefined and $\alpha+\beta=1$, i.e. constant returns to scale prevail (as in the basic AK model) but diminishing returns to both factors hold separately; $A, H, K, Y > 0$. Accumulation processes of physical and human capital are as previously:

$\dot{H} = s_H Y - \delta_H H$,

$\dot{K} = s_K Y - \delta_k K$.

Thus, the resource constraint of an economy is:

$Y = C + I_K + I_H$.

Income can be used for consumption and investment in physical and human capital. If we make a simplifying assumption that there is no depreciation for human and physical capital we get:

$\dot{H} = Y - I_K - C$,

$\dot{K} = I_K$.

The problem is to choose consumption and investment in physical capital subject to equations of motion of human and physical capital, and the relation $P = K$. As previously, the representative consumer is not able to take into account the disutility of pollution. The current value Hamiltonian is:

$\hat{\mathrm{H}} = U(C, P) + \lambda \dot{H} + \mu \dot{K}$.

The first order necessary conditions for optimality are:

(106) $C^{-\theta} P^{-\eta(1-\theta)} - \lambda = 0$,

(107) $\lambda - \mu = 0$,

(108) $-\dfrac{\dot{\lambda}}{\lambda} = \beta \dfrac{Y}{H} - \rho$,

(109) $-\dfrac{\dot{\mu}}{\mu} = \alpha \dfrac{Y}{K} - \rho$.

Conditions (107), (108) and (109) imply that in optimum:

(110) $\alpha \dfrac{Y}{K} = \beta \dfrac{Y}{H}$.

The marginal product of physical capital must be equal to the marginal product of human capital. This condition clearly tells that accumulation of physical capital (and corresponding pollution flow) is the fundamental feature of the growing "free" market economy. If we introduce ecological sustainability requirement, $\dot{P} = \dot{K} = 0$, a few consequences result. Because of condition (110), we know that the optimal level of physical capital is at the highest level that is ecologically tolerable. This can be denoted as $\overline{P} = \overline{K} > 0$ (constant). Constancy of physical capital also means that $\dot{K} = 0$. Then, net investment in physical capital is zero and only maintenance investments are conducted. Because $\dot{K} = I_K = 0$, the resource constraint of an economy is reduced to $Y = C + I_H$ which implies that $\dot{H} = Y - C$. Constancy of K also means that the production function becomes

(111) $Y = A\overline{K}^{\alpha} H^{\beta}$.

Because physical capital cannot be accumulated in a balanced growth path, we must modify the optimality rule. Because in a growing economy *K* is 'exhaustible' in relative terms, we may apply the Hotelling rule. If the Hotelling rule is satisfied the programme is intertemporally efficient. According to the Hotelling rule the asset markets equilibrate, if the following arbitrage equation holds:

(112) $\frac{\dot{r}}{r} = w$.

With the Cobb-Douglas function condition (104) gives:

(113) $r = \alpha \frac{Y}{K}$,

(114) $w = \beta \frac{Y}{H}$.

α and β represent elasticities of output with respect to the two factors of production. They present the share of national income accruing to the factors under competitive conditions. For the Cobb-Douglas case these shares are constant. With this knowledge we can derive from (111), (112), (113), and (114) that

$$\frac{\dot{Y}}{Y} = \beta \frac{\dot{H}}{H} = \frac{\dot{r}}{r} = w = \beta \frac{Y}{H} > 0,$$

which is constant. Because *K* is constant, and both *Y* and *H* grow the general condition (110) can only hold if the share of factors of production change. From (110) we may derive a requirement $\frac{\dot{Y}}{Y} = \frac{\dot{\beta}}{\beta} - \frac{\dot{\alpha}}{\alpha} > 0$. Because $\alpha + \beta = 1$, this requirement means that in the long run as $t \to \infty \Rightarrow \beta \to 1$ and $t \to \infty \Rightarrow \alpha \to 0$. Under these conditions the production function (111) becomes

(115) $Y = AH$.

With constant flow of pollution the utility function also can be reduced: $U = U(C, \overline{P}) = \overline{P}U(C/\overline{P}, 1)$. Because $\overline{P}$ is constant we may normalize and set it equal to one. Now we may write $U(C,1) = u(C)$. With these modifications our problem has reduced to

$$\max_C W = \int_0^{\infty} u(C) e^{-\rho t} dt,$$

subject to

$$\dot{H} = Y - C,$$

$$Y = AH,$$

$H(0) = H_0 > 0$ (given),

and the transversality condition.

This is a standard AK, or preferably AH, model with familiar properties. The main difference is that the AK model is not sustainable with thermodynamic assumptions, while the AH model may provide sustainable development.

It is interesting to note some inconsistency in England (2000) regarding thermodynamic restriction (91). Clearly, an economy that is based on production function (92) may be sustainable. To take an extreme example, consider a primitive economy of food gatherers. They can live in balance with their environment. This kind of an economy must belong to the larger class of economies that are based on production function (92) which is able to provide constant output, *Y*, endlessly. It is comparable to any biotic (animal) population that does not increase entropy. However, thermodynamic assumption (91) is in contradiction to the constant level of economic activity, no matter how it is produced. According to this kind of thermodynamic assumption all kind of economies provide entropy, which obviously is not a case. In fact, (91) assumes that Earth is a closed system, which cannot be sustainable, if any kind of action is taken. Earth, however, is an open system which obtains energy directly from the Sun. Consequently, restriction (91) cannot be valid in general. That is why we prefer $\dot{K} = \dot{P} = 0$ as a thermodynamic restriction. This condition also indicates "an economic Plimsoll line" that limits the scale of throughput (see Daly 1991).

In environmental economics literature pollution can be treated as a factor of production (Cropper and Oates (1992). England (2000) includes natural capital into his production function as expressed in (90). This is also case in our formulation of production function, which can be expressed as $Y = AP^{\alpha}H^{\beta}$.

We can abstract Daly's (1991, 44–45) principles of sustainable development to correspond to our approach as follows:

1. One stationary economy principle is to limit the human scale. In the present model we can imagine that (admittedly extremely complex problem) human population is at constant level, and it can be normalized to one which indicates that $\dot{L} = 0$.

2. Another principle says that technological progress for sustainable development should not be throughput-increasing. In the present model this can be expressed as $\dot{K} = 0$ and $\dot{H} > 0$.

3. Waste emissions should not exceed the renewable assimilative capacity of the environment. In the present model this means that $\dot{P} = 0$.

4. Nonrenewable resources should be exploited, but at rate equal to the creation of renewable substitutes. We assume that nonrenewable resources are

efficiently managed, i.e. economic rents are invested into substitutes (e.g. man-made capital, natural capital, or human capital).

To conclude, let us sum up the main points. According to Daly (1999) the paradigm or pre-analytic vision of steady-state economics is development without growth. Typically, this means that economic growth rate must become zero sooner or later. For example England (2000) demonstrates that in the long run economic growth cannot be based on human capital, but on natural capital. Because the size of human capital and natural capital is limited, an economy becomes a stationary economy. According to Daly (1999) neoclassical resource and environmental economics considers natural resources as no different from other factors of production. This means that basically there are no definite limits to continual growth. The AK model with abatement technology can be understood to present this case.

Thus, a steady-state economy approach says that positive economic growth is not possible in the long run because of laws of thermodynamics. On the other hand the AK model suggests that continual growth is possible. We provide a different explanation for sustainable development. We take laws of thermodynamics seriously and assume that there must be some physical (ecological) limits to economic growth. However, economic wealth is an output of different economic production processes that use physical capital, natural capital and human capital. Throughput effects of the factors of production differ. Consequently, it may not be legitimate to pronounce that all economic activity (measured as gross national product) is deteriorating. Because of different kinds of production methods and qualitative features, we cannot be fixed to a stationary economy a priori. Formally, Daly proposes that in the long run $\overline{Y} = Y(\overline{K}) \Rightarrow \overline{Y} = A\overline{K}$, which is constant. England proposes $\overline{Y} = Y(\overline{K}, \overline{N}) \Rightarrow \overline{Y} = A\overline{N}$, which is constant. Our proposition is, in fact, of the form of $Y(t) = Y(\overline{K}, \overline{N}, H(t)) = y(H) \Rightarrow Y = AH$, which allows a growing economy with ecological sustainability.

5 CONCLUSIONS

Sustainability of economic growth and the environment is a problematic issue. Quite clearly, the environment can flourish without the existence of people and their artificial creation, an economy. Nowadays, it is also quite clear to many that an economy cannot survive without the support of the services that the environment provides. Further, many believe that an economy is able to cause irreversible damage to the environment. If the environment looses its viability, it also means that an economy as a human construction will decay. It is very likely that human economy is not able to completely destroy life from Earth, but surely it is able to commit to suicide. That is, human civilization is able to destroy or degenerate itself by many ways, and one such possibility lies behind severe environmental crisis.

This essay discusses in a simple theoretical framework the fundamental forces behind sustainable development. Here we understand sustainable development as follows. First we require that the environment can maintain its viability. That is, the absolute environmental pressure, which is caused by economic activities, does not increase in the long run. At the same time we require that economic growth can be positive in the very long run. That is, economic growth and progress can take place even though the environment does not loose its viability. To us, the environment basically means its life supporting ecological systems (biomass, ecological functions, biodiversity, and renewable resources). Nonrenewable natural resources as such are seen to present inputs to economic systems. We assume that their use is not a threat to sustainability, if they are used according to economic principles that can guarantee sustainable economic growth (for example by applying relevant variants of the Hartwich and Hotelling rules).

We describe the fundamental issues of sustainable development by the framework of a simple endogenous growth model. First, we discuss the features of the basic AK model without the environment. The basic AK model is able to produce balanced economic growth with positive growth rate. A model shows a theoretical possibility for never ending economic growth. Second, we introduce the environment into the model. The model suggests that economic growth is possible in the long run as long as productivity of capital exceeds disutility of pollution. The AK structure makes this as a viable solution. If we set an upper limit for pollution, the economy becomes a stationary one. In the third model, we require that environmental pressure (flow of pollution) stays constant in the long run. The AK model is able to produce sustainable development in such a way that environmental pressure does not increase even though economic rate of growth is positive. Sustainable development requires that abatement activities (that are part of man-made capital) grow at the same rate as polluting man-made capital. In short, AK model is able to show conditions for sustainable development.

In the above model sustained economic growth is possible only if man-made capital is growing. This feature is controversial. Many ecological economists think that the laws of thermodynamics imply that sustainable development is inconsistent with increasing material throughput (man-made capital). Even though the AK model reveals that sustainable development is possible in theoretical terms, some may think that its theoretical description is not plausible, not at least in the very long run, where the laws of thermodynamics must become restrictive. In the fourth modification, we make a very long run thermodynamic requirement; the level of man-made capital must not exceed some critical level. That is, the throughput that is caused by man-made capital must be constant. We retain the AK structure but we introduce man-made capital and human capital as separate variables. The trick is that (polluting) man-made capital now presents flow of capital services and (non-polluting) human capital is a stock variable. Both inputs are essential to production. The model reveals that in the very long run the ultimate engine of ecologically sustainable economic growth is human capital. Many two sector models suggest that human capital and man-made capital should grow at the same rate, that is, their relative shares do not change in the long run growth process. This model suggests that the relative importance of human capital will grow while relative importance of man-made capital (and natural capital) will be negligible in a long run growth process. This is so even both (all three) capital inputs are essential to production, and all factors of production are needed in order to guarantee sustainable economic growth. To conclude, sustainable development is possible if flows of pollution and man-made capital services remain constant. In other words, growing human capital combined with constant flows of natural and physical capital services is able to maintain continuous economic growth. New discoveries may justify ever increasing human capital. In the balanced growth path growth rate of an economy is equal to growth rate of human capital. Thus, human capital can increase productivity of other forms of capital. For example, the use human capital together with natural capital may produce new discoveries that increase productivity, e.g. because of the progress in gene technology. Even though physical capital and flow of pollution have an upper limit the use of knowledge is still intertwined to capital (service flow). There are plausible visions that suggest that some day it is economic to replace the current use of fossil fuels by solar power and controlled nuclear fusion. Also visions about new material technology and biotechnology are promising. The progress in these and other fields, however, requires accumulation of human capital. Human capital is needed to utilize available backstop technology.

Endogenous growth theory seems to be quite promising endeavor for economic research of sustainable development. Long-run sustainability, endogenous management of change and relevant choice variables can be expressed in explicit form. Different co-evolutionary paths for economy, the environment, and ecology are captured in the same consistent framework. Endogenous growth theory suggest that even though we do not exceed the critical limits of ecology, we still may get economic growth and increasing welfare by investing in human capital that is the fundamental engine of growth.

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ESSAY III
The EKC Hypothesis Does Not Hold for Direct Material Flows

The EKC Hypothesis Does Not Hold for Direct Material Flows: Environmental Kuznets Curve Hypothesis Tests for Direct Material Flows in Five Industrial Countries

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This study analyses the Environmental Kuznets Curve Hypothesis (EKC) with direct material flow data from the USA, Germany, Japan, the Netherlands and Finland in the years 1975 to 1994. Recently, there has been a discussion concerning the relevance of the EKC hypothesis suggesting that also the intensity of material use should decline with income growth. The EKC hypothesis has not been widely tested with direct material flow data, and this paper presents one of the first attempts to do such tests. The results of the empirical hypothesis tests indicate that the EKC hypothesis does not hold in the case of aggregated direct material flows among industrialised countries like Germany, Japan, the USA, the Netherlands and Finland.

KEY WORDS: economic growth; environment; direct material flows; EKC hypothesis; sustainable development.

INTRODUCTION

It is generally recognised that economic growth and the state of the environment are related. However, evidence on the nature and strength of

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the relationship are controversial. There are few alternative theories about the relationship, which do not unambiguously describe how the environment and economies co-evolve in reality. Because of this ambiguity an empirical analysis is needed in order to reach a deeper understanding of real-world development. The purpose of this paper is to examine how direct material flow and economic growth are related in some industrialised countries: Germany, Japan, the USA, the Netherlands and Finland. The framework for the analysis is the so-called Environmental Kuznets Curve hypothesis (EKC).

Roughly speaking, there are two contradictory views about the co-evolution of the environment and the economy. Firstly, it is argued that, economic growth unavoidably degrades the state of the environment, since the growth of economic activity always requires the intensified material use of natural resources and the environment. On the other hand, it is often argued that economic growth is needed in order to create wealth and technological progress so that we can afford to the better environment, and the means to sustain it. The optimistic growth view argues that individuals prefer environmentally friendly goods as their incomes rise. Consequently, people demand more environmental goods and services, which politicians and firms have to take into account in their decision-making processes. Thus, politicians take public action that should be beneficial to the environment, while firms try to attract customers with "green" products and production methods. As the latest technology enables corrective action, the empirical analysis should reveal the progress of indicators for environmental stress as compared to economic growth.

THE ENVIRONMENTAL KUZNETS CURVE HYPOTHESIS AND ITS ECONOMIC RELEVANCE

The EKC Hypothesis

The EKC hypothesis states that economic growth degrades the environment at low-income levels, but as incomes rise, harmful environmental impacts decrease (see also Kuznets, 1955). According to the theory, the environment is initially exploited to a great extent in order to create economic growth. When an economy becomes developed enough, the environment becomes more valued, and technical progress makes it possible to create wealth with less environmental stress. This means that one should be able to find a level of income after which the negative environmental impacts of economic activity will decline.

The EKC is a special case of the general Income-Emission Relation (IER). Before the early nineties the IER was said to be more or less linear: higher incomes meant more production and consumption, and it was presumed emissions would rise. This relation caused considerable concern as rich countries showed high growth rates and environmental pressures increased. Figure 1 represents a stylised view of the EKC hypothesis. The resource degradation or pollution is shown as initially increasing and then eventually declining. The EKC is also known as an inverse U-curve.

We may expect that developing countries are located on the left-hand side of the EKC curve (for instance, point A or D). On the other hand, we should expect that rich industrialised countries lie on the right hand side of the EKC (e.g., point E or C). The development of an immaterially oriented information society might provide a complementary explanation for the social behaviour behind the environmental Kuznets curve (see Jokinen et al., 1998).

Economic theory has shown that standard assumptions concerning the marginal values of consumption, pollution, and abatement costs may lead to the inverted U-shape relationship (Hettige et al., 1997, p. 1; see also Munasinghe, 1995, 1996). Thus, theory can provide critical pre-conditions for successful environmental policy making. Of course, actual turnaround

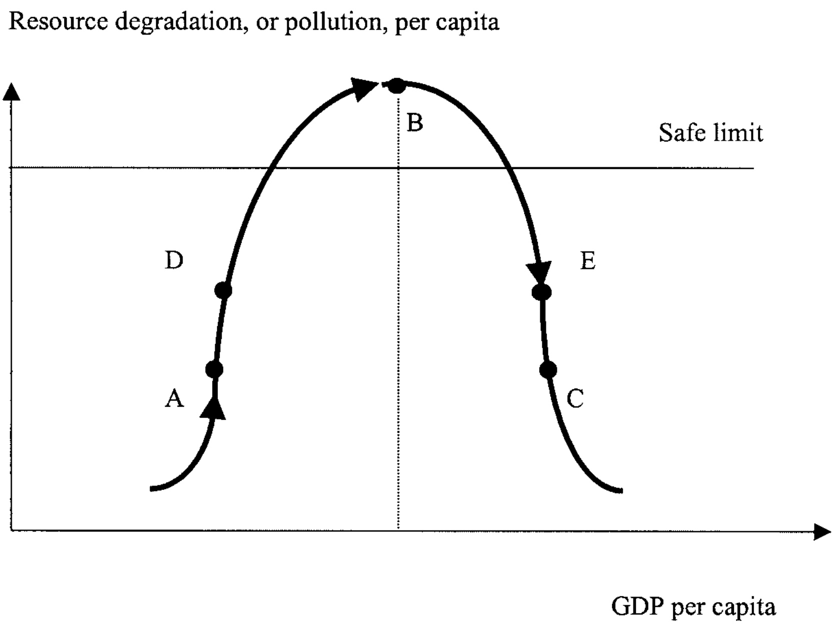

FIGURE 1. Environmental Kuznets Curve.

points depend on the relative magnitudes of the underlying parameters. On a general level, structural changes in the economy and effective environmental policy are important factors behind pollution abatement. Some authors have claimed that if the EKC hypothesis holds, economic growth is not at all a threat to global sustainability, and there are no environmental limits to growth (see for example the discussion in Stern et al., 1996, p. 1151). We can call this an extreme interpretation of the EKC. This means that environmental policy is not needed because economic growth leads to a better environment in the long run. This, of course, means that the EKC phenomena should be strong and wide enough, so that critical life supporting systems survive.

However, so far the EKC relationship has only been observed for certain substances, which could also be due to substitution processes among different natural resources. If the ecological system is to be sustained, some reduction of material flows may be necessary (Femia et al., 1999, pp. 3, 17). That is why the EKC hypothesis has to be tested also with aggregated direct material flow data. Direct material flows consist of ores, minerals, limestone, peat, stone material, wood, fossil fuels, cultivated resources produced in agriculture and market gardening, forest by-products and fisheries output.

Arguments for the EKC hypothesis are as follows (Ekins, 1997):

(a) Due to competition, firms continuously search for cost reduction in their activities. As a consequence, more efficient uses of inputs may also cause less pollution.
(b) The stages of economic development may be identified as follows: from subsistence economy to agricultural society, from agricultural society to industrial society, and from industrial society to service society and to information society. In this last stage environmental stress should have been considerably lessened by more efficient and new kinds of production methods. It is argued that the development process is independent of the policies practised in the economy. Rather, the stages of development depend on capital formation and the accumulation of human capital in an economy. This is a crucial argument behind the extreme interpretation of the EKC hypothesis.
(c) When environmental problems become so severe that they are real threats to human health and cultural values, environmental protection including new environmental laws, prohibitions and sanctions are to a large extent demanded by the people.
(d) At low income levels, consumers prefer commodities that are inexpensive but often environmentally unfriendly. As soon as incomes reach a higher level, the demand for environmentally friendly goods increases considerably. This means that the government and the market must respond to the new wants and needs of consumers.

Ekins (1997) has also presented the EKC hypothesis counter-arguments:

(a) Market agents make their purchase decisions according to the price information in the market. Often environmental resources are underpriced even though they have social value. This means that environmental resources are used uneconomically, that is, they are extracted in excess of what is environmentally sustainable. If this is the case, it is optimal for an individual economic agent to use environmental resources in excess, even though the use of resources is not optimal for the whole economy. As a consequence, resources are often exploited beyond a safe limit (see Fig. 1). For instance, biodiversity may be lost if environmental goods are not priced according to their full social value.
(b) Economic development in general may indicate that the use of the environment decreases in relation to economic growth. However, in absolute terms, the state of the environment may still degrade.
(c) Environmental policy is just one sector of the political arena. It is not guaranteed that an efficient environmental policy will be practised.
(d) Especially, in developing countries some environmental problems are real threats to health. The existence of environmental degradation does not mean that people were not willing to pay for a better environment. Instead, the limiting factor is budget constraints. Increasing demand for a better environment due to a rising income may also be harmful to the environment. For example, "eco-tourism" affects the original flora and fauna of holiday destinations. It is also questionable whether all the environmental requirements of the people and environmental campaigners are favourable to the environment. Very often, environmental cost-benefit analyses are based on local conditions and evaluations, and they may underestimate the interests of the poor and future generations, and the complexities of ecosystems.

The EKC Research

The EKC hypothesis analysis was introduced by Grossman and Krueger (1992), and Shafik and Bandyopadhyay (1992). Since then EKC-literature has expanded (Panayotou, 1993; Holtz-Eakin & Selden, 1995; Selden & Song, 1994; Tucker, 1995; Suri & Chapman, 1998; Dijkgraaf & Volleberg, 1998; Stern, 1998; de Bruyn et al., 1998; Rock, 2000, and others).[1]

Typically, in EKC research a quadratic or cubic function is analysed in reduced form in order to test the inverted-U shape of the EKC. In the basic setting a selected environmental indicator is explained by per capita GDP. In some studies additional explanatory variables are also included in the models: investment shares, electricity tariffs, per capita debt, political rights, civil liberties, and trade indicators among others (Agras & Chapman, 1999, pp. 268–269). Typical research problems are the following:

(1) Does pollution follow the Kuznets curve, first rising and then falling as income increases?
(2) At what income level does the turning point occur, if there is any?
(3) Do all pollutants follow the same trajectory?
(4) Is pollution reduction in industrialised economies primarily due to structural change, or to regulation? (Hettige et al., 1997, p. 1)

Grossman and Krueger (1995) analysed the relationship between per capita income and various environmental indicators. They estimated a reduced form of regression model. Their study covers four types of indicators: urban air pollution, the state of the oxygen in river basins, the fecal contamination of river basins, and contamination of river basins by heavy metals. They used panel data from Global Environmental Monitoring System (GEMS) covering both developed and developing countries in the years 1985–88. They found no evidence that environmental quality deteriorates steadily with economic growth. Rather, for most indicators, economic growth brings an initial phase of deterioration followed by a subsequent phase of improvement. The turning points for the different pollutants vary, but in most cases they are reached before a country reaches a per capita income of $8,000. However, their study does not strongly support the EKC hypothesis either, since other forms for the relationship were also recognised in their study. Ekins (1997) reported various EKC studies and evaluated their results. On the basis of Ekins' study it is possible to calculate (crude) critical threshold levels for air media, water media and land media. On the aggregate level the recognised turning points are as follows: for air media $10,824 on average[2] (range $3,000–35,400), for water media $6,443 (range $1,400–11,400) and for deforestation $3,051 (range $823–5,420).

Although turning points can be recognised for some environmental media, the EKC hypothesis cannot be generalised as a scientific fact at the global level (see Stern et al., 1996). This critical condition also holds for developed countries. Ekins (1997) has concluded that there are no deterministic forces that save or destroy the quality of the environment. Economic growth does not have an intrinsic mechanism, which automatically degrades or improves the environment. This means that we need an active environmental policy. Thus, we cannot be sure whether sustainable development is achieved or endangered through rising per capita GDP.

Even though, the EKC hypothesis is valid in some countries, we cannot conclude that there will not be any social or economic problems for their environmental resource management. This is because the EKC analysis is typically executed with environmental indicators only, and it does not include an analysis that takes into account an ecological carrying capacity or sustainability. Some economists like de Bruyn, van den Bergh, and Opschoor (1998) claim that the EKC hypothesis can be used for testing sustainable growth, which is defined as the rate of economic growth that does not lead to growth in emissions. They maintain that a sustainable growth rate can be calculated for each type of emission and country, based on estimated parameter values (de Bruyn et al., 1998, pp. 171–172). This approach has one deficiency: because emissions are indicators only, one can not assess, with this framework, whether or not emissions are optimal for sustainable growth. A deviation from the optimal sustainable growth path means that there may be too much, or too little emissions. This is clear, if different emissions and economic activities are interlinked so that some of them are substitutes or complements. If that is the case, it is impossible to conclude that growth or decrease in some emissions indicates unsustainable or sustainable growth. In addition, ecological carrying capacities are crucial factors behind ecological sustainability.

Even so, it is apparent that searching for empirical evidence of the existence, or non-existence of the EKC, is extremely important in providing background knowledge for the implementation of successful economic policies. If the EKC hypothesis does not hold the conclusion must be that there exist serious market or government failures and, consequently, harmful external problems in an economy. The EKC analysis can be seen as a basic empirical test for the proper functioning of an economy containing environmental goods. In this sense testing the EKC hypothesis can provide empirical information about the need for a more effective environmental policy. By considering selected five industrial countries we expect that the empirical evidence should support the EKC hypothesis, because they are among the most developed industrial countries. For the available data we apply time series regression models where the explanatory variable is GDP per capita and the dependent variables are direct material flows (also measured per capita). The purpose is to analyze whether the EKC hypothesis holds for direct material flows in these countries. In short, we analyse, if a pattern of economic growth can be observed that is consistent with a materials' consumption scenario, as regards the EKC hypothesis (see, e.g., Ayres, 1998, p. 5; de Groot, 1999).

THE MODEL AND DATA

The Model

In our study the basic form of an EKC model in statistical form is the following third order (or cubic) polynomial:

$$\ln DMF_t = \alpha + \beta_1 \ln GDPCAP_t + \beta_2 (\ln GDPCAP_t)^2 + \beta_3 (\ln GDPCAP_t)^3 + \varepsilon_t, \qquad (1)$$

where
$\ln DMF_t$ is the direct material flow per capita in logarithmic form;
$\ln GDPCAP_t$ is the real gross domestic product per capita in logarithmic form;
α is a regression constant, and β_1, β_2 and β_3 are regression coefficients to be estimated; ε_t is error term; t is time, t = 1975, . . . , 1994.

We can get this long run equilibrium function for direct material flows from autoregressive distributed lag (ADL) model as follows. In general an ADL model takes the form:

$$\ln DMF_t = \tau + \tau_1 \ln DMF_{t-1} + \varphi_1 \ln GDPCAP_t + \gamma_1 \ln GDPCAP_{t-1} + \varphi_2 (\ln GDPCAP_t)^2 + \gamma_2 (\ln GDPCAP_{t-1})^2 + \varphi_3 (\ln GDPCAP_t)^3 + \gamma_3 (\ln GDPCAP_{t-1})^3 + \varepsilon_t \qquad (2)$$

where it is assumed ε_t's are independent and identically distributed with zero mean and variance σ^2, and $|\tau_t| < 1$. In the long run we may assume that variables' deviations from their equilibrium values will diminish. Then we may write: $\ln DMF_t = \ln DMF_{t-1}$, and $(\ln GDPCAP_t)^i = (\ln GDPCAP_{t-1})^i$, i = 1,2,3. After rearranging we get the function (1) where long run response parameters are defined to be: $\alpha = \tau / (1 - \tau_1)$, $\beta_1 = (\varphi_1 + \gamma_1)/ (1 - \tau_1)$, $\beta_2 = (\varphi_2 + \gamma_2)/ (1 - \tau_1)$, and $\beta_3 = (\varphi_3 + \gamma_3)/ (1 - \tau_1)$.

The polynomial model allows us to determine the number of turning points of the direct material flow as a function of GDP (as well as the turning points themselves). The cubic form allows at most two turning points, which is sufficient for us, as our main interest is to study the existence of one turning point.

If $\beta_3 \neq 0$, there would be (at most) two turning points for the material flow curve. On the other hand, if $\beta_3 = 0$ and $\beta_2 \neq 0$, the material flow curve will have one turning point. The sign of β_2 determines if that point is a maximum ($\beta_2 < 0$) or a minimum ($\beta_2 > 0$). The case of an existing maximum point would be supportive to the EKC hypothesis. The testing is based on statistical regression analysis. The case of an existing maximum point would be supportive to the EKC hypothesis. This implies that to test the EKC hypothesis a one sided hypothesis test H_0: $\beta_2 \geq 0$ against H_1: $\beta_2 < 0$ must be performed. At the same time the existence of more than one turning point is checked by testing the hypothesis H_0: $\beta_3 = 0$ against H_1: $\beta_3 \neq 0$.

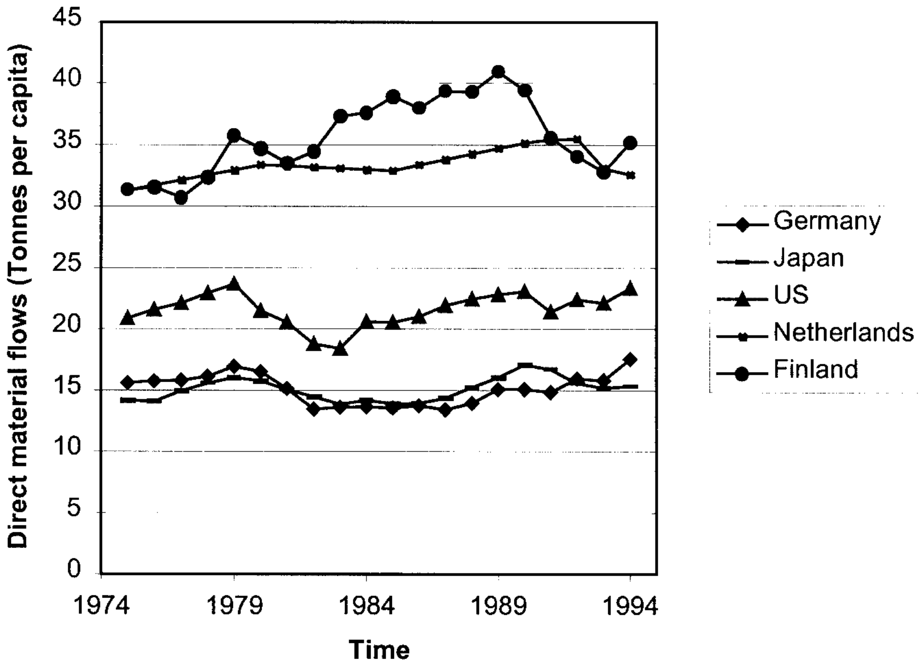

FIGURE 2. Direct material flows for Germany, Japan, the United States, the Netherlands and Finland, from 1975–1994.

Model specifications for individual countries were defined in two stages. Firstly, the relationship between direct material flow per capita and GDP per capita was determined by stepwise regression analysis. Secondly, the time series models were estimated by corrective autoregression procedures using Prais-Winsten and Cochrane-Orcutt methods to correct autocorrelation problems. The regression models reached in this way are reported below for each country under consideration.

Data Sources

The direct material flow data was collected from Hoffrén (Hoffrén, 1999, p. 52) and Adriaanse et al. (Adriaanse et al., 1997). Real GDP per capita (in 1985 international prices) data from 1975–1992 was collected from Penn World Tables (Summers-Heston data) and the rest of the data for—i.e., years 1993 and 1994—is based on the authors' own calculations.

EMPIRICAL TEST RESULTS

General Views

In Figure 2 direct material flows for Germany, Japan, the United States, the Netherlands and Finland between the years 1975–1994 are presented. One can see that during the whole period Finland and the Netherlands have the highest direct material flows per capita whereas the USA, Japan and Germany have significantly lower levels. Next the results of the regression analysis for each of the countries involved are presented.

Germany's EKC Curve?

In Figure 3 the direct material flows (DMF) and GDP per capita are presented as an index time series for Germany.

Figure 4 presents a scatter diagram of German GDP per capita and the direct material flows per capita. When running the regression it can be seen

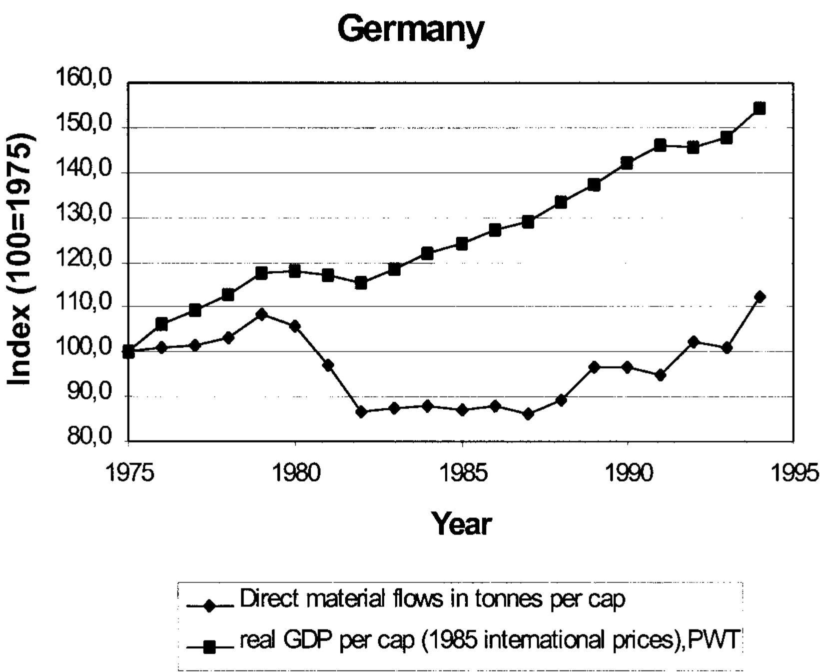

FIGURE 3. Germany: index series of GDP per capita and direct material flows per capita.

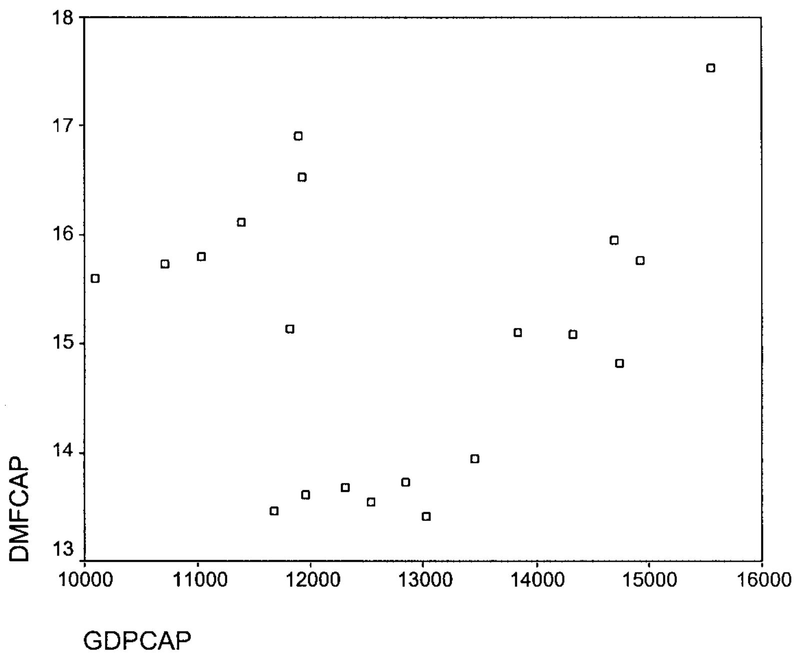

FIGURE 4. Germany's scatter diagram: GDP per capita and the direct material flows per capita.

that the 1st and 3rd order terms are not statistically significant. After using Cochrane-Orcutt method and statistical diagnostics, we end up with the following quadratic regression model:

$$\ln DMF_t = a + b_2(\ln GDPCAP_t)^2, \tag{3}$$

where the regression model is estimated as shown in Table 1.

TABLE 1

	Coefficient	Standard Error	t	Significance
b_2	0.099	0.024	4.14	0.0008
a	−6.409	2.218	−2.89	0.011
R-Squared	0.517			
Standard Error	0.038			
Durbin-Watson	1.290			

The significances reported are, as commonly, based on two-way tests. For the one-way EKC hypothesis H_0: $\beta_2 \geq 0$ against H_1: $\beta_2 < 0$, the statistical significance is $1 - 0.0008/2 = 0.9996$. Thus the null hypothesis of no EKC is not rejected.

So no statistical support for the Environmental Kuznets Curve hypothesis was found when the German data was analysed. The data implies strongly the opposite. Statistically the model is quite good but the problem of autocorrelated error terms did not disappear totally, as the Durbin-Watson test statistic shows. It is quite clear from the results and Figure 4 that for the material flow curve there exists a minimum rather than a maximum level during the period under consideration. The DMF curve seems to be a U type and therefore it can be considered as inverse EKC-type.

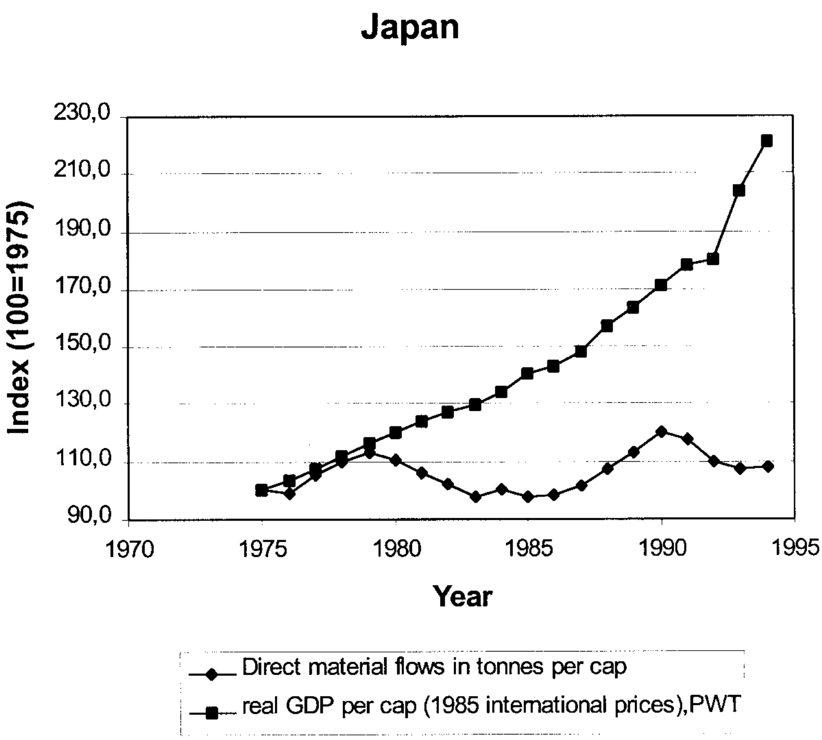

FIGURE 5. Japan: index series of GDP per capita and direct material flows per capita.

Japan's EKC Curve?

In Figure 5 the index time series of Japanese data is presented.

Figure 6 presents a scatter diagram for Japanese GDP per capita data and the direct material flows per capita.

The 1st order term is not statistically significant. After using the Cochrane-Orcutt method, the following model and statistics were found (see Table 2):

$$\ln DMF_t = a + b_2(\ln GDPCAP_t)^2 + b_3(\ln GDPCAP_t)^3. \quad (4)$$

Based on the regression model, empirical evidence supporting the EKC hypothesis in the Japanese case cannot be found. The no-EKC hypothesis is retained at significance level 0.962. Again there is the problem of autocorrelation; in addition the coefficient of determination R^2 of the model is quite low; therefore caution is advised concerning the scientific implica-

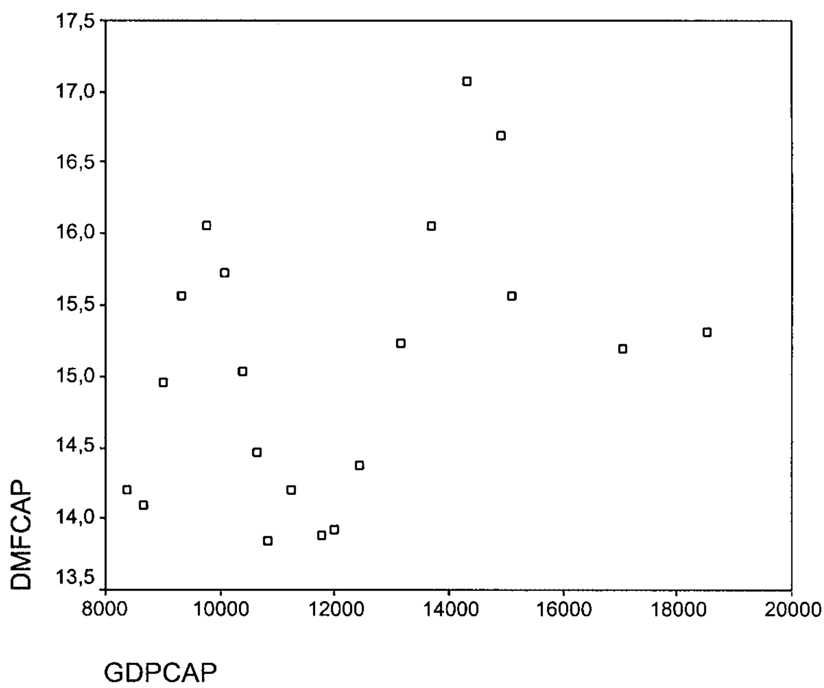

FIGURE 6. Japan's scatter diagram: GDP per capita and the direct material flows per capita.

TABLE 2

	Coefficient	Standard Error	t	Significance
b_2	2.224	1.173	1.90	0.077
b_3	−0.152	0.080	−1.89	0.078
a	−67.68	37.01	−1.83	0.087
R-Squared	0.198			
Standard Error	0.038			
Durbin-Watson	1.019			

tions of this model. From Figure 6 it seems evident that the material flow curve has three turning points, which would imply that a 4th degree polynomial model would be more appropriate. However, this was not used, as our concern in this study was to test the EKC hypothesis.

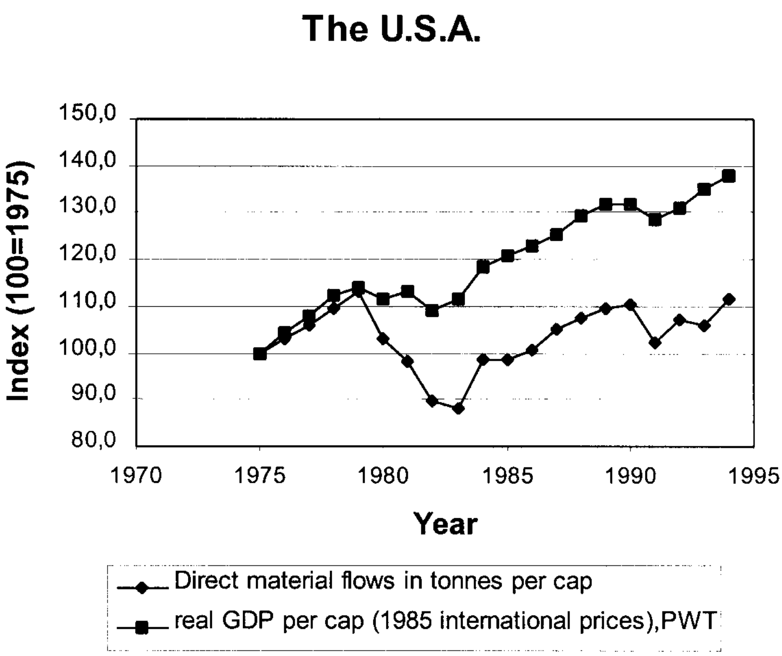

FIGURE 7. The USA: index series of GDP per capita and direct material flows per capita.

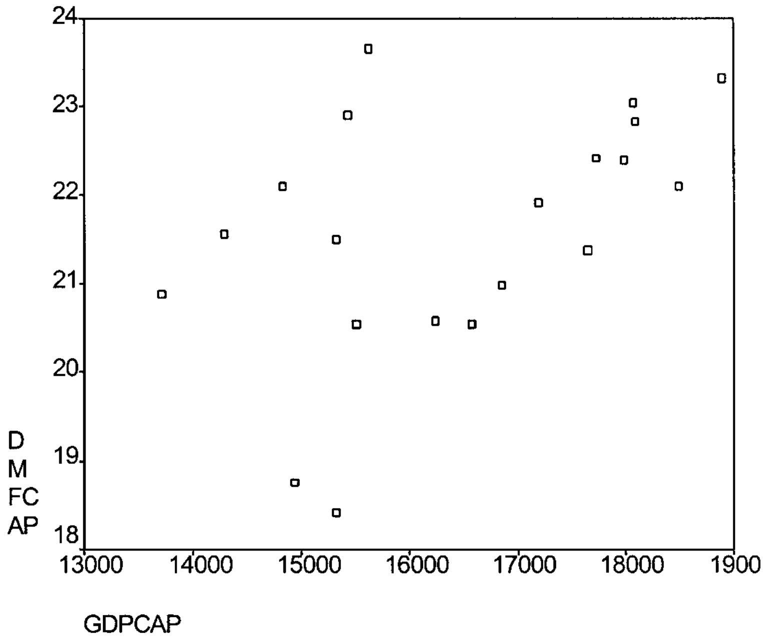

FIGURE 8. The USA's scatter diagram: GDP per capita and direct material flows per capita.

EKC Curve of the USA?

The EKC hypothesis was also tested with US data. Figure 7 presents the index time series for the US data.

Figure 8 presents a scatter diagram of the USA's per capita GDP data and direct material flows per capita.

The 1st and 3rd order terms are not statistically significant. After using the Cochrane-Orcutt method, the following model and statistics were found (see Table 3):

TABLE 3

	Coefficient	Standard Error	t	Significance
b_2	0.100	0.015	6.81	0.000004
a	−6.590	1.428	−4.61	0.00029
R-Squared	0.744			
Standard Error	0.027			
Durbin-Watson	1.242			

$$\ln DMF_t = a + b_2(\ln GDPCAP_t)^2. \quad (5)$$

Again, no statistical support for the EKC hypothesis was found, when the USA's data was analysed. The significance of the EKC test is 0.99999. The model strongly supports a positive relationship between the DMF and GDP. The DMF curve resembles a U type, similar to the German case. Statistically the model fits quite well but there are some autocorrelation problems. The EKC hypothesis is retained.

EKC Curve of the Netherlands?

We also tested the EKC hypothesis for the Netherlands' data. Figure 9 presents the index time series for the Netherlands' data.

Figure 10 presents a scatter diagram of the Netherlands' GDP per capita data and direct material flows per capita data.

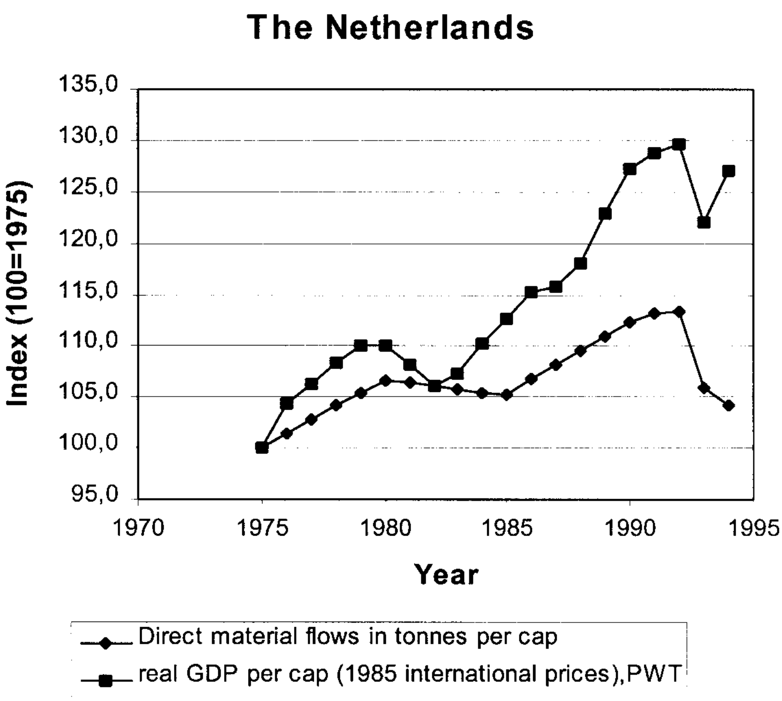

FIGURE 9. The Netherlands: index series of GDP per capita and direct material flows per capita.

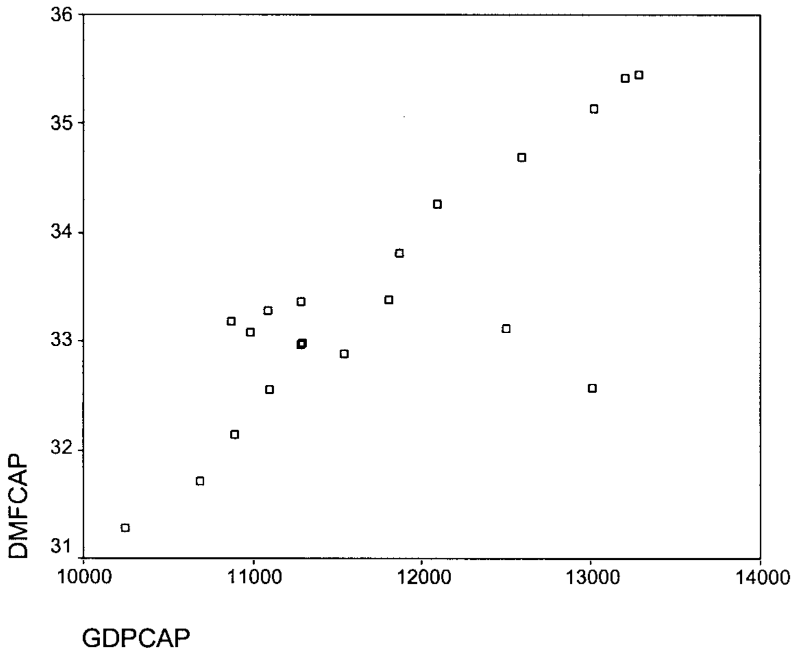

FIGURE 10. The Netherlands' scatter diagram: GDP per capita and direct material flows per capita.

The 1st and 3rd order terms are not statistically significant. After using the Cochrane-Orcutt method, the following model and statistics were found (see Table 4):

$$\ln DMF_t = a + b_2(\ln GDPCAP_t)^2. \quad (6)$$

TABLE 4

	Coefficient	Standard Error	t	Significance
b_2	0.151	0.006	2.67	0.01690
a	2.178	0.501	4.35	0.0005
R-Squared	0.308			
Standard Error	0.017			
Durbin-Watson	0.644			

There is a serious autocorrelation problem, and Prais-Winsten and Cochrane-Orcutt procedures do not give any remedial. Ignoring this the significance of the EKC hypothesis is 0.9985. If the autocorrelation problem of the model is neglected it can be said that the EKC hypothesis does not gain empirical support from the Netherlands' case either. The positive relationship between the GDP and DMF per capita can also be seen from Figure 10.

Finland's EKC Curve?

The EKC hypothesis was tested for Finnish data as well. Figure 11 presents index time series for the Finnish data.

Figure 12 presents a scatter diagram for Finland's GDP per capita data and direct material flows per capita.

The 1st and 3rd order terms are not statistically significant. After using the Prais-Winsten method, the following model and statistics were found (see Table 5):

$$\ln DMF_t = a + b_2(\ln GDPCAP_t)^2. \quad (7)$$

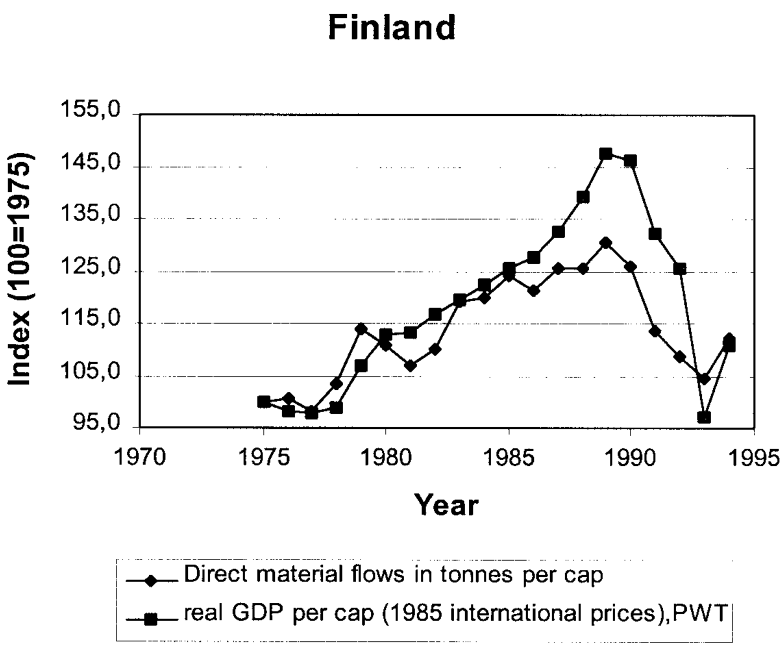

FIGURE 11. Finland: index series of GDP per capita and direct material flows per capita.

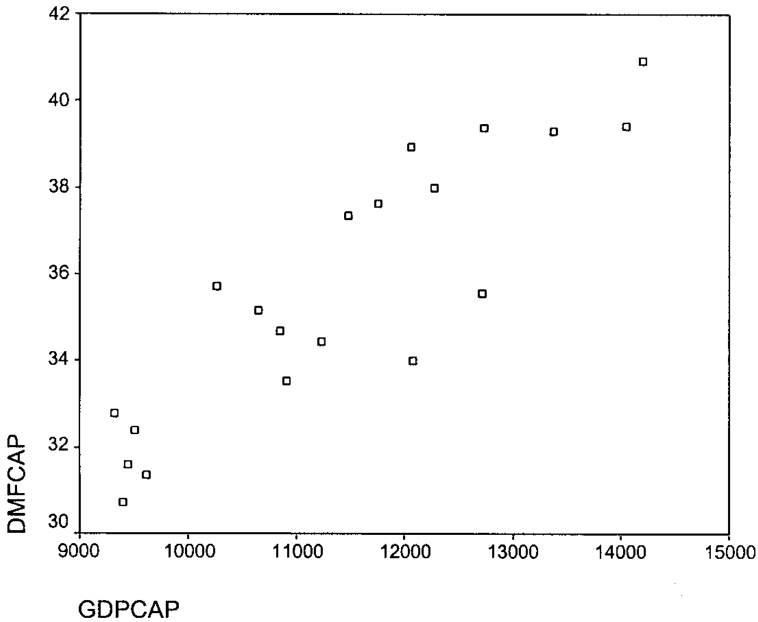

FIGURE 12. Finland's scatter diagram: GDP per capita and direct material flows per capita.

Again in Finland's case statistical support for the EKC hypothesis was not found. The significance for the EKC test is 0.99998. Therefore the EKC hypothesis for the Finnish data must be rejected. Statistically the model fits well; in this case there were no autocorrelation problems. The positive relationship between per capita GDP and DMF per capita can be seen quite clearly from Figure 12.

TABLE 5

	Coefficient	Standard Error	t	Significance
b_2	0.028	0.005	5.69	0.00003
a	1.136	0.427	2.66	0.017
R-Squared	0.656			
Standard Error	0.038			
Durbin-Watson	1.653			

SUMMARY

This study analyses the Environmental Kuznets Curve hypothesis with material use data for the USA, Germany, Japan, the Netherlands and Finland. The literature on this issue has developed rapidly over the last few years. There has been a long discussion concerning the relevance of the EKC hypothesis, which claims that as countries become wealthier environmental stress will begin to decline at a certain income level. However, the EKC hypothesis has not been widely tested with direct material flow data. In this paper, we have presented an attempt to test the EKC hypothesis via direct material flows. The results of the empirical hypothesis tests conducted here indicate that the EKC hypothesis does not hold for industrialised countries such as Germany, Japan, the USA, the Netherlands and Finland. This is the main result of the paper.

However, there are some limits in the time series data that make it somewhat difficult to totally deny the EKC hypothesis. If a longer time series analysis could have been made, the inverted U-curve might have been identified. On the basis of our analysis, we conclude that in sustainability analyses and policy making it seems there will be significant future challenges for the management of material flows. This conclusion can be derived from the fact that none of the countries under investigation showed an inverted U-curve.

ENDNOTES

1. Comprehensive surveys are presented by Stern et al. (1996), Ekins (1997), and Stern (1998). Some unresolved issues behind the EKC analysis are highlighted in Rothman and de Bruyn (1998).
2. An extreme value of one study (over 8 million $) is omitted.

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ESSAY IV

A Time Series Analysis of the Environmental Kuznets Curve for CO_2 Emissions in the EU-15 and the USA

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1 INTRODUCTION

There is no doubt that economic growth and the state of the environment are somehow related. However, the evidence on the nature and strength of these relationships is controversial. There are few alternative theories about the relationship, which, however, do not tell unambiguously, how the environment and the economy co-evolve in reality. Because of this ambiguity we need empirical analysis in order to get deeper understanding about the real-world development. The purpose of this paper is to examine how carbon dioxide (CO_2) emissions and economic growth are related in two most developed industrial economic entities, the USA and 15 EU countries[1]. The framework for the analysis is the so-called Environmental Kuznets Curve (EKC) hypothesis.

There are two extreme views about the co-evolution of the environment and the economy. First, it is argued by growth pessimists that economic growth unavoidably degrades the state of the environment, since the growth of economic activity always requires intensified material use of natural resources and the environment. On the other hand, it is often argued that economic growth is needed in order to create wealth and technological progress so that we can afford to the better environment, and technical support to sustain it.
According to the Environmental Kuznets Curve hypothesis economic growth causes degradation of the environment at low income levels, but as income rises, harmful environmental impact will decrease. The environment is extracted in great extent in order to create economic growth in early stages of development. As the economy is developed enough, the environment is more valued and demanded by people, and technical progress makes it possible to create wealth with less environmental stress. This means that one should be able to find a level of income after which negative environmental impacts of economic activity will decline.

Figure 1 represents the Environmental Kuznets Curve (see de Bruyn and Heintz 1999). The resource degradation or pollution will increase initially with economic growth and then eventually decline. The EKC is also known as an inverse U-curve.

[1] Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and United Kingdom.

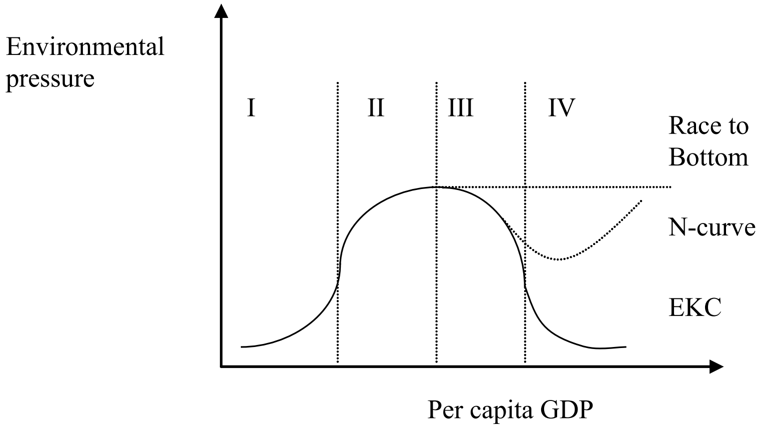

Figure 1 The Environmental Kuznets Curve

We may expect that developing countries locate at the left-hand side of the EKC curve (for instance phases I or II). Accordingly we should expect that rich industrialized countries lie on the right hand side of the EKC (e.g. phases III or IV).

Development from phases III to IV may not imply permanent relief, because development may take back to the so-called N-curve or to the Race to Bottom –model where environmental stress indicator stays at some relatively high constant level. There are several reasons for these possibilities including increasing costs to international competitiveness and pollutions havens hypothesis (Dasgupta et al. 2002, Dinda 2004). Also Common (1995, 100–105) argues that even if impacts per unit income of different countries approach some positive constant level, growing economies still exhibit the rising total levels of environmental stress violating the EKC in the long run (Perman et al 1999, p. 36–37). This outcome may be true for global pollutants like CO_2 emissions where also incentives for free riding are obvious.

There are a few arguments for the possible existence of the EKC. At the early stages of economic development material intensity and extraction of natural resources are intense. This means heavy load to the natural environment (Phase I in Figure 1). As consumers get richer they step on to a new level in their hierarchy of needs, where environmental values are more important. As people demand more environmental goods and services, politicians and firms have to take it into account in their decisions. Thus, politicians take public actions that should be beneficial to the environment, and the firms try to attract customers with ‘green’ products and production methods. The EKC gets flatter (Phase II) and eventually it may decline (Phase III). Environmental management and policy together with technological improvements enable corrective actions meaning also structural change in an economy where industrial society is replaced by services and information society. (Dasgupta et al. 2002, de Bruyn and Heintz 1999, Ekins 1997.)

On the other hand, there are several reasons that may obstruct the EKC behavior in favor of the so-called the Race to Bottom or N-curve hypotheses (Phase IV). One reason is embedded in lack of democracy or weaknesses of democratic system: Opportunism and rent-seeking of decision makers and interest groups may lead to unoptimal and environmentally harmful solutions that are disguised in the form of 'common good', like employment or international competitiveness. Even environmental policy with good intensions may be misguided, inefficient, or it may create unintended adverse incentive structures. Environmental policy is only one policy sector, and different policies may neglect environmental dimension. For example goals and means of competition policy, trade policy, and agricultural policy often are in contradiction with environmental policy. Better technology does not automatically mean better environment. New technology may give more out of less resources (say less pollution), but in total more resources are used, because goods are easier to use or cheaper to buy; the whole demand structure may take the new level. (Binswanger 2001.) Typically, environmental values are not of the highest priority for business firms. A change in consumer demand provides an incentive to the firms to create 'green image.' Business firms may take actions that benefit the environment, but there is always a possibility of disinformation and fraud. Even though environmental policy would be accurate at local level, global environmental problems suffer from incentives to free ride. Global green house gas emissions are an example of this. (de Bruyn and Heintz 1999, Ekins 1997.)

The EKC studies were launched by Grossman and Krueger (1992), and Shafik and Bandyopadhyay (1992). The EKC research has taken many directions ever since; see for instance Agras & Chapman (1999), Dasgupta et al. (2002), de Bruyn et al. (1998), Dijkgraaf and Vollenberg (1998), Hettige et al. (1997), Hilton and Levinson (1998), Holtz-Eakin and Selden (1995), Kaufmann et al. (1988), Khanna (2002), Mason and Swanson (2003), Munasinghe (1995), Rock (2000), Rothman (1998), Selden and Song (1994), Seppälä et al. (2001) Suri and Chapman (1998), Tucker (1995).[2]

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[2] Good surveys are Stern et al (1996), Ekins (1997), and Stern (1998). Some unresolved issues behind the EKC-analysis is highlighted in Rothmans & de Bruyn (1998).

As de Bruyn and Heintz (1999) detect, most studies conduct regression analyses with panel data for the general type of the model presented in Equation 1:

Equation 1 $P_{i,t} = \alpha_{i,t} + \beta_1 Y_{i,t} + \beta_2 Y_{i,t}^2 + \beta_3 Y_{i,t}^3 + \beta_4 Z_{i,t} + e_{i,t}$,

where P = environmental pressure, α = constant, Y = income, Z = other explanatory variables, β_k = coefficients for explanatory variables (k = 1, ..., 4), $e_{i,t}$ is statistical error, i = country index, and t = time index. de Bruyn and Heintz (1999, 659) recognize seven distinct cases (see also Dinda 2004):

1. $\beta_1 > 0$, $\beta_2 = \beta_3 = 0$: increasing linear relationship between levels of rising income and rising emissions.
2. $\beta_1 < 0$, $\beta_2 = \beta_3 = 0$: decreasing linear relationship between levels of rising income and declining emissions.
3. $\beta_1 > 0$, $\beta_2 < 0$, $\beta_3 = 0$: an inverted U-curve, i.e. the EKC curve.
4. $\beta_1 < 0$, $\beta_2 > 0$, $\beta_3 < 0$: a U-curve.
5. $\beta_1 > 0$, $\beta_2 < 0$, $\beta_3 > 0$: an N-curve.
6. $\beta_1 < 0$, $\beta_2 > 0$, $\beta_3 < 0$: an opposite to an N-curve.
7. $\beta_1 = \beta_2 = \beta_3 = 0$: rising levels of income do not affect emissions.

There exist numerous studies where the interest is on the development of CO_2 emissions. We briefly review some that are relevant for our present purposes. Roberts and Grimes (1997) examine how many kilos of carbon dioxide countries emitted per unit of gross domestic product for years 1962–1991. They call this measure as 'National Carbon Intensity'. Their findings suggest that the emergence of the EKC for carbon dioxide is the result of relatively small number of wealthy countries while the rest of the world is making no progress in CO_2 emissions. Time series analysis of de Bruyn et al. (1998) reveals that in West Germany, Netherlands, and the UK economic growth has had a positive effect on emissions of carbon dioxide, nitrogen oxides, and sulphur oxide. They argue that the EKC that is estimated from the panel data may not hold for individual countries over time, and possible emission reductions may be due to structural and technological changes in the economy. (See also Dasgupta et al. 2002).

Golove and Schipper (1997) use a method of factorial decomposition to measure the components of change in the energy use and carbon emissions in the USA (1960–1993). They find that while the overall US carbon emissions increase, the growth rate of carbon emissions fall behind the rate of GDP growth. This is because of efficiency improvements and the combined effects of activity and structural change. Luukkanen and Kaivo-oja (2003) analyze the G-7 countries with the IEA (1960–1999) data. By using a decomposition model they find that all the G-7 countries showed decreasing CO_2 emissions intensities after the year 1970. Using the same methodology and the same data source for years 1971–1999 Kaivo-oja and Luukkanen (2002) find that the USA and the EU have succeeded in relative CO_2 emission reductions that are implied by increasing energy efficiency and fuel switching to less carbon intensive energy production. Kaivo-oja and Luukkanen (2004) perform decomposition analyses of energy and CO_2 intensities of the EU countries and Norway (1960–1998). They conclude that there are large differences between countries.

Anderson and Cavendish (2001) produce CO_2 abatement scenarios for developing countries by using a dynamic simulation model. They conclude that technological development, policy, and other economic factors give much more possibilities for developing countries to reduce pollution than the EKC research has identified for advanced countries. Turning points may be realized earlier and at lower income levels. Estimated turning points for CO_2 emissions are somewhat ambiguous. Taking into account both developing or developed economies, or their sub-divisions, either monotonic increase is found, or turning points vary from $7,900 to $35,000 per capita GDP (in 1985 world prices), or it gets up to an extreme value like $8 million (Holtz-Eakin and Selden 1995, Shafik 1994, Unruh and Moomaw 1998). Recent EKC estimation by Martínez-Zarzoso and Bengochea-Morancho (2004) covers a panel of 22 OECD countries over the period 1975–1998. Dependent variable is per capita CO_2. They conclude that there exists an N-shaped relation for the majority of countries. This means that the existence of the EKC is temporary only, and increasing incomes will produce also higher per capita emissions.

Agras and Chapman (1999) argue that prices of energy have statistically significant effect on the EKC in explaining CO_2 per capita. Also Sun (1999) argues that the EKC hypothesis over-emphasizes the importance of GDP per capita as an explanatory variable. He demonstrates with the Chinese data that the EKC is just a reflection of the peak-theory of energy intensity. Income determinism of the EKC is questioned also by Unruh and Moowaw (1998). They show that the time trajectories of CO_2 emissions for several industrial countries show transitions that occur contemporaneously with energy crises of 1970's. High-income countries reveal beginning of downturns for 'national carbon intensity' at times of the oil crises in 1973 and 1979 (Roberts and Grimes 1997). Thus it remains unclear whether transitions in trajectories are a result of income increases, or contemporaneous economic shocks. Dinda (2004) argues that global environmental indicators like CO_2 either increase monotonically with income or have high turning points with large standard errors.

There are no doubts that the use of energy and economic growth are positively correlated. However, empirical results concerning the direction of causality between energy use and economic growth are mixed. Both bidirectional and unidirectional causality has been recognized. (See e.g. Jumbe 2004; Oh and Lee 2004). Because of this ambiguity, we do not include energy variables into this study. The focus of this paper is to compare traditional 'pure' EKC effects on CO_2 emissions. Also, because energy and GDP are correlated it may well be justified to use the reduced form model for our present purposes.

Most of the EKC studies are based on pooled panel data. Dijkgraaf and Vollebergh (1998) suspect that because of evident autocorrelation problems and strong 'unrealistic' assumptions, the cross-country regression analysis is not a suitable method for this research setting. Instead, they emphasize that the EKC analyses should be based on time series. Their time series analysis of CO_2 for OECD countries between years 1960–1991 suggest that turning points (if any), and functions for CO_2 emissions per capita reveal distinctive differences between countries. This indicates that conclusions made from cross-section studies are unreliable in large extent.

Before concluding this introduction it is important to remind that the EKC analysis has several deficiencies. Without going into details we briefly mention some of them (Tisdell 2001, Dinda 2004): (1) Improving local environment does not preclude deteriorating global environment. (2) There are claims that the EKC-relationship does not hold in any meaningful way for CO_2 pollutants. (3) Pollution flows as such may not be a proper indicator if pollution is cumulative, or its impacts are irreversible. The critical ecological threshold level may be reached before a turning point. This may cause more or less serious environmental, social, or economic catastrophes. There are estimates according to which rising greenhouse gas emissions may affect drastically to income generation processes and to the factors of economic growth. Consequently, the statistical EKC does not necessarily reflect sustainable development. (4) Even when pollution intensity has reached its maximum level, the total pollution will continue to rise at least for a time. It may be misleading or incorrect to estimate the EKC by pollution intensities. (5) The efficiency does not imply reduced global pollution. Input-savings and reduced pollution intensities resulting from improved efficiency may be offset by increased economic scale. Some empirical results indicate that material throughput has continued to rise even if countries are experiencing falling pollution intensities. (6) The observed EKC may not be a permanent one. Sometimes the EKC is followed by an N-shaped curve. (7) Cross-section panel estimates do not guarantee that individual countries move along the EKC over time. (8) Enough attention has not been given to time series analyses of the EKC.

Dinda (2004) summarizes that existence of the EKC is questioned by many, and only some local pollutants show the evidence of the EKC. In the literature there is no general consensus on the income level at which environmental degradation starts to decline. These critical thoughts in mind we perform below time series analyses with the data of International Energy Agency (IEA 2005) covering years 1960–2003. For consideration of time series analysis, it is interesting to note that if we consider per capita carbon dioxide emission trends in early industrialized countries over a very long period (1870–2028), oil price shocks do not seem to cause permanent breaks in the structure or level of emission series (Lanne and Liski 2004). In relatively short data structural brakes for the years of oil crises may be justified, but at least for a longer data possible structural brakes should be traced endogenously. The present paper is organized as follows. In section 2 the co-development of CO_2 emissions and real gross domestic product per capita is examined by visual inspection. Comprehensive time series analyses are conducted in section 3. By comprehensive we mean that the EKC hypothesis is scrutinized by three aspects: economic efficiency, per capita effect, and total environmental pressure. Section 4 concludes.

2 PRELIMINARY INSPECTION OF THE TIME SERIES FOR THE EU-15 AND THE USA

There are a few interesting topics to be analyzed. Before econometric analyses, we briefly consider through visual inspection whether there are signs for structural brakes at 1970's, do we recognize the EKC, Race to Bottom, N-curve behavior, or other kind of behavior for economies of the EU and the USA? The development of real GDP per capita and CO_2 emissions in time (annual data) for the EU-15 and the USA are shown in the following figures. All data is taken from the IEA database. Emissions are measured as million tonnes of CO_2, tonnes of CO_2 per capita, or kilogrammes of CO_2 per GDP, 2000 US$ PPP by using a Sectoral Approach. Real GDP per capita is calculated in 2000 prices US$ PPP.

2.1 EU-15 countries

Time series for CO_2 emissions per GDP and real GDP per capita for EU-15 countries seem to reveal de-linking behavior (Figure 2).

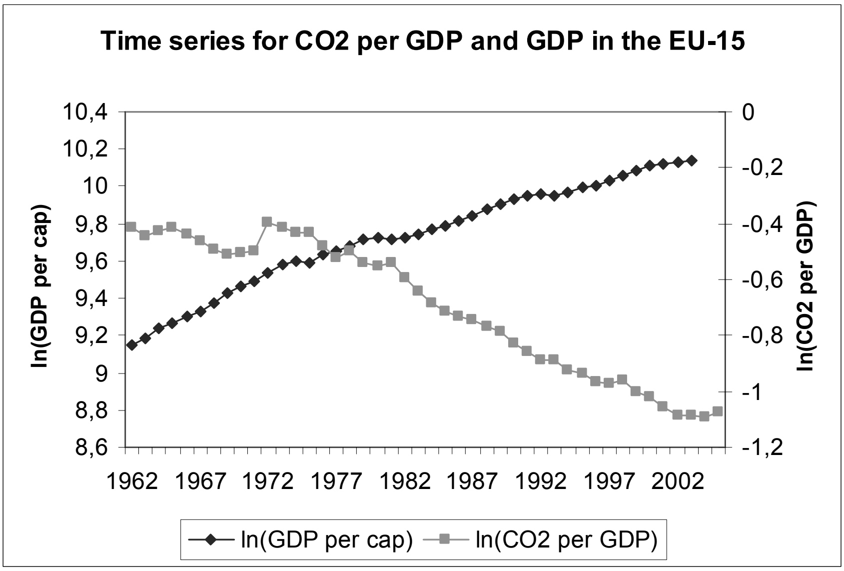

Figure 2 CO_2 emissions per GDP and GDP per capita in time for the EU-15 countries

This might indicate the EKC which is visually confirmed in Figure 3.

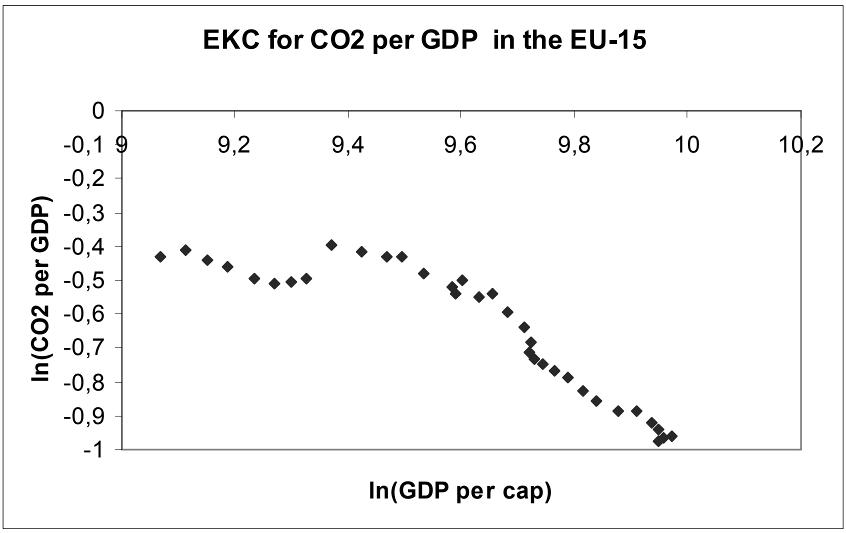

Figure 3 The EKC-setting: CO_2 emissions per GDP and GDP per capita for the EU-15 countries

Thus, the intensity effect gives us the first impression of the EKC. Structural brake for the oil crisis in 1973 seems to be present. Also structural brake for

1979 crisis is possible, but it is not obvious. To conclude we may expect that the EKC hypothesis holds for EU-15 countries for CO_2 intensity indicator.

In Figure 4 and Figure 5 development of CO2 emissions per capita are presented.

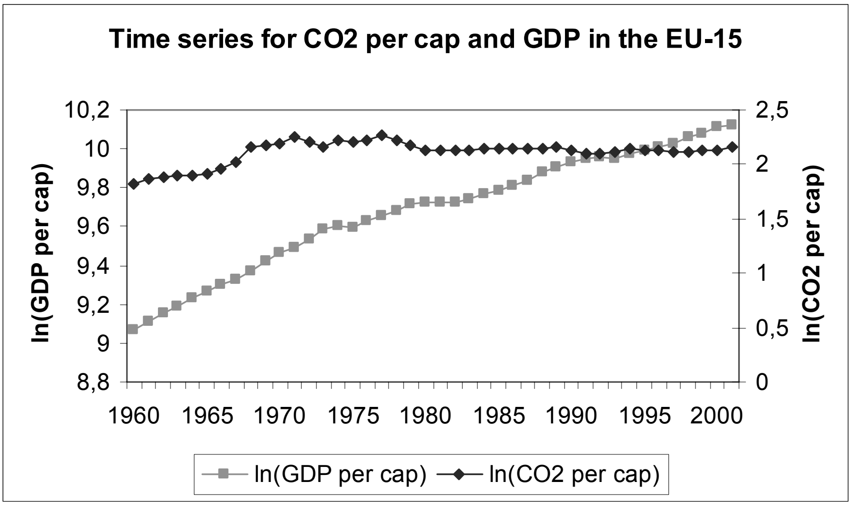

Figure 4 CO_2 emissions per capita and GDP per capita in time for the EU-15 countries

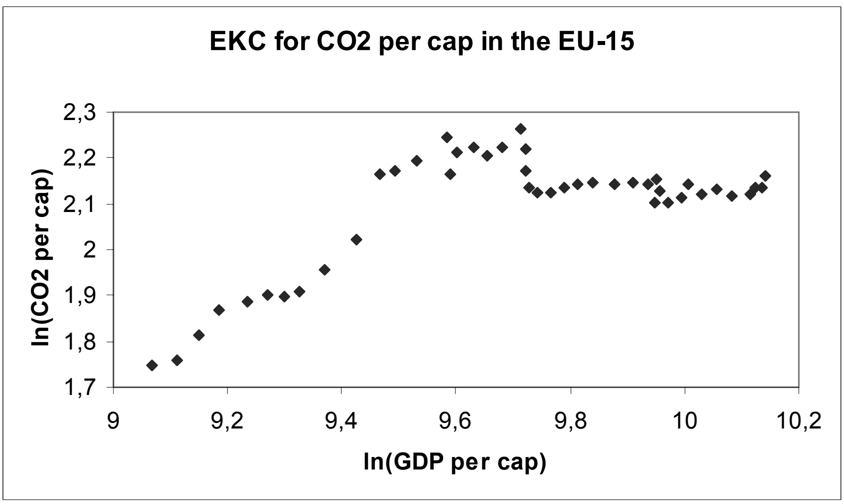

Figure 5 The EKC-setting: CO_2 emissions per capita and GDP per capita for the EU-15 countries

This measure is indicator of population effect, human exposure, or contribution of EU citizens to atmospheric environmental stress. Time series suggest that some kind of de-linking is occurring. Also structural brake for early 1970's seems to be present. The Figure 5 may reveal EKC behavior because of curvature. Yet, the shape of a curvature looks more like Race to Bottom –hypothesis.

The total environmental stress is shown in Figure 6 and Figure 7. In this paper the total environmental stress is defined as the total quantity of CO_2 emissions.

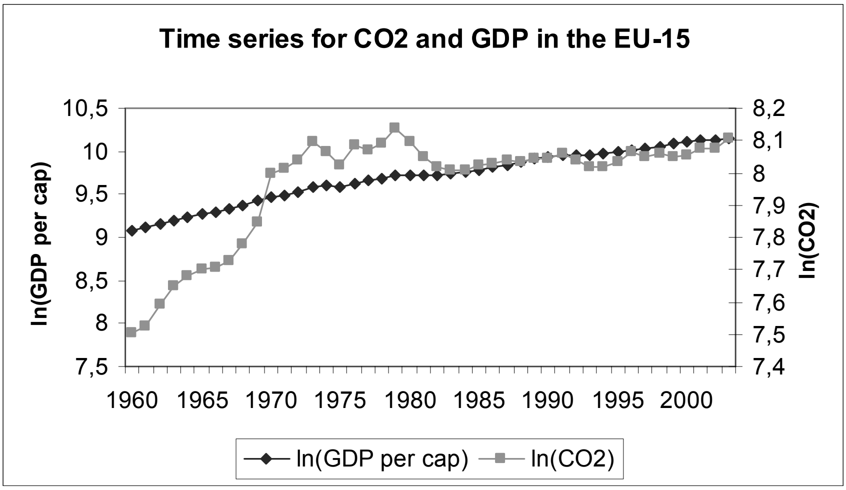

Figure 6 Total CO_2 emissions and GDP per capita in time for the EU-15 countries

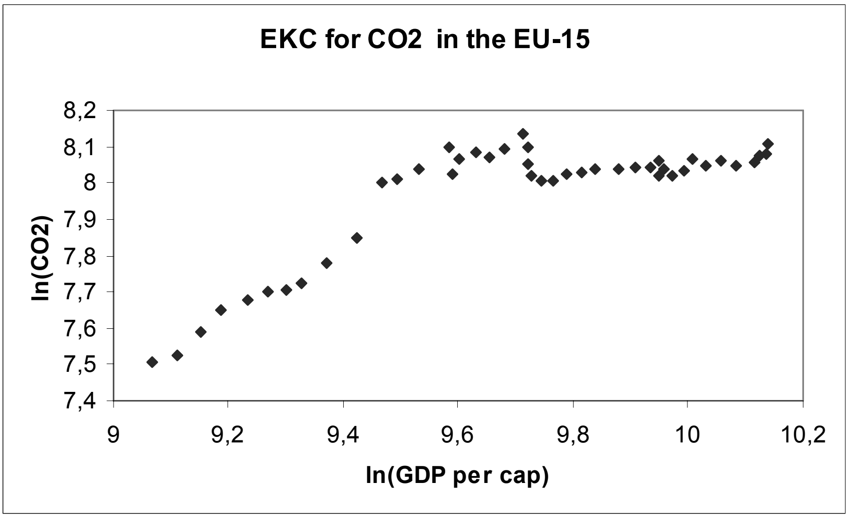

Figure 7 The EKC-setting: Total CO_2 emissions and GDP per capita for the EU-15 countries

Both time series and the EKC figures suggest that the total environmental stress for EU-15 countries is not decreasing. CO_2 emissions seem to be quite stationary and the EKC curvature resembles Race to Bottom behavior.

2.2 USA

Time series of intensity effect for the USA shows strong de-linking in Figure 8. Figure 9 seems to reveal the EKC behavior for this indicator.

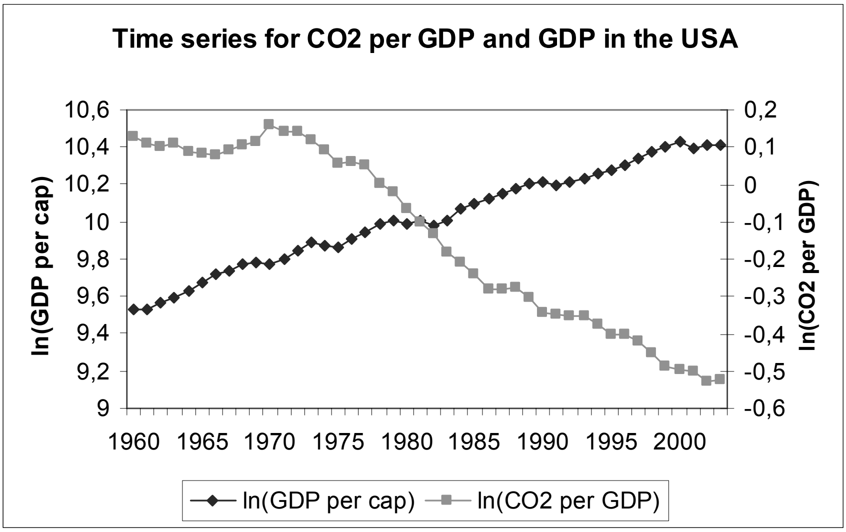

Figure 8 CO_2 emissions per GDP and GDP per capita in time for the USA

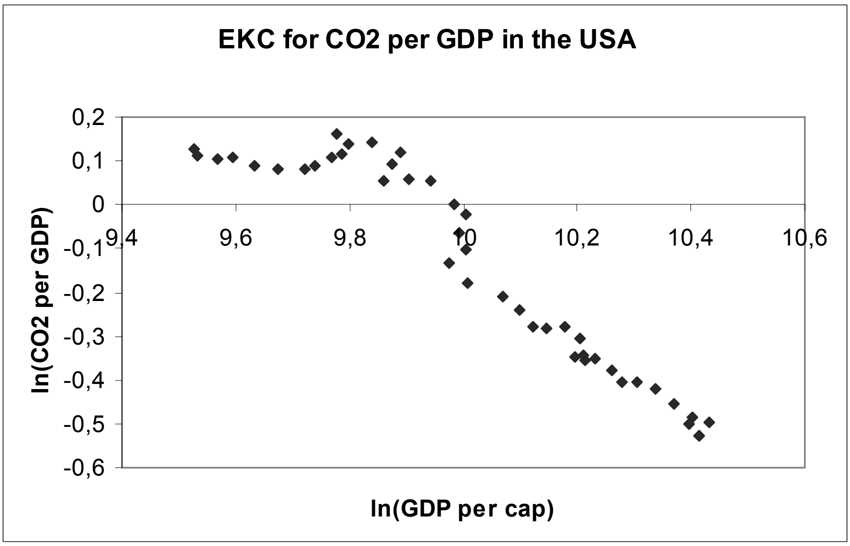

Figure 9 The EKC-setting: CO_2 emissions per GDP and GDP per capita for the USA

Again 1973 oil crisis seems to give an impetus for change in time series of CO_2 per GDP.

CO_2 per capita indicator also shows de-linking in Figure 10. The EKC behavior is not strong in Figure 11. It resembles more like N-behavior or Race to Bottom case.

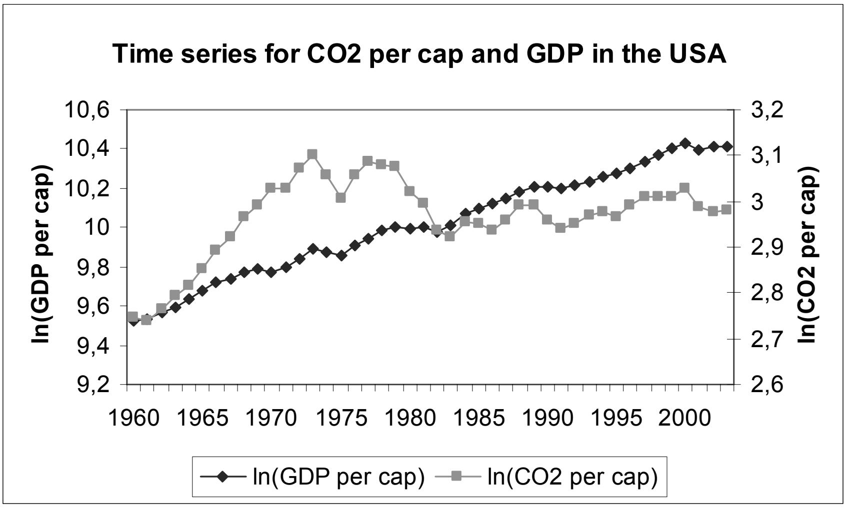

Figure 10 CO_2 emissions per capita and GDP per capita in time for the USA

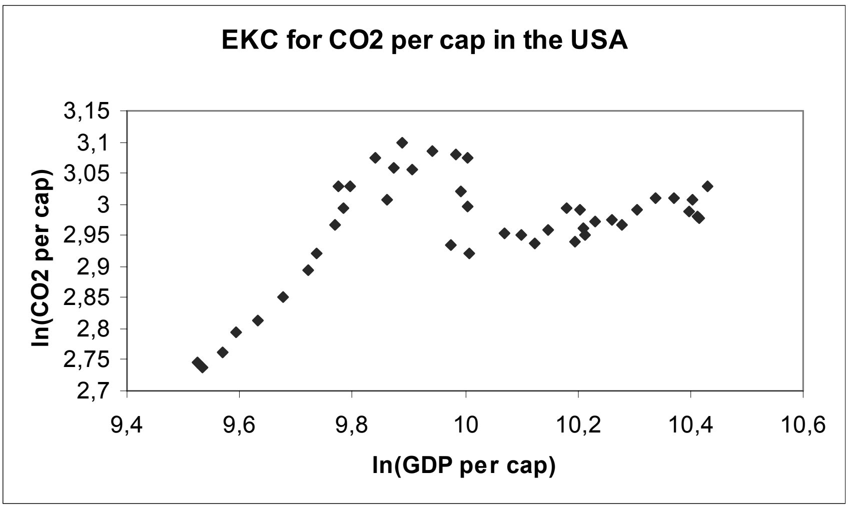

Figure 11 The EKC-setting: CO_2 emissions per capita and GDP per capita for the USA

Figure 12 and Figure 13 describe the total environmental stress.

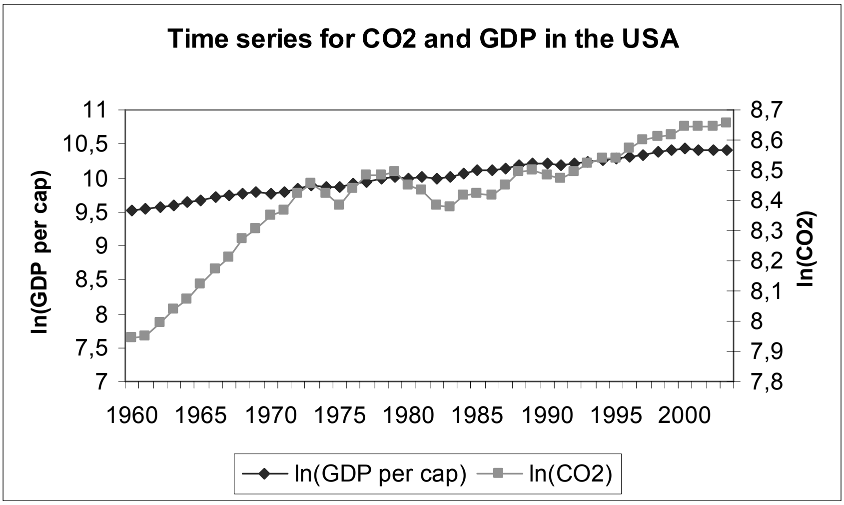

Figure 12 Total CO_2 emissions and GDP per capita in time for the USA

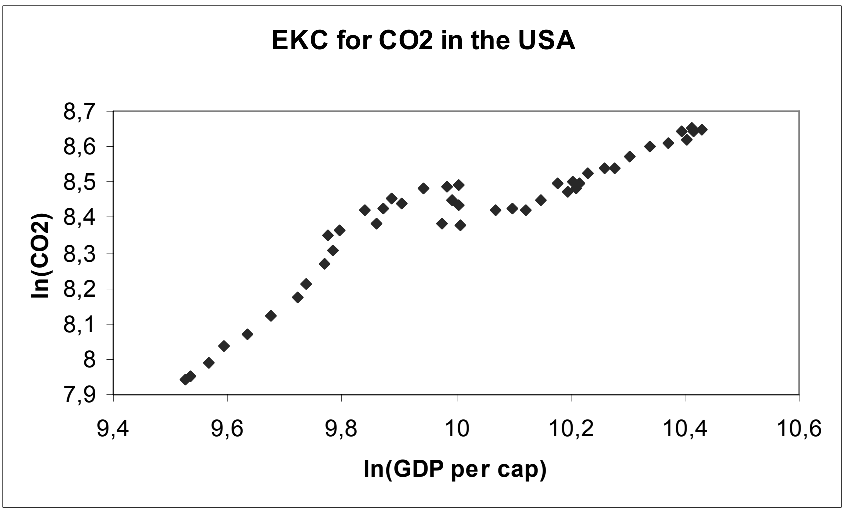

Figure 13 The EKC-setting: Total CO_2 emissions and GDP per capita for the USA

It seems that the EKC may not be found. Total environmental stress seems to increase. The EKC curve scatter gives an impression of increase that resembles arguments of Common (1995) of the total impact scenario. Even though pollution intensity would decline, positive growth rates of an economy may indicate growing emissions in absolute terms as emission rates approach some positive constant.

3 TIME SERIES ANALYSIS

Searching for the empirical evidence of the existence or non-existence of the EKC is important as background knowledge in order to implement successful economic policy. The EKC analysis can be seen as a basic empirical test for the proper functioning of an economy for environmental goods. In this sense the EKC hypothesis can give empirical information about the need of more effective environmental policy. By considering the highest performing industrial countries we should expect that the empirical evidence supports the EKC hypothesis, because these countries are the most developed ones.

In the following we apply regression models where the explanatory variable is GDP per capita and the response variables are CO_2 emission indicators. This analysis is executed for the EU-15 and the USA. The purpose is to get the comprehensive picture of the development: 'What kind of development is revealed by measures of CO_2 per GDP, CO_2 per capita, and total emissions of CO_2?' The first measure indicates efficiency, the second indicates human effect, and the last one indicates the total pressure on the environment. All variables are measured in logarithmic form.

3.1 Unit roots tests

Correlograms, correlation functions, and partial correlation functions for all series suggest that all series may have unit roots and they may take AR(1) form. Generally, it is controversial whether GDP series exhibit stationary or non-stationary data generation processes (Diebold and Senhadji 1999, Rudebusch 1999). Our testing strategy is based on conventional ADF estimation. The general ADF model takes the form

Equation 2 $$\Delta y_t = \rho^* y_{t-1} + \alpha + \beta t + \sum_{i=1}^{k-1} \rho_i^* \Delta y_{t-i} + u_t,$$

where $\rho^* = \rho$-1, and $u_t \sim \text{IID}(0,\sigma^2)$. The null hypothesis is that $\rho^* = 0$ indicating a unit root in a series. The power of a test is the probability of rejecting the null hypothesis when it is in fact false. The power of Dickey-Fuller tests is low, which means that too often a stationary series is considered to contain a unit root. If we cannot reject the unit root from a sample, we should next include time break for 1973 and use Perron (1989) methodology for unit root testing. However, if series imply stationary process, there is no need to use Perron methodology, because it favors rejecting unit root.

According to classical growth theory, real per capita GDP should be stationary. Different shocks may change level or slope of stationary process. New growth theory suggests that growth processes may also be non-stationary under certain circumstances. Our strategy is quite general. We begin our unit root analysis with basic ADF forms. Deterministic variables, constant and time trend, are selected using F-test. Ljung-Box Q-statistics is used to test autocorrelation. The appropriate numbers of lagged differences are determined either by Schwartz Bayesian information criterion (BIC) or by reduction method; we start with 11 lagged differences and sequentially remove insignificant (5%) lagged differences. All series are in logarithms. Table 1 collects the results of ADF tests.

Table 1 Augmented Dickey-Fuller unit roots tests

Variable	ρ*	$t_{\rho*}$	α	t_α	β	t_β	Lags	T	Crit.
GDP/cap(EU)	-0.0278	-4.36[b]	0.2938	4.77			0	43	Reduction
GDP/cap(US)	-0.4535	-3.85[a]	4.3420	3.87	0.0091	3.70	1	42	BIC
CO_2/GDP(EU)	-0.3345	-3.51[a]	-0.0640	-3.27	-0.0070	-3.51	7	36	Reduction
CO_2/GDP(US)	-0.6501	-4.41[b]	0.2513	4.10	-0.0132	-4.32	9	34	Reduction
CO_2/cap(EU)	-0.1167	-3.10[a]	0.2538	3.21			0	43	BIC
CO_2/cap(US)	-0.1516	-3.24[a]	0.4543	3.27			1	42	BIC
CO_2 (EU)	-0.1013	-3.49[a]	0.8206	3.55			0	43	BIC
CO_2 (US)	-0.0631	-2.94[a]	0.5468	3.03			0	43	Reduction

Note: ‘a’ denotes statistical significance at the 5% level, ‘b’ denotes statistical significance at the 1% level according to Dickey-Fuller tables.

It seems that all series obey stationary processes, even though we do not control structural brake at 1973. If all series are generated by stationary processes, cointegration and spurious regression problems do not arise. Thus, cointegration tests are not called for, but classical regression methods can be used.

3.2 Models

Our models for the EKC are conventional ones (Dinda 2004). The statistical model is an artifact that reduces a complicated socio-economic-environmental system into two dimensions. It is intended that the statistical model is based on the economic model which presents a long term relationship between CO_2 emissions and income per capita. We use the general-to-specific approach in order to test the EKC hypothesis in the EU-15 and the USA for CO_2 emissions. Because there are only 44 observations available, and we are dealing with annual data, three-period lags could be regarded as adequately covering the possibility of lagged responses. We want to test whether GDP variables in Equation 1 are able to capture the hypothesized EKC long-run dynamics. If *P* is pressure indicator of CO_2 and *Q* is per capita real GDP, then, the basic relationship with third-order lags can be expressed as

Equation 3

$$p_t = \alpha + \beta_{10} q_t + \beta_{20}(q_t)^2 + \beta_{30}(q_t)^3 + \beta_{11} q_{t-1} + \beta_{21}(q_{t-1})^2 + \beta_{31}(q_{t-1})^3 + \beta_{12} q_{t-2} + \beta_{22}(q_{t-2})^2 + \beta_{32}(q_{t-2})^3 + \beta_{13} q_{t-3} + \beta_{23}(q_{t-3})^2 + \beta_{33}(q_{t-3})^3 + \varepsilon_t ,$$

where variables in lower case letters denote natural logarithms. Our testing strategy is as follows. First, we search for the evidence of the basic EKC relationship. We start with a variant of an Equation 3, but without third order polynomials (Case 3 on the list of de Bruyn and Heintz). Second, if we are not able to find a good fit, we next estimate the whole Equation 3 in cubic form. This procedure produces regression results that are presented in tables 2 to 7. Table 2 shows the model for CO_2 emissions per GDP in the EU-15.

Table 2 Regression model for CO_2 per GDP in the EU-15. Estimation by Hildreth-Lu Search

Variable	Coefficient	Standard error	t	Significance
α	-175.144	32.180	-5.44	0.000003
q	35.254	6.413	5.50	0.000003
q^2	-1.785	0.320	-5.57	0.000002
Adjusted R^2 0.990, Standard Error 0.024, Durbin-Watson 2.072, Q-statistics 8.101				

The model strongly supports the EKC hypothesis. Calculation of a turning point for an inverted U-curve gives 19,438.29 US$ (in 2000 PPP prices). Per capita GDP was $19,494.69 in 1988. Thus, it seems that a turning point for an intensity indicator has been reached in late 1980's.

Table 3 shows a comparative model for the USA.

Table 3 Regression model for CO_2 per GDP in the USA. Estimation by Hildreth-Lu Search

Variable	Coefficient	Standard error	t	Significance
α	-1424.729	583.656	-2.44	0.020
q_{t-3}	354.000	171.756	2.06	0.047
q^2_{t-3}	-35.203	17.223	-2.044	0.049
q^3_{t-3}	1.167	0.576	2.03	0.050
Adjusted R^2 0.994, Standard Error 0.019, Durbin-Watson 1.77, Q-statistics 6.152				

CO_2 per capita model for the USA is a little more complicated. We cannot find a good fit to the basic EKC model. Adoption of three years lags and a cubic variant appears to suggest N-curve behavior (Case 5 in the list by de Bruyn and Heintz). Even though the second order term is quite strong, also cubic term has statistical significance. Visual inspection of the Figure 9 suggests that there has been a quite obvious case for the EKC, but a recent development may have caused the N-curve effect. The estimation of the EU-15 model in Table 2 with the US data gives the EKC model, which can be accepted at 8% risk level (for coefficients).

Table 4 gives a model for CO_2 per capita in the EU-15.

Table 4 Regression models for CO_2 per capita in the EU-15. Estimation by Hildreth-Lu Search

Variable	Coefficient	Standard Error	t	Significance
α	-182.238	32.314	-5.64	0.000002
q	36.297	6.440	5.637	0.000002
q^2	-1.787	0.322	-5.56	0.000002
Adjusted R^2 0.960, Standard Error 0.024, Durbin-Watson 2.094, Q-statistics 8.409				

Also emissions per capita indicator gives statistical support for the EKC hypothesis in the EU-15. However, as we calculate the possible turning point we get $25,848.30 which can be compared to the per capita GDP in 2003; $25,333.08. This implies that a possible turning point is very close or actual. As the evidence from the US data below suggests, we cannot completely rule out the N-curve behavior. It is interesting to note at this stage that the EU-15 data supports the EKC for emissions per GDP with relatively early turning point, but per capita indicator for emissions has much later turning point. Thus, it is important to use different indicators to get a complete picture of a real world development. We have no reason to be confident about sustainable development, if we are able to find statistical support for the EKC hypothesis from some data set, by one (conventional) means.

Table 5 displays the regression model for CO_2 per capita in the USA.

Table 5 Regression models for CO_2 per capita in the USA. Estimation by Hildreth-Lu Search

Variable	Coefficient	Standard Error	t	Significance
α	-1468.199	592.297	-2.48	0.0183020
q^2	0.049	0.007	6.67	0.0000001
q_{t-3}	367.566	174.229	2.11	0.0423253
q^2_{t-3}	-36.532	17.469	-2.09	0.0440524
q^3_{t-3}	1.211	0.584	2.07	0.0457319
Adjusted R^2 0.901, Standard Error 0.019, Durbin-Watson 1.772, Q-statistics 6.069				

Again, compared to the EU-15, the dynamics is complicated. Three years lagged terms seem to give an equilibrium model. There is, however, a squared instant growth effect term for emissions. Also cubic term is statistically significant, which implies the presence of the N-curve. Estimation of the EU-15 model with US data produces the EKC curve that is significant at 8% risk level (coefficients).

Table 6 displays the model for total CO_2 emissions in the EU-15.

Table 6 Regression models for CO_2 emissions (total) in the EU-15. Estimation by Hildreth-Lu Search

Variable	Coefficient	Standard Error	t	Significance
α	-169.386	32.742	-5.17	0.000007
q	34.855	6.526	5.34	0.000004
q^2	-1.712	0.326	-5.25	0.000006
Adjusted R^2 0.976, Standard Error 0.024, Durbin-Watson 2.035, Q-statistics 7.555				

The EKC hypothesis cannot be rejected according to statistical evidence. As we calculate a hypothetical turning point, we get $26,370.47 which should be compared to per capita GDP figure in year 2003; $25,333.07. This suggests that the turning point may be relatively close, but still ahead. Although, the EKC hypothesis gets statistical support from the data, we cannot preclude the N-curve or the Race to Bottom realizations in the future development. Yet, we should note that a turning point with this measure distinctively differs from the one that was implied by using the emissions per GDP indicator. We consider this as an important point for sustainability considerations.

Lastly, Table 7 presents the statistical model for total CO_2 emissions in the USA.

Table 7 Regression models for CO_2 emissions (total) in the USA. Estimation by Hildreth-Lu Search

Variable	Coefficient	Standard Error	t	Significance
α	-1614.773	623.482	-2.59	0.014033
q^3	0.003	0.001	5.77	0.000002
q_{t-3}	450.717	183.287	2.46	0.019175
q^2_{t-3}	-44.872	18.378	-2.44	0.019978
q^3_{t-3}	1.489	0.614	2.43	0.020765
Adjusted R^2 0.979, Standard Error 0.020, Durbin-Watson 1.853, Q-statistics 4.245				

The model suggests N-curve behavior. Also Figure 13 suggests that the EKC curve is absent. If we run the same EKC model as for the EU-15 for the US data, we find that the EKC model for the USA is otherwise statistically good (with Hildreth-Lu correction), but DW statistics is substantially below 2 (1.36). This implies that there may be some complex form of correlation among residuals in the model. Also we find that, if we run a linear two variable regression with one period lag in an explanatory variable per capita GDP (with Hildreth-Lu correction), we find that this positive linear trend model shows quite a good fit with better DW statistics (1.56). The latter linear model outperforms the basic EKC model. We conclude that there are no signs of the EKC curve for the USA if measured in total emissions.

4 CONCLUSIONS

Empirical EKC research shows mixed results for environmental pressure indicators. There are many theoretical and statistical problems involved. Our purpose in this paper is to get comprehensive picture of CO_2 emissions in the EU-15 and the USA. CO_2 emissions are measured from three different angles: efficiency, human effect, and total environmental stress.

CO_2 per GDP measures improvements in technical efficiency. For the EU-15, the EKC gets significant statistical support indicating technical efficiency; the EU is able to create more wealth with decreasing CO_2 emissions per output. Because of the recent development in the USA, the N-curve model gets statistical support. Despite of that, the EKC has strongly been present also in the USA. The picture becomes less optimistic as we measure CO_2 emissions in per capita terms. In the EU-15 there may be the EKC relation present, but in the USA the EKC process does not get significant statistical support, but the N-curve behavior is more likely. Models of the total CO_2 emissions suggests that in the EU-15 the EKC hypothesis may be present, but also Race to Bottom scenario is plausible, and N-curve behavior cannot be ruled out. There is no EKC for the USA in total CO_2 emissions.

To conclude, our experimentation highlights that the single piece of evidence for the EKC hypothesis does not mean that economic progress also promotes total welfare by reducing relative environmental stress. Comprehensive analysis for relative and total developments should be performed in order to get the whole picture of the need for corrective policy actions. Because the EKC cannot be ruled out for the EU-15, however measured, we might be cautiously optimistic that EU's active role in environmental policy can have real effects also for global pollutants. The successful management of global pollutants, however, requires that also other major economies take international environmental concerns more seriously.

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