Economic Growth and the Environment. Friends or Foes? The Environmental Kuznets Curve for CO_2 emissions

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Summary

The relationship between certain indicators of environmental quality and income, which in some cases has shows an inverted-U relationship, has been called The Environmental Kuznets Curve. The implications of this relationship in terms of economic and environmental policy are important. If there is reason to believe that environmental quality will improve after a certain income level, encouragement of economic growth will be optimal. If this relationship does not exist, a lack of focus on environmental problems can lead to potentially dramatic consequences. This paper explores the mechanisms behind the relationship, and for which pollutants the relationship exists. Specifically, the mechanisms can be categorized into income effects, and in relation to this, responsive democracies to act according to the demand of the populations, international trade and resource prices. Income effects can be described as the changes in preferences that come about due to increases in income. It is expected that the willingness to pay for a clean environment is low when income is low, and increases along with economic growth. Some theories have been put forth assuming thresholds in income, output or pollution. Only when the thresholds are passed environmental quality is prioritized, or it improves due to increasing returns in abatement. International trade can be thought of "pollution leakage": as countries become developed, the dirty industries producing pollution-intensive goods move to less developed countries, while the goods are exported back to the developed countries. According to Hotelling's rule, resource prices will increase as the resource becomes scarcer in supply, and this will bring about a shift in demand away from the resource to alternative resources as well as intensification per unit of the resource used. The characteristics of the pollutants are crucial in establishing the relationship with income also. Roughly speaking, the pollutants can be categorized into local and global pollutants, respectively. Local pollutants have direct effects on the polluters, and pose fewer problems with regard to policy in terms of preserving the environment. Global pollutants, on the other hand, are greenhouse gases (GHGs) that accumulate in the atmosphere, and thus have global impacts that affect not only the global population today, but also in the future. Carbon dioxide (CO_2) is one such global pollutant, According to the Intergovernmental Panel on Climate Change (IPCC), emissions resulting from human activities are substantially increasing the atmospheric concentrations of greenhouse gases, resulting on average in an additional warming of the Earth's surface. Empirical evidence shows that significant EKCs exist only

for local air pollutants, while indicators with a more global, more indirect, environmental impact either increase with income or else have high turning points with large standard errors.

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1 Introduction

The linkage between environmental degradation and economic growth has received increased attention, and been the subject of much discussion. Developed countries, coming to terms with the environmentally harmful policies of the past, are currently concerned with the long-run effects of global environmental degradation, while developing countries seek faster growth. Slowing economic growth in the interests of protecting the environment may appear to be a worthy cause to the richer countries, but is certainly not high on the agenda of the developing countries. This suggests a trade-off for developing countries between economic growth and environmental quality.

The literature on the relationship between environmental quality and economic growth was initiated by the Grossman and Krueger (1991) report on the environmental impacts of the NAFTA agreement, followed by the Shafik and Bandyopadhyay (1992) World Development Report. The concept of the Environmental Kuznets Curve saw the light of day after a Development Discussion paper as part of a study for the International Labor Organization by Panayotou (1993).The studies found empirical evidence of emissions of certain air pollutants rising with low income, and then reaching a turning point, and thereafter declining with income. The inverted U-shaped relationship was called the Environmental Kuznets Curve, due to its likeness to the original Kuznets curve, showing an inverted U-shaped relation between income and social inequality (Kuznets, 1955).

The debate over the validity of the EKC hypothesis has given way to numerous studies of the pollution-income relationship. The following two positions describe well the extreme views taken in this debate. Meadows et al (1972) stressed the importance of the limited natural resources of the world, and warned that this finiteness of resources may hinder further economic growth. They advocated that world would be better off limiting its growth as opposed to continuing reaching for maximum growth in the long run. The “imprudent use of the environmental resource base” as Arrow et al (1994) puts it, “may irreversibly reduce the capacity for generating material production in the future”. Beckerman (1992), on the other side, made the argument that “in the end the best – and probably the only – way to attain a decent environment in most countries is to become rich”. In this point of view, the economies of the world are better off getting rich as fast as they can. These two perspectives highlight the need to understand the relationship between income and pollution. A few questions are worth asking regarding environmental policies when it comes to the EKC: Is it valid for all types of environmental pressure? Is it permanent? Does it imply a sustainable development path? Establishing whether it exists at all, and for which pollutants, will be particularly fruitful when it comes to assessing the need and usefulness of environmental policies.

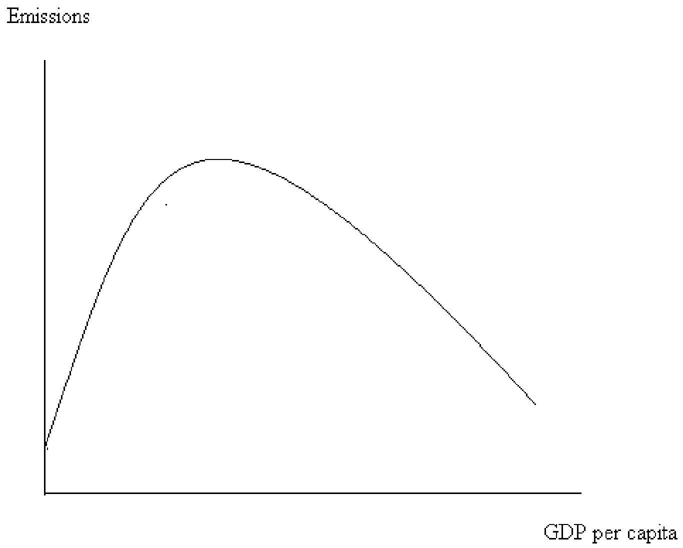

Figure 1: An illustration of a hypothetical Environmental Kuznets Curve

Most scientists consider it likely that if the atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases continue to rise, the earth's climate will eventually become warmer. While relatively little is known about the likely costs and benefits of such warming, it seems clear that both depend critically on the rate at which warming occurs. The rate of future warming depends, in turn on a number of poorly understood natural processes and on future emissions of greenhouse gases. Key climate processes involve long lags, and GHGs remain in the atmosphere for many years after they are emitted. The consequences of a warmer global climate may be quite different for different countries, but the environmental changes themselves depend only on worldwide aggregate emissions.

The crucial question is then whether or not there is any predictability in the relationship between CO_2 emissions and economic growth. If it is possible to establish how certain mechanisms play a role in the relationship, and in particular, if there is anything automatic about the relation as income increases, the policy implications are great.

This paper explores the mechanisms behind the relationship, and for which pollutants the relationship exists. Specifically, whether or not the relationship exists for CO_2. Section 2 reviews the hypothesized mechanisms behind the EKC. They can be categorized into income effects, international trade and resource prices. Income effects can be described as the changes in preferences that come about due to increases in income. It is expected that the willingness to pay for a clean environment is low when income is low, and increases along with economic growth. Some theories have been put forth assuming thresholds in income, output or pollution. Only when the thresholds are passed environmental quality is prioritized, or it improves due to increasing returns in abatement. International trade can be thought of "pollution leakage": as countries become developed, the dirty industries producing pollution-intensive goods move to less developed countries, while the goods are exported back to the developed countries. According to Hotelling's rule, resource prices will increase as the resource becomes scarcer in supply, and this will bring about a shift in demand away from the resource to alternative resources as well as intensification per unit of the resource used. Section 3 reviews the characteristics of the pollutants. Roughly speaking, the pollutants can be categorized into local and global pollutants, respectively. Local pollutants have direct effects on the polluters, and pose fewer problems with regard to policy in terms of preserving the environment. Global pollutants, on the other hand, are greenhouse gases (GHGs) that accumulate in the atmosphere, and thus have global impacts that affect not only the global population today, but also in the future. Section 4 explores the role of the democracy and institutions in establishing the mechanisms behind the pollution-income relationship. Section 5 reviews the empirical evidence of the EKC. Two main methods have been used to explore the empirical relationship, namely econometric analysis and decomposition analysis, respectively. The econometric evidence points to there being EKCs only for local air pollutants, while indicators with a more global, more indirect, environmental impact either increase with income or else have high turning points with large standard errors. The decomposition studies point to there being two main reasons for reductions in emissions: the type of energy used in production has changed; and the amount of energy used per unit of output. Section 6 discusses and concludes.

2 Explanations for the EKC

Sectoral change

Sectoral change can be thought of through the following framework: developing countries start out with the economy grounded in mainly subsistence economic activity, such as agriculture, fishing, and hunting, where little pollution is generated. Eventually the economy will industrialize, and start producing manufacturing goods, which will result in pollution rising monotonically with output (unless pollution regulation and/or abatement technologies are readily available). As income is increasing, the structure of the economy changes from being primarily in pollution-intensive industries to service-based industries. As a result, one can expect the environmental quality to improve (Arrow et al (1994), World Development Report (1992)).

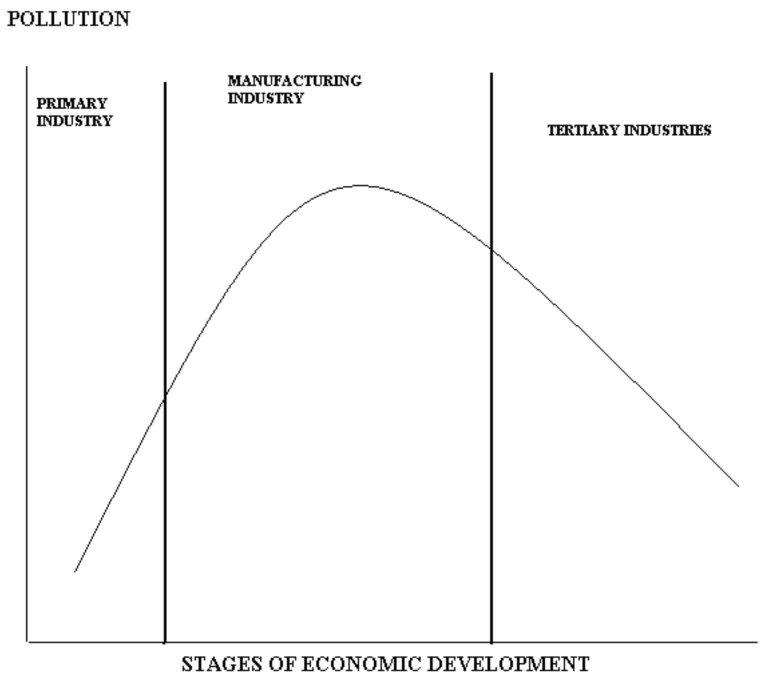

Figure 2: Stages of economic development

The growth in production of a particular sector relative to the growth in other sectors depends on two factors: whether or not it is producing a normal good or a necessary good; and whether the growth in productivity is higher than the average growth in the economy. Sectors producing luxury goods will grow faster than other sectors, everything else the same. Sectors with higher-than-average growth in productivity will be able to produce more, and thus offer lower prices, increasing the demand for their goods. Agricultural goods, i.e. food, can be considered necessary goods that cannot easily be substituted for other goods, and thus agricultural production will grow less than the average in the economy. Industrial goods can be considered luxury goods when income is low, so the industrial sectors will grow faster than the rest of the economy at a low income level. As income continues to grow, industrial goods become necessary goods, and combined with reduced productivity growth, one can expect to see a downturn in industrial production. Many service-based sectors produce goods that can be considered luxury goods. In service sectors the technical progress can be expected to be small.

Second, sectoral changes are observed because pollution-intensive production is moved to other economies further to the left on the stages of development curve. These goods are then exported back to the economies on the right side of the curve. There will be a downturn in emissions in the rich countries, but as there is no elimination of the pollution, only a geographical shift in pollution, the problem is rather 'put on hold' than solved. Eventually there will not be poor countries to which the richer countries about to transition into the third stage can move their production to, and thus only in the richest countries will one observe a downturn in emissions.

2.1 Income effects

Income effects, as mentioned above, are the effects that come about to changes in preferences as income changes. If preferences are homothetic, the demand for all normal goods increases proportionally with income: one percentage change in income brings about one percentage change in willingness to pay for a good. If preferences are non-homothetic, a percentage change in income does not bring about a percentage change in demand for a good. Then it depends on the type of good: if the good is luxury good, the demand for the good might be low or non-existent at low incomes, but if there is a unit income increase, the demand for the good increases with more than a unit. Thus, as income per capita grows high, and environmental quality is a luxury good, the share of income spent on environmental quality will be higher the more income increases. The preferences of the public can be expressed through the willingness to pay for goods (*WTP*). If the share of *WTP* for environmental quality over income (y) is given by

$$s = \frac{WTP\ (y)}{y}$$

When the increase in the share of WTP as income increases is positive:

$$\frac{\partial s}{\partial y} > 0$$

The income elasticity of demand for environmental quality is greater than one:

$$\frac{\partial WTP}{\partial y}\frac{y}{WTP} > 1$$

In words, if the willingness to pay for environmental quality increases relative to other goods when income goes up, or equivalently, if the demand goes up by a greater proportion than income increases, environmental quality is a luxury good. In this case, preferences are non-homothetic and s will increase with income. Superficially, the Environmental Kuznets Curve can be seen as evidence that environmental quality decreases monotonically with income as pollution rises. At a certain income, the concern for the environment is getting so pronounced that it is counteracting the scale effect of income increasing (and consumption increasing with it). This concern for the environment means that s has grown so large that environmental degradation improves as a result of pollution decreasing.

Environmental quality is a normal good if the demand goes up by the same proportion as income. Normal goods mean that the income elasticities of demand are positive. Thus, concern for the environment will increase at the same rate as demand for other goods, in absolute terms. One can say that there is an inflated demand for all types of goods. In this case, preferences are homothetic, in which a percentage increase in income leads to a percentage increase in consumption, everything else the same. An income elasticity of demand for environmental quality between zero and one implies that the share of willingness to pay for the environment will not increase as income grows, it will stay the same. This in turn implies that there will not necessarily be an 'induced policy response' as a result of economic growth, and environmental degradation will continue.

2.1.1 Homothetic preferences

In his model, Lopez (1994) has assumptions on production such that any increase in output will be followed by a proportional increase in pollution. Even if polluters pay the full social cost of pollution, such that all externalities are internalized, pollution will increase with economic growth if preferences are homothetic. In this scenario, even if consumers are concerned with the environmental quality, their marginal propensity to consume is so great that it counteracts any effect that environmental concerns might lead to, such as a higher share of 'green goods' in consumption. The only way to preserve the environment is to stop economic growth. If preferences are non-homothetic, the way pollution grows with income will depend on the elasticity of substitution between pollution-intensive inputs and non-pollution inputs in production.

2.1.2 Threshold models

The common characteristic for the following models – threshold models- is that abatement technologies are not undertaken until thresholds are reached in output, consumption or pollution. Generally, one can say that these thresholds are reflections of income effects: income needs to reach a certain level before it is optimal with to invest in the environment.

Threshold in output/income:

Selden and Song (1994), John and Pecchenino (1994), and Stokey (1998) developed models where there is a threshold in output (or equivalently, in income). Abatement is not undertaken before the threshold. The downturn in emissions after a period of pollution increasing monotonically with income is explained by there being abatement in production once the threshold is reached. Jones and Manuelli (1995) developed a model where there is threshold in development in institutions. Only after this threshold is reached, institutions are developed enough to deal efficiently with pollution through environmental regulations and policies.

A representative consumer has preferences for consumption and environmental quality such that utility is given by

$$U\ (C, E) = \ln C + \ln E$$

Production *X* can be thought of as potential production where *X* can be consumed through consumption *C* or spent on abatement *A*(where δ is a parameter with value between zero and one):

$$C = X - \delta A$$

The environmental quality in the economy is given by

$$E = E_0 - P + A = E_0 - X + A$$

Rearranging, we get the expression for abatement, *A*:

$$A = E - E_0 + X$$

Inserting the expression for A into the budget constraint, we get

$$C = X - \delta(E - E_0 + X)$$

$$C + \delta E = (1 - \delta)X - \delta E_0$$

The above expression can be interpreted as the budget constraint (denoting M as income), such that we can write

$$C + \delta E = M = (1 - \delta)X - \delta E_0$$

Now, the social planner has the problem

$$\max U\ (C, E) = \ln C + \ln E$$

subject to

$$C + \delta E = M$$

We get first order condition

$$C = \delta E$$

The *marginal rate of substitution* measures the rate at which a consumer is ready to give up one good in exchange for another good while maintaining the same level of utility. Marginal utility of consumption is given by $U_C = \frac{1}{C}$, while marginal utility of environment is given by $U_E = \frac{1}{E}$. Thus, the marginal rate of substitution is

$$MRS = \frac{U_E}{U_C}$$

If the consumer puts higher value on consumption C than environmental quality E, or equivalently: $U_C > \frac{1}{\delta} U_E$, there will be no abatement, *A = 0* - and one unit of production will be equal to one unit of consumption which in turn will produce one unit of pollution , *X = C = P*. This makes intuitive sense if initially there is little pollution, and little consumption, which will leave E to be relatively large. Only when the environmental degradation becomes great enough, consumers are willing to sacrifice consumption in order to have more environmental quality. Then the marginal rate of substitution is equal to one, and we have $U_C = \frac{1}{\delta} U_E$, or equivalently, $E = \frac{1}{\delta} C$.

$$C + \delta E = M = (1 - \delta)X - \delta E_0$$

$$2\delta E = X(1 - \delta) + \delta E_0$$

$$E = \frac{1}{2\delta} \left(X(1 - \delta) + \delta E_0\right)$$

This expression for *E* is inserted into the expression for *A*:

$$A = \frac{1}{2\delta} \left(X(1 - \delta) + \delta E_0\right) - E_0 + X$$

$$A = X + \frac{1}{\delta} X - E_0$$

The turning point is given by

$$X = E_0 \left(\frac{1}{(1 + \delta)}\right)$$

$A \geq 0$ is no longer binding, and we have environmental quality increasing in production.

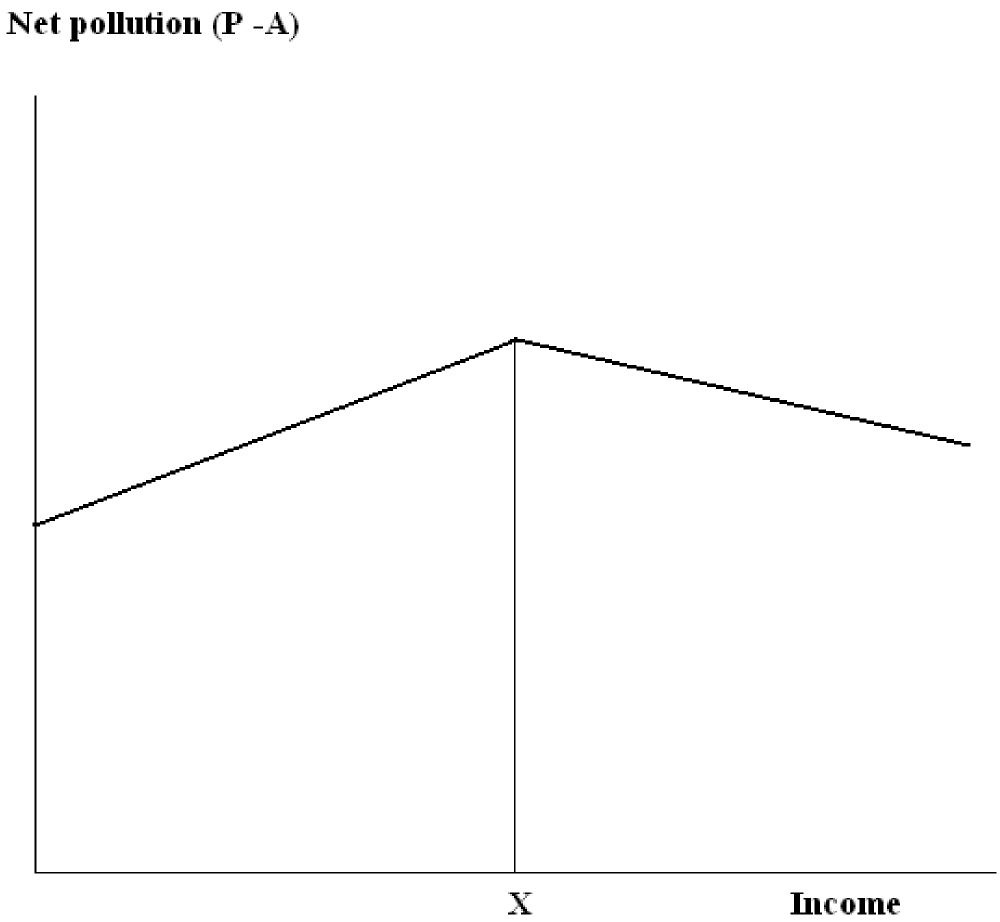

Figure 3: Threshold in consumption.

In this model, it is not optimal with abatement in production until output reaches X^*. Before this point, output is too low to justify expenses on the environment, but at X^* the consumer's marginal benefit from additional consumption is less than the marginal benefit of environmental quality. Abatement comes about immediately as a result of willingness to pay for a clean environment.

In the above static model, there is one representative consumer maximizing utility with respect to the budget constraint. If the number of consumers were two or more, there would be externalities from consumption. The agents would maximize their utility taking only their private disutility from pollution into account when choosing optimal consumption level, while the socially optimal outcome will only come about if the agents maximize total disutility from income. Our interpretation of the model is that the main focus is to maximize social welfare, and we assume that there is a benevolent government that can implement the appropriate policies and regulations. Thus, the model predicts an environmental Kuznets curve when this is the case.

In Stokey's model there is a choice of production technologies and before the threshold only the dirtiest production techniques are used. With the dirtiest production technology, pollution rises linearly with income until the turning point is reached, where cleaner technologies are available. This creates an inverted-V shaped curve, similar to curve illustrated below. In the overlapping-generations model by John and Pecchenino (1994), environmental quality is a stock resource which degrades over time unless maintained by investment in the environment. Their results are similar to the model above, with the pollution-income curve having an inverted-V shape. However, in an overlapping-generations model, the actions (in this case, consumption) of the agents have consequences that outlive them. The consumption of the agents degrades the environment bequeathed to the next generation, so if there have not been investments in environmental quality ($A = 0$) in the prior generation, the current generation will require more investment in order to stay at the same utility level. Selden and Song (1995) describe a variety of possible pollution-income paths in their dynamic model, getting an inverted-U shape for the pollution-income relationship and a J-shape for abatement. Jones and Manuelli (1995) More general versions of the threshold model above have been developed, with pollution either as a product of consumption, or production as seen in this model (McConnell, 1997); Lieb, 2002).

Threshold in pollution: increasing returns to scale in abatement

Andreoni and Levinson (2001) show in their model that an Environmental Kuznets Curve can be derived directly from the technological link between consumption of a desired good and abatement of its undesirable by-product. Utility of a representative consumer is increasing in consumption and decreasing in pollution, and is given by

$$U(C,P) = C - \theta P$$

The budget constraint of the consumer is given by $M = C + E$, where M denotes income. Pollution is created by consumption, but reduced by abatement:

$$P = C - A$$

Abatement is given by

$$A(C,E) = C^{\alpha}E^{\beta}$$

Thus pollution can be written as

$$P = C - C^{\alpha}E^{\beta}$$

Assuming that $\theta = 1$ the utility is $U(C, E) = C^{\alpha}E^{\beta}$. Maximizing utility subject to $C + E = Y$ yields the following first order conditions:

$$C^{*} = \frac{\alpha}{(\alpha + \beta)}M$$

$$E^{*} = \frac{\beta}{(\alpha + \beta)}M$$

This gives the optimal pollution level:

$$P^{*}(M) = \frac{\alpha}{(\alpha + \beta)}M - \left(\frac{\alpha}{(\alpha + \beta)}\right)^{\alpha} (\frac{\beta}{(\alpha + \beta)})^{\beta} M^{\alpha+\beta}$$

The derivative of this equation represents the slope of the EKC, in which the slope depends on α and β. When $\alpha + \beta = 1$, $\frac{\partial P}{\partial M}$ is constant. Then the effort spent on pollution abatement has constant returns to scale. When $\alpha + \beta < 1$, the effort spent abating has diminishing returns to scale, and the pollution function is convex. When $\alpha + \beta > 1$, the effort spent on pollution abatement has increasing returns to scale, and the pollution function in concave.

In this model, there are no fixed costs. However, one can think of a small economy where implementation of abatement technology requires large fixed costs, but has a low marginal cost. Initially, there is too little pollution to get a good return on the abatement, but as the share of pollution-intensive goods in the economy; the high fixed cost-technology may become cost-effective. Thus, for a larger economy the marginal cost of abatement can be less than that of a smaller economy, and if this is the case, the abatement technology will have increasing returns to scale.

This can be called a threshold model (and thus brought about by income effects) because the point where abatement becomes cost-effective is a threshold, although this threshold differs for different pollutants and it depends on the size of the economy. Still, the more gross pollution there is before abatement is undertaken, the cheaper it is to abate per unit of pollution. This means that output (and income, assuming a linear relationship between output and income) needs to grow to a certain turning point before abatement becomes economically beneficial. Andreoni and Levinson illustrate that this model can be seen as a more general version of the some of the other models in the literature. The model of Stokey (1998) and Selden and Song (1994) can have fixed costs in abatement technology, and this causes the threshold. Only when the output reached the threshold in production the abatement will be cost-effective. In the model of Jones and Manuelli (1995) there are fixed costs, or IRS, in setting up environmental regulatory mechanisms. Only advanced economies are developed enough to have political processes that can correctly internalize externalities: a benevolent government that can implement the appropriate policies and regulation is needed to bring about the social optimum.

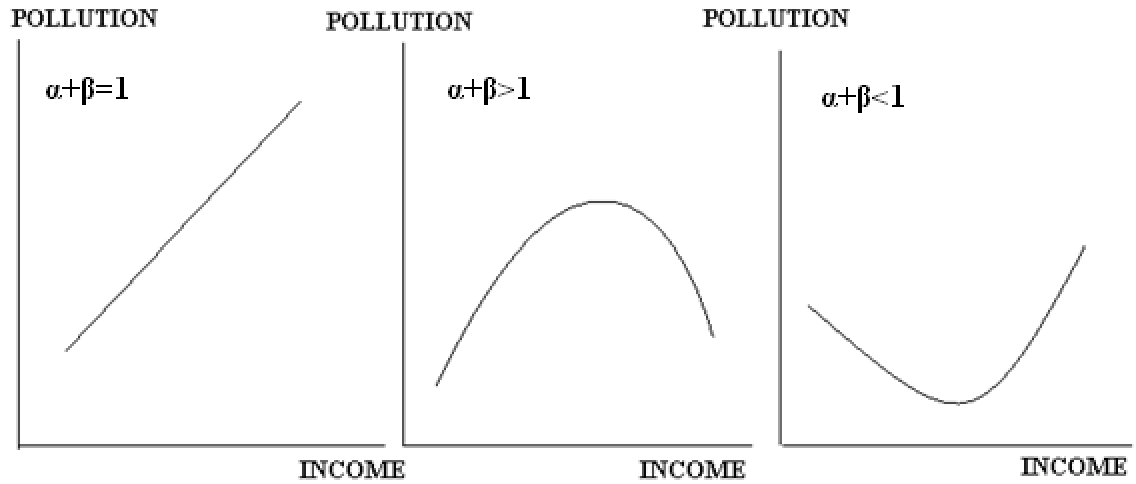

Figure 4: Shapes of the pollution-income relationship given the values of returns to scale.

2.2 International trade

International trade can serve as explanation for the downturn in the EKC through two main hypotheses: “displacement” and “pollution haven hypothesis” (Copeland and Taylor, 1994). If changes in the structure of production in developed countries are not accompanied by equivalent changes in the structure of consumption, the EKC relationship simply shows the displacement of dirty industries to less developed countries. The “pollution haven hypothesis” claims multinational firms relocate their pollution-intensive production to poor countries with little regulation. In any case, the cause of weak regulation in less developed countries can be due to many factors.

First, weak regulation can be a result of little willingness to pay for environmental quality in poor countries, as well as underdeveloped and undemocratic institutions. If these factors can explain the lack of environmental policies, then becoming rich will be a solution to environmental problems. Second, weak regulation can come about as a way of competing on the world market, in the sense that poor countries have comparative advantage in weak regulation. This can be working together with a low willingness to pay for environmental quality, as well as bad institutions.

If international trade is indeed responsible for the downturn in emissions observed in some developed countries, as suggested by Arrow et al (1994), there is a geographical shift rather than elimination of pollution. For the system to continue to function, other countries at lower stages of development enter the international trade arena and become net exporters of products that cause pollution and high pressure on finite natural resources. This means that there might not be any environmental gains from a global perspective if some developed countries show the EKC pattern.

2.3 Resource prices

A “self-regulatory market mechanism” has been suggested to account for the downturn in the EKC (The World Bank, 1992; Moomaw and Unruh, 1997). Natural resources are heavily exploited at the outset of industrialization, but as prices of natural resources start to reflect their actual value; resources are used more efficiently at later stages of growth. This reduces the environmental degradation associated with the use of the resources. Higher prices also force producers to shift to less resource-intensive technologies (Torras and Boyce, 1998).

The main cause of carbon dioxide emissions worldwide is use of fossil fuels for energy consumption in both production and households. Economic theory predicts that as resources become scarce, resource prices will rise and this will encourage producers to search for cheaper substitutes and increase factor productivity. The market generates signals and incentives which ensure that discovery and substitution are carried out at an appropriate intensity. Hotelling’s rule for the extraction of non-renewable resources says that the present value of the resource must be the same for every point of time in the future. The rate of change in the price of the resource is equal to the discount rate:

$$\frac{\dot{p}}{p} = r$$

If this was not the case and the owner of the resource believed that the discounted profits would be higher at some point in the future, it would be economically rational to cut current production and wait until profits increased. Uncertainty about the future and concerns about receiving returns on investments increase rates of discount. For an oil company working in a country without a stable government putting restrictions on the rate of extraction, the primary goal will be to get a financial return on their investment as fast as possible.

The Hotelling rule says that the real prices of fossil fuels should increase over time. This implies that there will be lower demand for fossil fuels over time. As income grows, there should be a downturn in emissions, giving the environmental Kuznets curve.

For exhaustible resources such as coal, oil and ores cheapest sources are used first and then the more expensive ones follow. As the resource becomes scarcer, costs keep rising and the price with it. Production falls and finally stops when the resource becomes so costly to extract that consumers will no longer pay for it. The price of oil should in theory be stable, since oil is a normal good and oil production is flexible.

However, the existence of the OPEC cartel controls output from the different producers in such a way that the price stays higher, and does not follow supply and demand it otherwise would have done. As Adelman (2002) puts it "*the oil price is high and unstable because the competitive thermostat has been disconnect*ed". But the problem (at least not the problem addressed here) is not the lack of competitive prices of fossil fuels. Rather, the issue at hand is that despite high prices, consumption of fossil fuels is still too high relative to the rate at which CO_2 is accumulated in the atmosphere. Thus, in order to bring down demand of fossil fuels, and induce substitution of fossil fuels to alternative energy sources, the prices need to be regulated.

2.4 Issues concerning the explanatory mechanisms

Kriström and Riera (1999) review a number of studies of willingness to pay for environmental quality, and find that the income elasticity of demand is between zero and one. This implies that environmental quality is indeed normal but not a luxury good. This in turn implies that dealing with dealing with environmental problems when rich is not an optimal course of action for poor countries. Lieb (2002) points out that a large part of the models explaining the EKC shows that in order to have an inverted-U pattern for the income-pollution relationship, environmental quality must be a normal good (Lopez, 1994; John and Pecchenino, 1994; Selden and Song, 1995; Stokey, 1998).

Obviously, as it is difficult, if not impossible, to measure environmental quality and consumers' willingness to pay, the discussion on the income elasticity of demand for environmental quality becomes nothing more than a pointer to what the true elasticity is. One can assume that a high acceptance for environmental regulation and taxes reflect increased willingness to pay for the environment.

Kriström and Riera (1999) advocate that poor countries should be allocated larger shares of emission rights in international agreements, such as the Kyoto Protocol, if the income elasticity of demand is between zero and one. An income elasticity of demand for environmental quality between zero and one will imply that if the share of willingness to pay for a clean environment in poor countries (expressed through environmental regulation and taxation) is not high to begin with, emissions will increase substantially with income before the concern for environment becomes pronounced enough to deal with the emissions. Thus, in order to curb emissions early, giving the poorer countries larger shares will give them opportunity to grow as well as allowing them to control emissions through the quota system. A high income elasticity of demand for environmental quality may not be sufficient or even necessary for pollution emissions to decline at later stages of development. Other factors besides growth in per capita income may be relevant in leading high-income countries into the downward-sloping segment of the EKC.

As Stokey points out, the optimal regulation problems analyzed in her paper can be interpreted as models of democratic societies in which income is not too unequally distributed. This puts a constraint on the generalizability of the threshold model, as it is meant to be applicable only in democratic economies with an equal distribution of income. The scope of the discussion on the effect on income distribution within a country versus a representative consumer is too extensive for this occasion. How the optimal pollution level differs from the viewpoint of the individual agent, as he will only maximize his own private benefit, from the optimal level of the social planner, will be analyzed in greater detail in section 3.

Andreoni and Levinson (2001) point out that in their model that different pollutants have differing pollution-income shapes depending on their returns to scale. They argue that this does not mean that countries should pollute more and be less concerned with environmental regulation, as a laissez-faire attitude towards pollution could easily result in an inverted-U shaped curve for the pollutant in question, but the amount of pollution at every point will be inefficiently high. Also, they point out that based on the abatement technology, the pollution-income relationship can take on any shape. They expect that for different pollutants, with different abatement technologies, the curves may or may not be inverse-U-shaped.

3 Local and global pollution

In the output threshold model described in section 2.1.2, the social planner can implement the social optimal outcome which internalizes all externalities because there only one representative consumer. In a model with N consumers, the individual utility of each consumer is given by

$$U_i = C_i(P_i) - D_i\left(\sum P_j\right)$$

Where $C_i(P_i)$ denotes the consumption of consumer i and where consumption generates pollution P_i. The function $D_i(\sum P\ )$ is a measure of the environmental costs, which depends on the value of total pollution generated by total consumption in society. Each consumer will choose their pollution level such that

$$C_i'(P_i) = D_i'(\sum_j P_j) \quad (1)$$

This level of pollution does not take into account the damage, or disutility, their pollution causes other agents in society. The social optimal level of pollution that does take this into account is given by

$$C_i'(P_i) = \sum_j D_j'(\sum_j P_j) \quad (2)$$

To correct for this externality problem, the government introduces an emission tax q. Consumers react to this tax by choosing pollution so that their marginal consumption is equal to the tax rate (assuming that the values of the marginal consumption and marginal damage cost can be measures in monetary terms):

$$C_i'(P_i) = q \quad (3)$$

This tax is a Pigovian tax, where all externalities are internalized. This expression gives us the marginal willingness to pay for environmental quality, or *the social cost of pollution*. The consumers will now choose to consume such that

$$C_i'(P_i) = q + D_i'(\sum_j P_j)$$

(The last term on the right hand side is negligible when the number of consumers N is large, which it is in the case of the pollution problems addressed here.)

3.1 The social cost of pollution

The social cost *q* values the consumers' marginal utility of environmental damage in comparison to the marginal utility of consumption. Equivalently, *q* measures the relative marginal willingness to pay for environmental quality. Economic growth can increase the value of the environment for consumers. If this value is manifested in the market, firms will have to pay an increasing price for pollution-intensive inputs. A high elasticity of substitution in production between normal inputs and pollution implies that for firms it is less costly to reduce pollution by substituting it for other inputs.

However, the marginal willingness to pay for environmental quality by consumers does not necessarily take into account the actual social cost of pollution. Consumers will choose a pollution level such that their marginal benefit of pollution is equal to the marginal private cost of pollution. In a social optimum, consumers must instead choose their pollution level such that their marginal private benefit is equal to the marginal social cost of pollution.

In addition to the market failure decribed in the above section, the demand for a clean environment by individuals today does not reflect the value of demand in the future. Some environmental problems arise because of the long time scales involved before the consequences of the current actions will materialize. The true costs of current actions fall not on the current generation but a future generation. In making their decisions the current generation give little or no weight to the costs borne by the future population.

Second, there is distinction between the willingness to pay for environment and the value placed on environment. Individuals with a low income might put a high value on the environment, although their willingness to pay for it will not reflect this value.

Third, even if willingness to pay is used as an indicator of demand for environmental quality, the existence of market imperfections will affect the willingness to pay for the environment: lack of knowledge among the poor (who tend to be less educated than the rich) about the adverse effects of environmental degradation; producers not paying the full social price of their inputs (such as natural resources) and the social cost of the externalities from polluters, who are then imposing their burden of production on others at little cost (Munasinghe, 1999).

3.2 Local pollutants

Certain indicators of pollution, such as emissions of sulphur dioxide and nitrogen oxide, access to clean water, urban sanitation, waste and deforestation, are of a category where the effects of pollution are felt on a local[1] level, and more or less directly by the polluters. This means that the more pollution a society generates the more negative consequences it will experience as a result. For pollutants with local effects it has been possible to recognize EKC relationships with various successes (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992; Panayotou, 1993; Cole et al, 1997. For extensive surveys on the EKC literature, see Ekins (1997) and Stern (2004)). Local environmental problems such as lack of clean water and urban sanitation systems, as well as high urban smoke and dust concentrations, normally will be solved early in a development process. These are problems that have a direct on welfare and in turn will generate a demand for the appropriate infrastructure and regulation. In line with the model above, the regulators can implement a Pigovian tax that will internalize all the externalities of the pollution:

$$C_i'(P_i) = q$$

In real life, Pigovian taxes are difficult to implement. Direct regulation is viewed as having a higher cost to society because Pigovian taxes raise revenue and respond automatically to changes in the market such as lowered cost of production or pollution mitigation. With a

[1] "Local" referring to effects whose costs are felt by populations within a certain geographical area, not necessarily within the borders of the polluting country.

Pigovian tax there is always an incentive to reduce pollution, whereas with direct regulation, a polluting company has no incentive to pollute any less than what is allowable. However, to attain an efficient pollution level, knowledge of the benefits and damages of pollution is required. Environmental regulators will in practice have limited information when making pollution control decisions are to be made.

3.3 Global pollutants

Another group of pollutants which we will here refer to as global pollutants, such as CO_2 and other greenhouse gases, have potential global impacts of the emissions. In the case of CO_2, one can consider the atmosphere a common pool resource over which property rights are not assigned. Assume $\boldsymbol{W_i}$denotes welfare of country *i*, $\boldsymbol{F_i}(\boldsymbol{P_i})$ denotes the revenue of country *i* and $\boldsymbol{D_i}(\sum_j \boldsymbol{P_j})$ is the damage of total pollution to country *i*. Then we have

$$W_i = F_i(P_i) - D_i(\sum_j P_j)$$

This expression is equivalent to the utility function of the individual consumers above. The same point is valid here concerning the optimal pollution level. Here, we can think of $F_i'(P_i)$ as the chosen abatement level of country *i*. Each country will maximize their welfare, while taking emission levels of other countries as given.

$$F_i'(P_i) = D_i'(\sum_j P_j)$$

Instead, the marginal abatement cost in country *i* should be equal to the sum of marginal environmental costs its emissions causes in all countries:

$$F_i'(P_i) = \sum_j D_j'(\sum_j P_j)$$

If there existed an international government being able to regulate the global level of emissions, a Pigovian tax could be devised and levied on each country in order to bring about the socially optimal level of emissions. However, this will not be the abatement level chosen by the individual countries. If all countries were to cooperate on reducing global emissions, they would all benefit from being in the cooperative equilibrium. The optimal strategy for every country will be to free-ride on the other countries, benefiting from the reduced damages resulting from there being less pollution from all other countries, but not reducing own emissions. Thus, we will end up in an equilibrium where nobody cooperates, as they will all gain more from free-riding than cooperating – and as a result, everyone is worse off.

3.3.1 CO_2 and climate change

In order to deal with the global pollution problems, a supranational institution is needed to implement appropriate policies. These policies can be direct regulation, Pigou taxes or quota systems – either way they will bring about a more socially optimal level of global pollutants. In the case of CO_2, the legitimacy of such a supranational institution is called into question by critics being skeptical of the scientific proof of climate change. Thus, political and public debate continues regarding global warming, and whether or not to take (any) action in response. Emissions of CO_2 caused by human activity are considered to be one of the main causes of increased concentrations of CO_2 in the atmosphere. CO_2 make up about 80 percent of all greenhouse gases emitted globally. Carbon dioxide (and other greenhouse gases) traps heat in the lower atmosphere. Radiative forcing, the degree of warming GHG transmits to each square meter of the earth's surface, varies with a gas' concentration in the atmosphere and its ability to absorb infrared radiation (IPCC, 2007). According to the Intergovernmental Panel on Climate Change (IPCC), emissions resulting from human activities are substantially increasing the atmospheric concentrations of greenhouse gases, resulting on average in an additional warming of the Earth's surface. They have estimated that the global temperature change over the coming century to be from 1.8 to 4° C. To put this into perspective, the change in temperature is much more rapid than any changes that have occurred in the past 10,000 years. On a global scale, GHG emissions have increased with 70 % between 1970 and 2004, which have led to a marked increase in atmospheric GHG concentrations (IPCC, 2007). The IPCC estimates that with the current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next decades. Potential impacts of climate change (the most important one being temperature changes) on the natural and human environment include sea-level rises, implying major changes in coastlines and ecosystems. The costs of relocating populations, economic activity and infrastructure can potentially be very large (IPCC, 2007).

4 The role of government

4.1 Democracy and institutions

The elasticity of marginal willingness to pay for environmental quality can be seen in relation to both environmental awareness and environmental regulation regimes. How individuals value the environment can be translated into aggregate demand, in terms of political pressure and "greener" consumer demand. This, in turn, can be translated into demand on the part of the government for environmental policies, and shift in production and technologies towards more environmentally friendly activities. The government translates consumer demand into binding regulations that apply to polluters. Grossman and Krueger (1991) explain the observed downturn in emissions as a result of "induced policy response" – as a society becomes wealthier, the public will demand stricter policies directed towards environmental preservation – and the policies that come about due to public demand will induce a decline in emissions.

4.1.1 Implications for policymakers

If there is a development path with primary, secondary and tertiary “stages” of production for countries experiencing growth, the optimal course of action for policymakers is to encourage economic growth, as this will bring about both increasing incomes as well as improved environmental quality once the "tertiary" stage is reached. However, unless there is a government that can set regulations such that the marginal private benefit of pollution is equal to the marginal social cost of pollution, as seen in equation (2) , the level of pollution will be higher than what is optimal (as shown in equation (1)).

With thresholds in either production output or pollution level, encouragement of economic growth will be optimal, although the existence of a benevolent social planner being able to set regulations and policies such that abatement is carried out is crucial. The level of pollution will be higher than what is optimal unless a regulator can internalize the externalities of pollution. Regulations and taxation will put restrictions on pollution, causing the environmental degradation to slow down as a result of producers having to substitute dirty inputs and technologies for cleaner ones or forcing consumers to buy more environment-friendly goods than before. For example, taxation on leaded gasoline in Norway led to lead emissions being almost completely eradicated. In the absence of taxes, governments can impose regulations on sources of pollution and levels of safety for the public.

The pollution-exporting hypothesis implies that international trade- and capital controls may be necessary to preserve environmental quality, as there will be a geographical shift rather than elimination of pollution. As more stringent environmental policies acts as a deterrent to dirty good production, the pollution-intensive production will be concentrated in developing countries. Transfers of technology from developed countries to developing countries will be one way of solving the problem.

In the case of greenhouse gases, the observed relationship between total emissions and income is monotonically increasing in most developed countries. While the exact future pace and extent of global warming is uncertain, there is little doubt that climate change will have large economic and environmental costs. The task for the policymaker is to weigh the cost of slowing climate change against the damages of more rapid climate change. Not doing anything - leaving emissions unregulated - seems like an incredibly risky endeavor as warnings of potential doom in the future are being voiced.

Competition in the market of natural resources will potentially have adverse effects on the environment as there is no global equivalent to national governments in controlling the pollution. The use of market forces to environmental problems will most likely just exacerbate the existing environmental problems we see today, as price competition will bring about a lower price encouraging higher demand. For instance, there is no effective market incentives for developing countries like China to avoid repeating the problems experienced in industrialized countries in the use of coal.

The regulators can help correct the failing markets by levying taxes on fossil fuels: carbon taxes, and thereby raising the prices of fossil fuels. The “carbon price” can be said to be the price of emissions of carbon dioxide. One can look at it as the social cost of carbon- the present value of additional economic damages now and in the future caused by additional carbon emissions. This cost of carbon can be “materialized” through taxes on carbon emissions; or a cap- and-trade system as in the Kyoto Protocol. Nordhaus (2007) estimated the social cost of carbon to be $30 per ton. Policies that beneficial in their own right, such as abandoning coal and agricultural subsidy programs and liberalization of energy markets, will be another way of curbing emissions.

How the social costs of carbon dioxide emissions are decided upon depends on the discount rate used. If the discount rate is high, it is beneficial to not reduce emissions today, but rather encourage economic growth and put abatement “on hold”. On the other hand, if the discount rate is low, the optimal strategy involves reduction of economic growth and a high level of current abatement.

Under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), industrialized countries have committed themselves to legally binding emissions targets, and must reduce their emissions of six greenhouse gases by at least 5 % below 1990 levels over the commitment period 2008 - 2012. The UNFCCC is an international environmental treaty with the goal of achieving "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." (UNFCCC, 1998)

The Protocol offers countries three market-based mechanisms in meeting their targets, in addition to any national measures undertaken by the individual countries: emission trading through a “cap-and-trade”[2] system; clean development mechanisms (CDM)[3]; and joint implementation[4].

[2] Emission trading allows countries having excess emission capacity to sell these to countries with too little emission capacity quotas.

[3] Clean Development Mechanisms allows developed countries with emission-limitations to implement sustainable development projects in developing countries. Such projects earn emission reduction credits, which can be counted towards meeting Kyoto targets.

[4] Joint Implementation enables industrialized countries to carry out joint implementation projects with other developed countries.

5 Empirical EKC studies

The early empirical literature on the Environmental Kuznets Curve have consisted mainly of studies using an econometric framework, in particular the reduced form model using either a quadratic or cubic form to capture the relationship between pollution and income. Decomposition studies, a purely descriptive technique that can be used for analyzing determinants for changes in variables, have also been extensively used in analyzing CO_2 emissions. The following section reviews the framework used in most econometric EKC studies; then the early econometric EKC literature is reviewed, in particular the literature covering CO_2. Decomposition studies are then reviewed.

5.1 Econometric studies

5.1.1 Econometric framework

The framework used in the majority of studies in the EKC literature is the following reduced-form model:

$$P_{it} = \alpha_i + \gamma_t + \beta_1 Y_{it} + \beta_2 Y_{it}^2 + \beta_3 Y_{it}^3 + e_{it}$$

This basic functional form captures the relationship between GDP per capita and pollution. $\alpha_i$and γ_{it} are intercept parameters which vary across countries or regions *i* and years *t*.The assumption is that, though the level of emissions may differ over countries at any particular income level, the income elasticity is the same in all countries at a given income level. P_{it} is the environmental indicator. Y_{it} is GDP per capita. $\beta_1, \beta_2, \beta_3$ are parameters to be estimated. e_t is normally distributed error term. A significant, negative β_2 indicates the relationship between income and pollution is that of the environmental Kuznets curve. A significant, positive β_3 means that the eventually pollution will start to increase with income again.

With $\beta_1 > 0$ and $\beta_2 = \beta_3 = 0$, we get a monotonically increasing relationship between pollution and income. $\beta_1 < 0$ and $\beta_2 = \beta_3 = 0$ implies that the relationship between pollution and income is monotonically decreasing. If $\beta_1 > 0$ and $\beta_2 < 0$, $\beta_3 = 0$, we get the inverted-U-shaped relationship between pollution and income characterizing the Environmental Kuznets Curve. If $\beta_1 > 0$, $\beta_2 < 0$, $\beta_3 > 0$, the relationship is first positive –pollution increasing with income, then negative – pollution decreasing with income, and then finally, increasing again.

This is an N-shaped relationship. Inverted-U relationships between emissions and income have been found for e.g. sulphur dioxide emissions and concentrations by Shafik and Bandyopadhyay (1992), Panayotou (1993), and Selden and Song (1994), amongst others. The turning point of the EKC is given by

$$X_{TP} = -\frac{\beta_1}{2\beta_2} \text{ with } \beta_3 = 0$$

These estimated regressions are reduced-form relationships: they reflect correlation rather than a causal mechanism by which the growth process affects the environment. That makes it difficult to interpret the determinants underlying the relationship: as Grossman and Krueger (1995) pointed out, it is not clear why the estimated relationships exist and what kind of interpretation should be given to the coefficients. However, the advantage of working with this model is that the influence of income on environmental pressure is estimated directly.

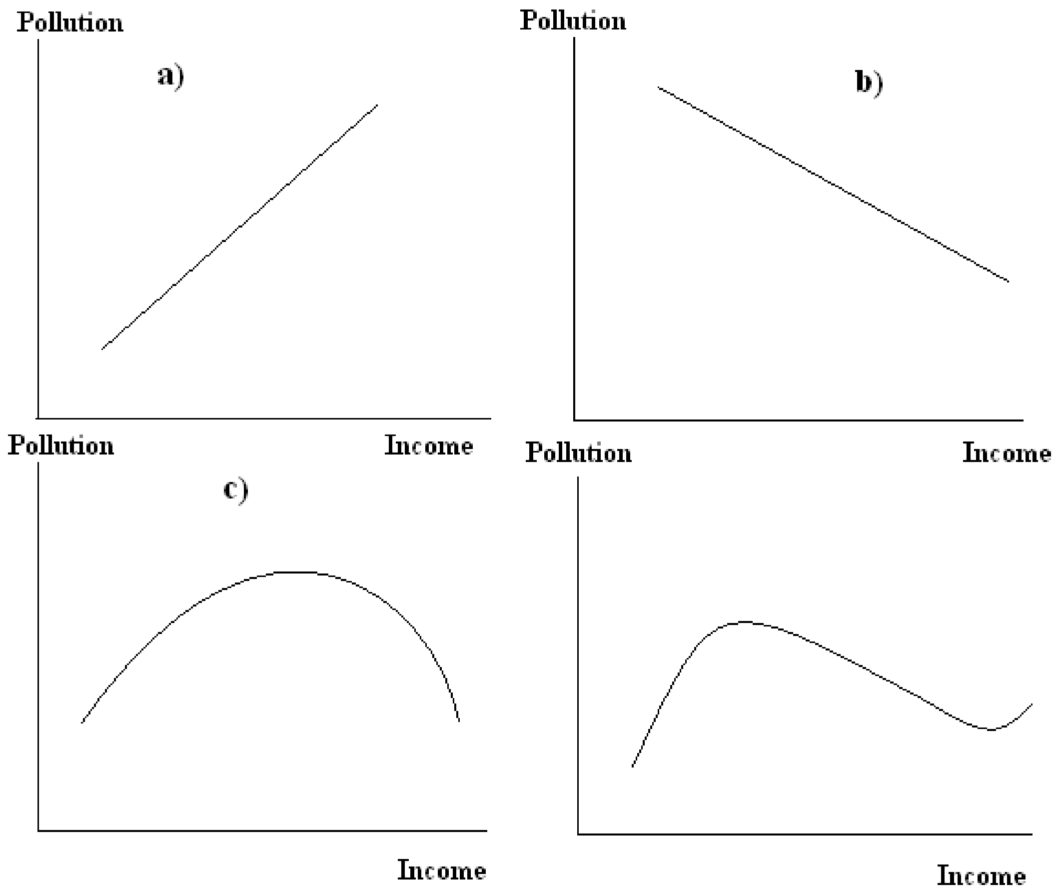

Figure 5: The various shapes of the pollution-income relationship.

5.1.2 Early empirical work on the EKC

Grossman and Krueger (1991) studied the impacts of the North American Free Trade Agreement on the environment, and estimated EKCs for sulphur dioxide (SO_2), fine smoke (dark matter) and suspended particles. They found turning points for SO_2 and fine smoke to be around $4,000-5,000, while the concentration of suspended particles seemed to decline at lower income levels. At income levels over $10,000-15,000 they found increasing levels of all pollutants, which point to N-shaped relationships between the pollutants and GDP per capita.

Shafik and Bandyopadhyay (1992) estimated the coefficients of relationships between income and environmental degradation for ten different indicators of environmental degradation as a part of a study for the World Development Report for 149 countries for 1960-1990. The environmental indicators are lack of clean water, lack of urban sanitation, ambient levels of suspended particulate matter, ambient levels of sulphur dioxide, rate of deforestation, change in forest area, dissolved oxygen in rivers, fecal coliform in rivers, municipal waste per capita and carbon dioxide emissions per capita. Lack of clean water and lack of urban sanitation were found to decline with increasing income, indicating a monotonically decreasing relationship with GDP per capita. The indicators for deforestation were found to be insignificantly related to GDP, with turning points around $2,000. The river quality indicators showed a negative relationship with income. However, both measures of local air pollutants showed inverted-U shaped relationships with GDP, indicating EKCs for both sulphur dioxide and suspended particulate matter. The turning points for both pollutants were found to be between $3,000-4,000. Both municipal waste and carbon dioxide emissions per capita they found to be monotonically increasing with income.

Panayotou (1993) estimated EKCs for SO_2, NO_x, suspended particulate matter and deforestation. He found turning points for deforestation to be $823 per capita. For SO_2 emissions per capita the turning point was given by $3,000 per capita, for NO_x $5,500 and for SPM around $4,500. Selden and Song (1994) estimated EKCs for SO_2, NO_x, SPM and CO. The turning points were given by $8,709 for SO_2; $11,217 for NO_x; $10,298 for SPM; and $5,963 for CO. They suggest that their higher turning points are due to their measures of pollutants being in kilograms per capita on a national basis instead of ambient concentrations, because ambient pollutions levels are likely to decline before aggregate emissions.

Cole, Rayner and Bates (1997) found that for local airborne pollutants, the turning points for concentrations of pollutants in urban areas would be at lower per capita income levels than for total emissions per capita. This can be explained by a higher income per capita for urban residents, which translates into a higher marginal willingness to pay for a clean environment and for instance, higher education level in urban populations.

Several papers have attempted to test the EKC in relation to international trade, amongst others Suri and Chapman (1998). But as Stern (2004) points out, testing for international trade may involve a multicollinearity problem, as international trade and income may be highly correlated.

Common for these early studies is that they all found turning points for several pollutants (SO_2, NO_x and SPM) in a similar income range of $3,000- $5,000 per capita. The finding by GK of all pollutants beginning to increase again after income levels over $10,000-$15,000 may be a result of the cubic equation used in the estimation and the limited number of observations at high-income levels. In general, the urban and /or local air quality indicators reveal the inverted-U relationship with income. For water quality, there is evidence of EKCs for some indicators. Other environmental indicators such as urban sanitation and access to safe drinking water tend to improve steadily with income, as these environmental problems have direct impact on human health.

5.1.3 Econometric studies on CO_2 and income

Holtz-Eakin and Selden (1994) found that CO_2 emissions per capita initially rose with per capita GDP, but fell eventually, with an estimated turning point of $35,428 (levels). Estimated in logs, the turning point was above $8 million. However, these estimated turning points rely on the out-of-sample properties of the estimated functions. Within the sample, one could only observe a stabilization of emissions. Moomaw and Unruh (1997) found a statistically significant turning point of $12,813 when testing for a quadratic relationship between CO_2 emissions per capita and income, but also turning point of $18,333 when testing for a cubic relationship, also statistically significant. This would imply an income range for CO_2 emissions to decline between $12,813 and $18,333. The policy implication of this finding is that income per capita should lie in this range, which seems rather unreasonable. Cole, Rayner and Bates (1997) found the turning points for carbon dioxide emissions per capita and total energy use per capita to be well outside the observed income range, with relatively large standard errors.

Cole, Rayner and Bates (1997) examined indicators that have indirect impacts on the environment (per capita energy use, energy use from transport, municipal waste and traffic volumes). These indicators may have serious, but indirect environmental consequences, so that their relationship with per capita income can be similar to that of global air pollutants, as a result of the lack of incentives for government action. They found all these indicators to increase monotonically with income, as the estimated turning points had large standard errors and were thus unreliable. They also found that the Montreal Protocol may have had a role in reducing the consumption of CFCs and halons, illustrating the potential effectiveness of multilateral response to a global environmental problem. They do point out that this may not be relevant for the problem of reducing CO_2 emissions, as cleaner alternatives and low abatement costs for CFCs and halons make it relatively easy for the involved parties to reduce emissions.

Sun (1999) argues that the CO_2 EKC is a reflection of the peak theory of energy intensity. The peak theory of energy intensity says that energy increases in a period of industrialization, then reaches a peak, and finally decreases. Usually one will see shifts in the structure of the economy from higher energy intensity of pollution-intensive industries to low intensity of light industry, and the product structure changes from being material production to knowledge production. The implication of Sun's argument is that the CO_2 EKC has only occurred in those countries where an energy peak has occurred. He finds that this is the case for China.

Moomaw and Unruh (1997) identified 16 countries that demonstrated sustained income growth with stable or decreasing levels of CO_2 emissions per capita over time. They found that the estimated peaks of CO_2 emissions per capita of these countries could be seen as a *structural break.* Pre-peak emissions were rising monotonically with income, while post-peak emissions fluctuated or declined monotonically with income. The structural break, or transition, could be seen to correspond to the oil price shocks of the early 1970s. This would imply that countries did not reduce their emissions due to income effects, but because of rising fuel prices, which prompted energy-reducing technologies and shifts to alternative energy sources. Their structural transition model shows that income turning points and relative CO_2 emissions levels are not constrained to lie within certain values, but rather that emission peaks vary over a great range over incomes and emission levels.

The evidence in favor of a reasonable inverted-U relationship for carbon dioxide is mixed. Few studies have managed to find significant turning points. Overall, there is no reason to assume that global CO_2 emissions will decrease with income in the near future.

5.2 Decomposition analysis

The econometric studies attempting to figure out the determinants of pollution can only give a piece of the puzzle. Regression analysis can establish that there is indeed a relationship between pollution and income, but not which variables are decisive in shaping the pollution path. Decomposition analysis, on the other hand, is a purely descriptive technique of determining the changes in pollution. It can determine the exact forces behind the changes in pollution, whether the changes come about due to sectoral change or technological progress. Further, one can then establish the optimal policies, as the different effects have different policy implications. Direct regulation on abatement practices, or “caps” on emissions will force producers to make the use of pollution-intensive inputs more efficient, and stimulate development of new abatement technologies. Taxation of pollution-intensitve goods and inputs will increase prices for both consumers and producers, and hence lead to structural changes in the economic activity as well as technological progress.

Economic growth can be expected to have a damaging effect on the environment through increasing output. This is the *scale effect*: increasing output in production per unit of area means increasing input. Using more resources results in more waste and pollution, everything else the same. Emissions may decline despite the growth in output if the technological and structural effects outweigh the scale effect. Shifts in production and consumption patterns towards existing or new sectors or industries that are less environmentally damaging are shown through the *composition effect*: The structure of economic activity, or the composition, affects the level of pollution due to the differences between sectors in their pollution intensity. The *technique effects* shows how technological progress, as a result of increasing income, will lead to more efficient use of inputs and improved abatement practices.

Technological progress can be categorized into i) more efficient use of inputs; ii) substitution of less environmentally intensive inputs; iii) less generation of wastes; iv) transformation of wastes to less environmentally harmful forms; v) containment or recycling of wastes; vi) a shift within a sector towards new, less environmentally harmful products or processes (Ekins, 1997).

5.2.1 Decomposition method (following Grossman, 1995):

Decomposition analysis is a descriptive technique that can be used for analyzing determinants of change of aggregated variables. These variables, for instance CO2 emissions, are emitted through a number of different production processes in various economic sectors. The relationship between income and environment can be described by

$$E_t = \sum_{j=1}^{n} Y_t I_{j,t} S_{j,t} \qquad (4)$$

E is the emissions of pollutant in question, j = 1, 2,.., n represents the various sectors in the economy and $Y_t$is the GDP. The emission intensity of the sector j:

$$I_{j,t} = \frac{E_{j,t}}{Y_{j,t}}$$

The share of sector j in GDP:

$$S_{j,t} = \frac{Y_{j,t}}{Y_t}$$

Differentiating (4) with respect to time, we get

$$\hat{E} = \hat{Y} + \sum e_j + \sum_j e_j \ \hat{I}_j \qquad (5)$$

e_j is the share of emissions in sector j in total emissions

$$e_j = \frac{E_j}{E}$$

$$X = \frac{X}{X_t}, X \in \{E, I, S, Y\}$$

The first part on the right hand side of equation (5) is the scale effect, while the second part is the composition effect. The third term is the technique effect.

5.2.2 Empirical decomposition studies

Bruvoll and Medin (2003) decompose the changes in emissions of ten pollutants to air in Norway over the years 1980, 1987, and 1989 to 1996. The model used decomposes energy-related emissions in a given year into individual components:

$$P = \sum_j \sum_i \sum_w \frac{P_{wij}}{E_{wij}} \frac{E_{wij}}{E_{ij}} \frac{E_{ij}}{E_j} \frac{E_j}{Y_j} \frac{Y_j}{Y} \frac{Y}{B} B$$

P is emissions from combustion of energy; *E* energy use; *Y* production; *B* population; *w* combustion method; *i* energy type; and *j* sector. The term $\frac{Y}{B}$ denotes GDP per capita; $\frac{Y_i}{Y}$ sector *i*'s share in GDP - the composition component; $\frac{E_j}{Y_j}$ is the energy intensity component; $\frac{E_{ij}}{E_j}$ is the energy mix component; $\frac{E_{wij}}{E_{ij}}$ is the combustion method component; and $\frac{P_{wij}}{E_{wij}}$ is the other technique component.

For all the pollutants, they find population and scale components to be 7 and 52 percent respectively, adding up to a total GDP growth of 59 percent. A growth in the energy sector of 210 percent contributed to an increase of 8 percent in CO_2 emissions. This growth in the energy sector was mainly due to expansion of offshore activity in the oil and gas industry. The factors leading to reductions in emissions are decreased energy intensity and changes in energy mix – thus, one can attribute the negative impacts in growth in emissions to technique effects. Decreased energy intensity led to a decrease in emissions by 22 percent, while the energy mix component contributes to a 17 percent decrease in emissions. In sum, for CO_2 they find that the overall percentage increase in emissions is 26. In comparison, they find that lead decreased by 99 percent over the same period. Composition effect led to a decrease in emissions of 13 percent, while technique effects led to decreases of a total of 121 percent. The introduction of unleaded gasoline and subsequently the reduction in lead emissions from vehicles were been important for the reduction in the lead emissions. This was strongly stimulated regulations and taxes on leaded gasoline. Also the treatment of process related dust emissions in the metal producing industries contributed to emissions reductions. The emissions of sulphur dioxide were decreased by 76 percent in the period 1980-1996. The composition effect contributed to a decrease in emissions of 13 percent and technique effects led to a total of 83 percent decreases.

Bruvoll, Fæhn and Strøm (2003) run a simulation on the effect of policy changes on CO_2 emissions in Norway, using a complex computable general equilibrium model that integrates environmental and economic mechanisms. They measure the changes in emissions to air of 13 pollutants. They use historical emission data to forecast future emissions of CO_2, which is made from 2000 to 2030, and they make two separate projections: a constant policy scenario, where the real CO_2 tax rates are kept constant at their 1990 level; and an endogenous policy scenario. The endogenous policy scenario produces a carbon tax that initially is lower than the constant 1999 tax, but that increases above and beyond it, and ultimately reduces carbon emissions by 5 million tons CO_2 in 2010 and by 18 million tons in 2030. In the endogenous policy scenario, economic activity, along with long-run aggregate consumption, falls, especially through that fact that offshore activities fall by 2.9 percent in annual terms, as well non-sheltered manufacturing industries with high labor intensity contracting. Compositional effects reduce the future growth rates for all emissions analyzed. Oil-refining increases its gross product by 5.3 percent, as it is both capital-intensive and favored by increased demand, especially if electricity prices increase strongly relative to oil prices.

For all the pollutants analyzed in the above decomposition studies, the main reason for change in emissions was technique effects. There seems to be some evidence for structural change, but very little, especially in the case of CO2. In the case of lead, technique effects were the main reason for reductions in emissions, but also changes in consumption as a result of well-aimed policies and regulation. Torvanger (1991) decomposed the changes in CO_2 emissions from manufacturing sectors in nine[5] OECD countries over the period 1973-1987, and failed to find strong evidence of structural change. He found that overall carbon dioxide intensity (emission per unit of output); was reduced by 42 % in the period, mainly through the general reduction in manufacturing intensity. The reduction in emission intensity is attributed to increasing energy prices and economic growth.

Has shifts in production patterns been accompanied by shifts in consumption patterns, or are the same consumption of environmentally intensive goods increasingly being met by imports? In a study by Kander and Lindmark (2006), they find that Sweden would have had an even larger decline in CO_2 emissions between 1975 and 1995 had it not been for international trade. Bruvoll and Medin find that increased significance of energy production in Norway continued to lower the otherwise environmentally positive structural changes in the period of study. Bruvoll, Fæhn and Strøm project import surpluses in Norway to be increasing from 2018 and onwards, despite the fact that export surpluses are expected to be high in the nearest future. This turn from export surplus to import surplus will be due to gradual downscaling of oil production, and thus export and the related increased reliance on income flows of foreign currency from financial assets.

5.3 An EKC for CO_2?

In general, the empirical basis for the EKC is not entirely sound; one can rather conclude the contrary. The downturn in emissions can only be said to be valid for some pollutants, in particular those pollutants with direct impacts and there is an obvious link between the concentration of the pollutant and the welfare of the populations. The results actually observed in the empirical studies for carbon dioxide are not as clear-cut. The turning points are ranging from reasonable turning points to income thresholds out of sample (Holtz-Eakin and Selden; Cole et al); the energy intensities have decreased over the sample periods; and there are changes in the energy input mix. Looking at the decomposition studies in total, there is little evidence of there being an unambiguous compositional effect. In Norway, there would be a clear structural effect if the energy sector was excluded from the economy- as the energy sector has expanded more than any sectors have contracted, and thus any negative effect on

[5] The countries included in the study were France, Germany, USA, the UK, Italy, Norway, Denmark, Sweden and Japan.

emissions would be counteracted by the energy sector. The technological effects have played the most important role in reducing CO_2 emissions through energy use: namely changes in energy mix and increases in energy intensities. International trade (the pollution haven hypothesis) seems to have a small effect on changes in pollution, if any. Increased use of carbon-free energy sources, along with substitution of natural gas for the more pollution producing coal and oil, would clearly reduce CO_2 emissions.

6 Discussion/conclusion

In the debate concerning the tradeoff between the environment and economic growth, the idea of the Environmental Kuznets Curve offers an optimistic outlook of the future. Instead of having to choose one or the other as the chosen path, countries can have both. Having a period of environmental degradation as the economy grows and the society develops is an acceptable idea as long as one is safe assured that the environment will improve once income per capita is high enough. On the other hand, uncertainty concerning the pollution levels of today makes it a daring, maybe too daring, endeavor to assume that the environmental degradation we cause today will not have grave consequences in the future. For all we know, the carrying capacity of the earth may be surpassed sooner than we think. Ultimately, it is important to understand the mechanisms driving pollution, in order to correctly assess the need and usefulness of environmental policies.

A number of theoretical models have been developed to capture this relationship, having assumptions on preferences, technologies and the economy. While they do give insight into the relationship between pollution and income, their applications are limited as the assumptions made in the models are limiting in themselves. Also, none of the theoretical models have been tested empirically (Stern, 2004), further limiting their applicability.

The good news is that the changes in economic activity comes along with growth in income per capita, which means that people will have higher and more pronounced demand for environmental quality. The bad news is that most of the world's population lies on the upward-sloping part of the estimated EKCs (Ekins, 1997). This means that income per capita has to increase substantially across the world before global emissions can reach their turning point and start decreasing.

The above arguments illustrate perfectly how economic growth can prove to be both the friend and foe of the environment. On one hand, there is hope. Environmental quality can improve when income per capita grows and reach a certain level. On the other hand, the environmental degradation that will come about due to poor countries of today reaching a high income level per capita can possibly bring about such great costs that the accumulated environmental damage can far exceed the present value of higher future growth.

If it is possible to make the “stages of economic development” hypothesis general for all pollutants, one would expect to see a decline in emissions of carbon dioxide in the richest countries. While this has happened in absolute terms in a few countries, the main trend in most developed countries is that emissions are increasing, or stabilizing at a high level. One can hardly claim that there is enough empirical evidence to assume that there is an EKC for CO2, irrespective of the measures used are total emissions, emissions per capita, or emission intensities. While pollution per unit of output (emission intensity) might decrease, total pollution might still increase if the rate of growth in output is higher than the rate of decrease in emission intensity.

The height of the pollution-income curve indicates the level of environmental degradation per capita income. While this depends in part on income levels (stages of development), the efficiency of markets and policies largely determines the height of the income-pollution curve. The higher the pollution level, the more likely it is that critical ecological thresholds will be crossed and irreversible changes take place (Panayotou, 2003). For example, tropical deforestation, the loss of biological diversity, extinction of species, and destruction of fragile ecosystems are either physically irreversible or prohibitively costly to reverse. As Panayotou points out *“… the economic and social consequences of damage to mental development and learning capacity from high lead levels in the blood of school-age children (due to lead emissions), are not easy to reverse, and they are certainly not reversed by switching to unleaded gasoline at later stages of development”* (Panayotou, 2003: pp. 54-55).

Arrow et al (1994) criticize the EKC hypothesis for the lack of feedback from environmental damage to production. The economy is assumed sustainable, as environmental damage does affect economic activity enough to stop the growth process, and there are no irreversible damages so severe that future income will be reduced. In the absence of endogenously generated signals of increasing scarcity, economic activity may expand at a pace and scale that overwhelms the much slower expansion of the carrying capacity of the planet, resulting in irreversible damage to the productivity of the resource base, and the unsustainability of economic growth itself.

Despite its theoretical foundations, the EKC is ultimately an empirical relationship. The theoretical models developed to explain the downturn in emissions all assume various conditions that may or may not be realistic, but in either case they are included in the models in order to give the inverted-U shaped relationship between pollution and income. Sadly, the empirical evidence of the EKC does not point in the desired direction. Rather, it points in every direction: certain pollutants show the inverted-U relationship with income, but the results are not conclusive and seems to be dependent on the country studied; as well as the characteristics of the pollutant in question.

In the case of CO_2, the empirical evidence is pointing in one direction: upwards. There is little evidence of an EKC. Although there is progress both when it comes to more efficient use of energy in production as well as shifts away from fossil fuels to cleaner energy sources, the growth in GDP and population size outweighs any reductions in emissions. Even though there were to be a global CO_2 EKC, the time it would take to get to the "peak" of total emissions would entail potentially enormous costs to society, based on what we know about climate change today.

The impacts of decisions made today about greenhouse gas emissions will continue to emerge for decades or even centuries. Governments worldwide have been implementing various policies and measures to mitigate emissions. Carbon taxes, for instance on gasoline, and other measures to curb emissions are relatively common on some developed countries. Carbon dioxide and climate change are well-pronounced problems in the Western world. Consumers know that an airplane emits more CO_2 than a train does travelling the same distance, and that the environment will be better off if one chooses public transportation over a private car. Yet, CO_2 emissions are monotonically increasing in income per capita in both developed and developing countries. While there are many important actions to address climate change, such as carbon taxes and carbon trading, and the coming into force of the Kyoto Protocol, these measures may not be enough.

Even though the environmental changes themselves may depend only on worldwide aggregate emissions, the consequences of a warmer global climate may be quite different for different countries. In developing countries, such as China, larger percentages of the economies are grounded in climate-sensitive sectors such as agricultural activity. These countries will be more vulnerable to damages, and at the same time be less able to adapt to climate change than developed countries. And then there is the question of equity: rich countries today have emitted harmful global substances for a longer period than poor countries, and thus the poor countries demand a “grace period” of economic growth without restrictions on emissions. These issues complicate the issue of carbon dioxide emissions and its implications even further.

In general, the EKC as a concept has its flaws. Environmental quality does not come about automatically as a result of economic growth. Sectoral changes does not bring about a downturn in pollution alone, nor does international trade. However, there is light at the end of the tunnel. Economic growth, and in turn, high incomes per capita, imply that people care more about the environment (at least in economic terms). There will be increased demand that more attention is paid to the environment. This is illustrated perfectly by how developed countries typically enjoy relatively high environmental quality, but they also have relatively stringent environmental standards and stricter enforcement of their environmental laws than their less developed counterparts. Appropriate environmental policies are necessary in order to bring about reductions in pollution in most cases.

7 References

Adelman, Morris (2002): "World Oil Production and Prices 1947-2000", the Quarterly *Review of economics and finance*, 42, 169 -191

Andreoni, J. and Levinson, A. (2001): "The simple analytics of the Environmental Kuznets Curve", *Journal of Public Economics*, 80, 269-286

Arrow, K., Bolin, B., Constanza, R., Dasgupta, P., Folke, C., Holling, C. S., Jansson, B., Levin, S., Mäler K., Perrings, C., and Pimental, D. (1995): "Economic Growth, Carrying Capacity, and the Environment", *Ecological Economics,* 15, 91-95.

Beckerman, W. (1992): "Economic Growth and the Environment: Whose Growth? Whose Environment?", *World Development,* 20, 481- 496.

Bruvoll, A., Fæhn, T. and Strøm, B. (2003): "Quantifying Central Hypotheses on the Environmental Kuznets Curves for a Rich Economy: a Computable General Equilibrium Study", Discussion Papers No. 341, Statistics Norway, Research Department

Bruvoll, A. and Medin, H. (2003): "Factors Behind the Environmental Kuznets Curve: A Decomposition of the Changes in Air Pollution", *Environmental and Resource Economics,* 24, 27–48

Cole, M. A., Rayner A. J., and Bates J. M. (1997): "The environmental Kuznets curve: an empirical Analysis", *Environment and Development Economics,* 2, 401–416

Copeland, B. and Taylor, M. S. (2004): "Trade, Growth and the Environment", *Journal of Economic Literature*, 42, 7-71

Ekins, P. (1997): "The Kuznets Curve for the environment and economic growth: examining the evidence", *Environment and Planning A*, 29, 805 – 830

Grossman, G. M. (1995): “Pollution and Growth: what do we know?”, in I. Goldin and L. A. Winters, eds., *The Economics of Sustainable Development*, Cambridge University Press, Cambridge, 1947

Grossman, G. M and Krueger, A. B. (1991): “Environmental Impacts of a North American Free Trade Agreement”, in P. Garber (Ed.), *The US-Mexico Free Trade Agreement*, Cambridge MA: MIT Press

Grossman, G. M and Krueger, A. B. (1995): “Economic Growth and the Environment”, *The Quarterly Journal of Economics*, 110, 353-377

Holz-Eakin, D. and Selden, T. M. (1995): “Stoking the Fires? CO2 Emissions and Economic Growth”, *Journal of Public Economics*, 57, 85-101

IPCC, 2007: *Summary for Policymakers. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden and C. E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 7- 22

IPCC, 2007: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

John, A. and Pecchenino, R. (1994): “An Overlapping Generations Model of Growth and the Environment”, *Economic Journal*, 104, 1393-1410

Jones, L. E. and Manuelli, R. E. (1995): “‘A Positive Model of Growth and Pollution Control’, NBER Working Paper No. 5205

Kander, A. and Lindmark, M. (2006): “Foreign trade and declining pollution in Sweden: a decomposition analysis of long-term structural and technological effects”, *Energy Policy*, 34, 1590–1599

Kriström, B. and Riera, P. (1996): “Is the Income Elasticity of Environmental Improvements Less Than One?”, *Environmental and Resource Economics*, 7, 45-55

Kuznets, S. (1955): “Economic Growth and Income Inequality”, *American Economic Review*, 49, 1-28.

Lopez, R. (1994): “The Environment as a Factor of Production: The Effects of Economic Growth and Trade Liberalization”, *Journal of Environmental Economics and Management*, 27, 163-184

Lieb, C. M. (2002): “The Environmental Kuznets Curve and Satiation: A Simple Static Model”, *Environment and Development Economics*, 7, 429–448

McConnell, K. E. (1997): “Income and the Demand for Environmental Quality”, *Environment and Development Economics*, 2, 383-399

Meadows, D. H., Meadows, D. L, Randers, J. and Behrens, W. (1972): “*The Limits to Growth*”, New York: Universe Books

Moomaw, W. and Unruh, G. (1997): “Are the environmental Kuznets curves misleading us? The case of CO2 emissions”, *Environment and Development Economics*, 2, 451-463

Munasignhe, M. (1999): “Is environmental degradation an inevitable consequence of economic growth: tunneling though the environmental Kuznets curve”, *Ecological Economics*, 29, 89-109

Nordhaus, W. (2007): “The Challenge of Global Warming: Economicc Models and Environmental Policy“, www.nordhaus.econ.yale.edu/dice_mss_072407_all.pdf

Panayotou, T. (1993):” Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development”, Working Paper WP238, Technology and Employment Programme, International Labour Office, Geneva

Panayotou, T. (2003): “Economic Growth and the Environment”, *Economic Survey of Europe*, 2, 45-72

Shafik, N. and Bandyopadhyay, S. (1992): “Economic Growth and Environmental Quality Time-Series and Cross-Country Evidence, Background Paper for the World Development Report 1992, The World Bank, Washington, DC

Selden, T and Song, D. (1994): “Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions”, *Journal of Environmental Economics and Management*, 27, 147-162

Selden, T and Song, D. (1995): ”Neoclassical Growth, the J Curve for Abatement, and the Inverted U Curve for Pollution”, *Journal of Environmental Economics and Management* 29, 162-168

Stern, D. (2004): “The Rise and Fall of the Environmental Kuznets Curve”, *World Development*, 32, 1419–1439

Stokey, N. (1998): “Are there limits to growth?”, International Economic Review, 39, 1-31

Sun, J. W., (1999): “The Nature of CO2 Emission Kuznets Curve”, *Energy Policy,* 27, 691-694

Suri, V. and Chapman, D. (1998): “Economic growth, trade and the energy: implications for the Environmental Kuznets Curve”, *Ecological Economics*, 25, 195-208

Torras, M. and Boyce, J. K. (1997): “Income, inequality, and pollution: a reassessment of the environmental Kuznets Curve”, *Ecological Economics* 25, 147-160

Torvanger, A. (1991):” Manufacturing sector carbon dioxide emissions in nine OECD countries, 1973-87: A Divisia index decomposition to changes in fuel mix, emission coefficients, industry structure, energy intensities and international structure”, *Energy Economics*, **13,** 168-186

World Bank (1992): “W*orld Development Report, 1992 - Development and the Environment*”, New York

United Nations Framework Convention on Climate Change (1998), Kyoto Protocol to the United Nations Framework Conventiono on Climate Change, located online: http://unfccc.int/kyoto_protocol/items/2830.php