

# **Bioenergy, Pollution, and Economic Growth**

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## Abstract

This thesis consists of four papers: two of them deal with the effects on the forest sector of an increase in the demand for forest fuels, and two of them concern the relation between economic growth and pollution.

**Paper [I]** is a first, preliminary study of the potential effects on the Swedish forest sector of a continuing rise in the use of forest resources as a fuel in energy generation. Sweden has made a commitment that the energy system should be sustainable, i.e., it should be based on renewable resources. However, an increasing use of the forest resources as an energy input could have effects outside the energy sector. We consider this in a static model by estimating a system of demand and supply equations for the four main actors on the Swedish roundwood market; forestry, sawmills, pulpmills and the energy sector. We then calculate the industries' short run supply and demand elasticities.

**Paper [II]**, is a development of the former paper. In this paper, we estimate the dynamic effects on the forest sector of an increased demand for forest fuels. This is done by developing a partial adjustment model of the forest sector that enables short, intermediate, and long run price elasticities to be estimated. It is relevant to study the effects of increased demand for forest fuels as the Swedish government has committed to an energy policy that is likely to further increase the use of renewable resources in the Swedish energy system. Four subsectors are included in the model: forestry, sawmills, pulpmills and the energy industry. The results show that the short run elasticities are fairly consistent with earlier studies and that sluggish adjustment in the capital stock is important in determining the intermediate and long run responses. Simulation shows that an increase in the demand for forest fuels has a positive effect on the equilibrium price of all three types of wood, and a negative effect on the equilibrium quantities of sawtimber and pulpwood.

In **paper [III]** a Shephard distance function approach is used to estimate time series of shadow prices for Swedish emissions of CO<sub>2</sub>, SO<sub>2</sub>, and VOC for the period 1918 - 1994. The shadow prices are in a next step regressed on GDP per capita. The objective of the study is closely linked to hypothesis of environmental Kuznets curves. We conclude that the time series of the shadow prices from this approach can not be used to explain the EKC's found for Swedish emissions.

In **paper [IV]**, we calculate time series of shadow prices for Swedish emissions of CO<sub>2</sub>, SO<sub>2</sub>, and VOC for the period 1918 - 1994. The shadow prices are in a next step related to income, to explain the EKC's previously found for Swedish data on the three emissions. Newly constructed historical emission time series enable studying a single country's emission paths through increasing levels of economic activity. A directional distance function approach is used to estimate the industry's production process in order to calculate the opportunity costs of a reduction in the emissions. The time series of the shadow prices show support for EKC's for the Swedish industry.

**Keywords:** Forest sector, Forest fuels, Dynamic factor demand, Adjustment costs, Economic growth, Pollution, Environmental Kuznets curve, Shadow price, Distance function.



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This thesis consists of an introductory part and four papers.

- [I] Ankarhem, M., Brännlund R. and Sjöström M. (1999). Biofuels and the forest sector. In Yoshimoto, A. and Yukutake, K. (eds.). *Global Concerns for Forest Resource Utilization; Sustainable Use and Management*. Kluwer Academic Publishers, Dordrecht. (Reprinted with permission from Kluwer Academic Publishers.)
- [II] Ankarhem, M. (2005). Effects of Increased Demand for Biofuels: A Dynamic Model of the Swedish Forest Sector, *Umeå Economic Studies* **658**, Umeå University.
- [III] Ankarhem, M. (2005). Shadow Prices for Undesirables in Swedish Industry: Indication of Environmental Kuznets Curves?, *Umeå Economic Studies* **659**, Umeå University.
- [IV] Ankarhem, M. (2005). A Dual Assessment of the Environmental Kuznets Curve: The Case of Sweden. *Umeå Economic Studies* **660**, Umeå University.





# 1 Introduction

The four papers in this thesis can be separated into two categories. Papers [I] and [II] focus on a change in the Swedish energy system and its effects on the industries in the forest sector. Papers [III] and [IV] concern the relation between pollution and economic growth.<sup>1</sup> A common denominator for both categories of papers is the environmental impacts of the Swedish industry. The first two papers have their background in the policy to convert the Swedish energy system to be ecologically as well as economically sustainable. One of the underlying reasons for this change is a political aim to reduce Sweden's emission of greenhouse gases, such as carbon dioxide (CO<sub>2</sub>). In papers [III] and [IV] we study how the marginal abatement costs for the emissions of CO<sub>2</sub>, sulphur dioxide (SO<sub>2</sub>), and volatile organic compounds (VOC), change through the different stages of a country's economic growth. This issue is closely related to the much debated hypothesis of an environmental Kuznets curve (EKC),<sup>2</sup> which states that environmental damage will initially increase as the GDP per capita increases, but after a turning point it will decrease again. If this relation holds, the country could to some extent "grow out" of polluting problems, or the pollution could increase at a slower pace.

The use of biofuels has been increasing steadily in Sweden during the last three decades. In 1970 less than 10 percent of the energy supply was derived from biofuels and in 2003 the corresponding figure was almost 20 percent. In 1999 a number of long term environmental objectives were adopted, where one of them is aimed at limiting Sweden's emissions of greenhouse gases. In its present form the objective states that the Swedish emissions of greenhouse gases during the period 2008 to 2010 has to be reduced to a level at least 4 percent lower than the levels of 1990. However, indicators show that the level of emissions will only be slightly lower in 2010 than in 1990, so to meet this goal a continuous conversion of the energy system is assumed to be needed, and this is likely to imply a further increase in the use of renewable resources.

One of the main energy users is the district heating industry, and since the beginning of the 1980s there has been an extensive substitution of forest fuels for oil as input in this industry. An increasing demand for biofuels may have effects outside the energy industry, most notably in the forest sector. Today, a large part of the biofuels consists of residues from forestry and by-products from the sawmills and the pulp industry. However, a substantial rise in the use of

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<sup>1</sup>The papers [I] and [II] were financially supported by the Swedish National Energy Administration, and papers [III] and [IV] by The Bank of Sweden Tercentenary Foundation.

<sup>2</sup>The EKC is named after Kuznets (1955, 1963) who originally proposed a similar relationship between inequality in distribution of income and economic growth.

renewable resources would imply that forest resources, which may have an alternative use (e.g., pulpwood), could have to be considered for energy purposes. This is likely to have an effect on other users of forest resources, such as the sawmills and the pulp industry, and therefore it is important to analyze how such an energy policy will affect the competition for the forest resource.

In papers [I] and [II], we study the effects on the Swedish forest sector of an increase in the demand for biofuels. To do this we estimate a system of supply and demand equations, and calculate supply and demand elasticities, for the four main actors on the roundwood market; the forest owners, the sawmill industry, the pulp and paper industry, and the energy industry. A static model is used for a first preliminary study in paper [I], whereas a partial adjustment approach is used in paper [II] to capture the dynamic long run response of, e.g., a price change. The estimated model in paper [II] is finally used to simulate the short and long run effects of a government induced subsidy to increase the energy industry's demand for forest fuels. Previous studies of the Swedish forest sector are, e.g., Bergman and Brännlund (1995), Brännlund and Kriström (1996), Lundgren and Sjöström (1999). Studies that more specifically concern the district heating plants and the market for pulpwood are, among others: Brännlund and Kriström (2001) and Sjöström (2004).

The main objective in papers [III] and [IV] is to analyze the relation between economic growth and pollution over a long period of time. To do this, a two step procedure is employed. In the first step we estimate time series of shadow prices for emissions of carbon dioxide ( $\text{CO}_2$ ), sulphur dioxide ( $\text{SO}_2$ ), and volatile organic compounds (VOC) for the Swedish industrial sector. In a second step, these shadow prices are regressed on the per capita GDP. The objective is closely linked to the EKC mentioned above.

The idea of an environmental Kuznets curve is not new. There has been an ongoing debate since the early 1970s, when Meadows et al. (1972) put forward a view that economic growth requires greater use of energy and material, and will thereby generate larger quantities of emissions and waste as by-products. A substantial extraction of natural resources and increased concentration of pollutants will then lead to a degradation of the environment. This view was later challenged by the view of the EKC proponents, originating from The World Bank's *World Development Report 1992* (IBRD, 1992). It argues that the traditional way of relating growth to environmental damage is based on assumptions that are too static with regard to technology, consumer preferences and environmental investments. It is suggested, instead, that growth may improve environmental quality via technological progress and a rising demand for a clean environment. If the second view is correct, then one expects emissions to increase when a country with low economic activity increases its production. As the economic activity increases there

will eventually be a turning point after which pollution is decreasing.

There is an extensive literature on the EKC. Among the theoretical studies are: Lopez (1994), Selden and Song (1995), Stokey (1998) and Andreoni and Levinson (2001). The bulk of the empirical literature originates from the study by Grossman and Kreuger (1991). Other empirical studies are: Holtz-Eakin and Selden (1995), Cole et al. (1997), Panayotou et al. (1999). See Stern (1998; 2004) for comprehensive overviews of the literature.

The method used in paper [III] originates from Färe et al. (1993), who develop a distance function approach to obtain shadow prices for undesirables in the absence of market prices. This method has recently been generalized to use what is called the directional distance function (Färe et al, 2002; Färe and Grosskopf, 2004). When using the latter method in paper [IV] the results differ substantially from the ones in paper [III].

## 2 Methodologies

### 2.1 Papers [I] and [II]

Both papers [I] and [II] study the effects on the Swedish forest sector, of an increase in the demand for forest fuels. A system of supply and demand equations is estimated and price elasticities are calculated for the four main actors on the roundwood market; the forest owners, the sawmill industry, the pulp and paper industry, and the energy industry. The major difference between the two studies is that a static short run model is used for a first, preliminary analysis in the former paper, whereas a more comprehensive dynamic long run model is used to capture the intertemporal aspects in the latter paper. The static model in paper [I] is based on the assumption that capital is fixed, whereas all other inputs are flexible. This implies that the estimated elasticities can be interpreted as short run elasticities, since they are conditioned on a fixed capital stock. The results from the study show that the forest owners short run own price supply elasticity for forest fuels is close to zero. In addition, the positive cross price elasticities between pulpwood and forest fuels suggest that they are complements to each other. One explanation to this result is that there is a joint production of forest fuels and pulpwood. When the forest owners respond to higher pulpwood prices by increasing the supply of pulpwood, there will also be an increase in the supply of wood residues (forest fuels) as a side effect.

Dynamic models impose some kind of adjustment process when changing an input factor. Models within the dynamic framework can be divided into three sub groups; first, second, and third generation of dynamic factor demand models. In the first two generations, the adjustment process is introduced in the econometric specification, whereas in the third generation framework, it is introduced in the theoretical model.

Third generation dynamic factor demand models are based on dynamic optimization.<sup>3</sup> They incorporate adjustment costs for quasi fixed (fixed in the short run) inputs, and thereby provide well defined and theoretically motivated measures of short and long run elasticities. In paper [II], we use a model which is in line with the third generation type of models. There are two central issues regarding adjustment costs. The first concern the source of the adjustment cost, and here, the adjustment costs are seen as, e.g., costs in terms of forgone output that arise when the firm devotes resources to install new machinery instead of producing output. The second issue regard the structure, or the shape, of the adjustment cost function. It plays an important role for determining the firm's intertemporal behavior. In the literature these costs are divided into five categories; 1) Lumpy, or fixed; meaning that there is a lump sum cost when adjusting the quasi fixed input factor. 2) Linear; the costs are proportional to the size of the change. 3) Concave; there are economies of scale in adjusting the quasi fixed inputs. 4) Convex; the marginal adjustment costs increase with the size of the change and 5) The adjustment costs are convex for small changes in the input, but the function then turns concave for larger changes. Hamermesh and Pfann (1996) and Chirinko (1993) provide comprehensive overviews of adjustment costs in factor demand and investment.

In paper [II], we assume capital adjustment costs according to the fourth category. This type of cost function has somewhat different implications than the other ones. Since the marginal adjustment costs are increasing, large changes are penalized and therefore the changes in the capital stock over time is likely to be gradual and continuous. Using a partial adjustment approach (as is done in paper [II]) is in line with this category of cost functions. A smooth convex cost function may describe adjustment costs well on an aggregate level. However, on the firm level this might not be the case. A firm may experience lumpy costs and there might also be threshold levels under which there is no investment taking place. When the need for investment exceeds this level, all changes will occur at the same time. However, all firms do not necessarily have the same thresholds. This means that, at the aggregate level, the response to a price or policy change will appear to be gradual, and the adjustment costs can be approximated with a smooth convex cost function.

Some of the short run elasticities in paper [II] are different from the ones in paper [I]. Most notably, the pulpwood and the forest fuels have become substitutes in paper [II], and the own price supply elasticity for forest fuels is negative which is hard to find plausible. One reason for the pulpwood and the forest fuels to have become substitutes might be that the data set in paper [II] has been updated and observations for more recent years are included. It is possible that the increase in the demand for forest fuels has changed the forest fuels from being a by-product

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<sup>3</sup>Seminal papers for the third generation of dynamic models are Lucas 1967a and Lucas 1967b.

to pulpwood to become a product worth cutting "by itself". Another reason can be that the dynamic specification captures aspects that are missed by the static model. This seems to be true for the pulp industry's own price demand elasticity. The elasticity is positive in the static specification, but negative in the dynamic model. The results from paper [II] also indicate that the own price demand elasticities are greater in magnitude than they are in the short run, which implies that they meet the LeChatelier principle. Except for the own price supply elasticity for forest fuels, the results from paper [II] are in line with economic theory and they seem to give a reasonable description of the forest sector.

## 2.2 Papers [III] and [IV]

The theoretical framework used in papers [III] and [IV] is analogous to Brännlund and Kriström (1998) and Kriström and Lundgren (2005). Using this framework, the equilibrium is found where the marginal willingness-to-pay (MWTP) for environmental quality is equal to its supply cost in terms of foregone output. The EKC is then interpreted as the expansion path of this equilibrium over different income levels. We only have data on the production side of the economy, and therefore the problem is simplified to a "partial analysis", in the sense that we disregard the consumers utility function and estimate only the society's production possibilities.<sup>4</sup> The shadow price is then calculated, at the equilibrium, as the marginal rate of transformation between the good product and pollution. The results in papers [III] and [IV] differ substantially from each other and, therefore, the difference in the methods used in the studies will be briefly explained in the following.

Pollution is viewed as a by-product to the production of the desirable good, and it is therefore natural to model the desirable and undesirable goods as joint-products of a multi-output production technology. To do this, we assume that a vector of inputs,  $\mathbf{x}$ , is used in the production of good outputs,  $\mathbf{y}$ , together with bad outputs,  $\mathbf{b}$ . In a traditional multi-output model, where all the outputs are desirable, the optimality condition requires that for any two outputs the slope of the production possibility frontier is equal to the ratio of the two output prices. The same reasoning applies here except that we do not restrict all prices to be positive. Instead, the prices of the undesirables are non-positive, and so we define  $\mathbf{p}_y > \mathbf{0}$ , for the desirable outputs and  $\mathbf{p}_b \leq \mathbf{0}$  for the undesirable outputs.

The production technology underlying the transformation functions in paper [III] and [IV] can be represented in different ways; two approaches that do not require data on market prices are the multi-output production function and the output distance function. Not having to rely on market prices is essential here, since the undesirable outputs are not traded on the

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<sup>4</sup>This simplification is not unproblematic, as will be further developed later in this section.

market and therefore the data we use contain only observations on inputs and outputs, and not on market prices. In these studies, the distance function is preferred to the multi-output production function since the former is invariant to the choice of dependent variable. Färe et al (1993) develop the Shephard distance function approach to estimate shadow prices for bads. This approach is used in paper [III], and may be written:

$$D_o(\mathbf{x}, \mathbf{y}, \mathbf{b}) = \min_{\beta} \left\{ \beta : \left( \frac{\mathbf{y}}{\beta}, \frac{\mathbf{b}}{\beta} \right) \in P(\mathbf{x}) \right\},$$

where the solution  $\beta^*$  gives the maximum expansion of both good and bad outputs. This means that a technically feasible output vector  $(y, b)$  is scaled so as to reach the production frontier. In Figure 1 this is seen as a movement from  $B$  to the frontier along the radial, and the shadow price is then measured at  $C$ . This approach has been used in a number of studies to estimate shadow prices (abatement costs) for various emissions and industrial wastes (e.g., Coggins and Swinton, 1996; Hetemäki, 1996; Reig-Martinez et al., 2001).

According to the Shephard distance function the producer is regarded as more technically output efficient, the closer to the frontier it can produce. This means that increasing the good and bad outputs proportionally (along the radial) is making the producer more technically output efficient. In a model with only good outputs, this seems reasonable, but it is a questionable feature when jointly modelling good and bad outputs. If it is agreed instead that bad outputs are undesirable, then a reduction in the bad output, given unchanged or increased production of the good output, should be considered as an efficiency gain. This view underlies the method used in paper [IV], which is usually referred to as the directional distance function (Färe et al; 2002). When using the latter method, as in paper [IV], the results differ substantially from the ones in paper [III].

The directional distance function is defined on the output set,  $P(x)$ , as

$$\vec{D}_o(\mathbf{x}, \mathbf{y}, \mathbf{b}; \mathbf{g}) = \max_{\beta} \{ \beta : (\mathbf{y} + \beta \cdot g_y, \mathbf{b} - \beta \cdot g_b) \in P(\mathbf{x}) \},$$

where the solution,  $\beta^*$ , gives the maximum expansion and contraction of good and bad outputs, respectively. The vector  $\mathbf{g} = (g_y, -g_b)$  specifies in what direction an output vector is scaled so as to reach the boundary of  $P(\mathbf{x})$ . This means that the producer becomes more efficient when simultaneously contracting the bad output, and increasing the good output. In paper [IV], the directional vector  $\mathbf{g} = (1, -1)$  is chosen, and this can be seen as a movement from  $B$  to  $A$  in Figure 1. The shadow price is then measured at point  $A$ . The method is used by Marklund (2003), Marklund and Samakovlis (2003) and Färe et al. (2005) to calculate shadow prices of various pollutants such as a compound of greenhouse gases and  $\text{SO}_2$ . Using either of the approaches in paper [III] or in paper [IV], we may write the shadow price of a bad output in

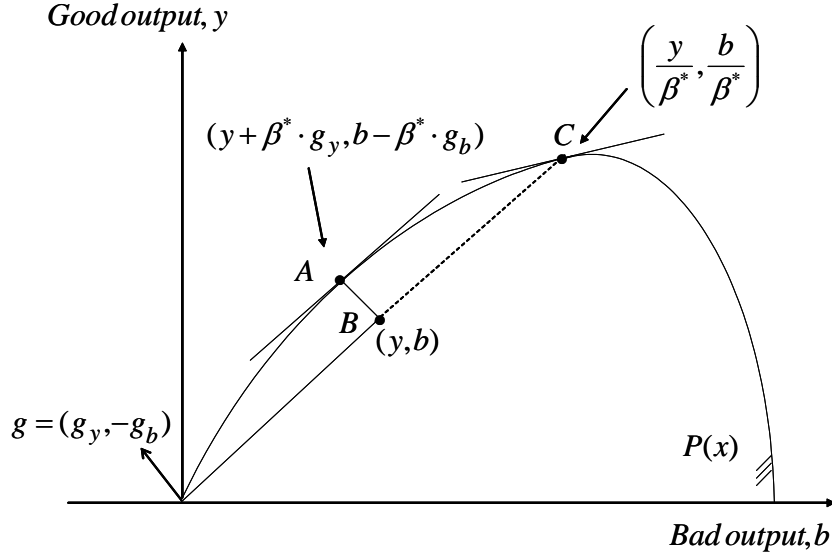


Figure 1: The Shephard's, and the directional distance function.

terms of the price of a good output:

$$\frac{p_b}{p_y} = \frac{\partial D_o(\cdot)/\partial b}{\partial D_o(\cdot)/\partial y},$$

and performing this calculation for each year will give a series of annual shadow price observations that is regressed on the GDP per capita.

As can be seen in Figure 1, the choice of direction is highly important in determining the shadow price. This choice turns out to be crucial in paper [III] and [IV], where the Shephard's and the directional distance functions produce different results. To avoid being dependent on an arbitrary choice of direction it would be optimal to include consumers' preferences in the model, thus treating the direction as endogenous. Estimating the distance function simultaneously with the utility function would thus give the shadow price at the point on the true frontier where the marginal rate of substitution equals the marginal rate of transformation.

From paper [III] we do not find any indication that the shadow prices increase with increasing levels of income.<sup>5</sup> These results are contradicted by the results in paper [IV] that clearly indicate increased shadow prices as income rise.

In paper [III], the model is estimated econometrically and in paper [IV] it is estimated using linear programming (LP). One major difference between the estimations is that in the econometric estimation we do not impose restrictions in the same manner as in the LP estimation.

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<sup>5</sup>In paper [III], a price that becomes more negative is referred to as decreasing. However, since the shadow prices correspond to opportunity costs, it may be natural to regard a price, that becomes more negative, as *increasing*. The latter notation is therefore used in this introduction and in paper [IV].

Most notably, we do not impose restrictions on the derivatives with respect to the good and bad outputs, which means that the shadow prices are not restricted to be negative. To evaluate if the reason to the different results lies in the estimation technique, the directional distance function is also estimated econometrically. However, the results from the econometric estimation resembles the ones from the LP estimation.

### 3 Data

The data used in paper [I] consist of annual time series observations for the period 1967-1994. Most of the data are collected from Swedish official statistics, mainly SOS Industry but also from the Yearbook of Forest Statistics, and Energy in Sweden. In paper [II] the data set is widened to include the variables needed for the dynamic model, and also extended to cover the years until 2003. Using annual time series is not optimal for this type of study since it yields few observations, but also because historical data are then used to evaluate the presence and, as in paper [II], to simulate the future. It would therefore be preferable to have access to a panel data set with perhaps fewer years but with several different plants.

In papers [III] and [IV] we use a panel data set including newly constructed historical emission time series for the period 1913-1999 (Lindmark, 2003). Since we are interested in the relation between economic growth and pollution over a long period of time, the time dimension in this case is a strength. It enables calculations of long series of shadow prices for a single country. Generally, data on emissions are not long enough in order to cover a country's different phases of economic development. Due to this, most previous studies have used panels consisting of a sample of countries for a shorter period of time. This means that almost all low-income observations come from developing countries and all the high-income observations from developed countries. The approach then entails a risk that a relation such as an EKC just reflects two separate findings; developing countries have a positive relationship between income and pollution, together with a fundamentally different negative relationship for developed countries. However, these findings may not be a single relationship that applies to both categories of countries (Vincent, 1997). Using our data set, we avoid such problems and may study how the shadow prices of emissions change as the country develops from a low-income to a high-income economy.



## 4 Summary of the papers

### **Paper [I] Biofuels and the Forest Sector - An Econometric Model of the Swedish Forest Sector.**

The main purpose of this paper is to analyze potential effects on the Swedish forest sector of a continuing rise in the use of forest resources as a fuel in energy generation. The background to the problem can be found in the commitments Sweden has made concerning energy policy. Two such commitments are the phase-out of nuclear power, and a decision that the Swedish energy system should be sustainable, i.e. it should be based on renewable resources. However, an increasing use of forest resources, as an energy input, may have effects outside the energy sector. In this paper we attempt to consider this by estimating a system of demand and supply equations for the four main actors on the Swedish roundwood market; forestry, sawmills, pulpmills, and the energy industry. The purpose of the paper is thus to analyze the effects on each of these markets as a result of a switch in energy policy, towards an increase in the use of biofuels. The data we use are aggregate time series covering the period 1967 to 1994 and we estimate the demand and supply functions using 3SLS and GMM. According to our results, the own price supply elasticity for biofuels is close to zero. In addition, our results suggest that biofuels and pulpwood are complements to each other, as the cross price supply elasticity of pulpwood and biofuels is positive. One explanation for this result is that there is a joint production of pulpwood and biofuels, i.e., a higher price of pulpwood increases pulpwood supply, but also increases the supply of wood residues (biofuels), as a side effect.

### **Paper [II] Effects of Increased Demand for Biofuels: A Dynamic Model of the Swedish Forest Sector.**

In this paper, we estimate the dynamic effects on the forest sector of an increased demand for biofuels. This is done by developing a partial adjustment model of the forest sector that enables short, intermediate, and long run price elasticities to be estimated. It is relevant to study the effects of increased demand for biofuels as the Swedish government has committed to an energy policy that is likely to further increase the use of renewable resources in the Swedish energy system. Four subsectors are included in the model: the forest owners, who supply sawtimber, pulpwood and forest fuels; the sawmills which demand sawtimber; the pulp and paper industry which demands pulpwood; and the energy industry which demands forest fuels. The data set used in paper [I] is updated so that it includes observations until 2003. The results show that the short run elasticities are fairly consistent with earlier studies, and that the capital adjustment costs are important in determining the path to long term responses. The capital adjusts to the

optimal level in approximately 10 years for the sawmills, and in 8 years for the pulp and paper industry. However, capital in the energy industry seems to take more than 40 years to adjust to its optimal level. This is unlikely and it suggests, instead, that the adjustment function parameter is much underestimated.

One of the energy policy objectives for Sweden is to reduce the emissions of greenhouse gases so that it, by 2010, is at least 4 percent lower than the 1990 levels. To meet this goal a continuous conversion of the energy system will presumably be needed. One way for the government to help such a conversion in the right direction could be to stimulate the use of forest fuels in the energy industry. Therefore the analysis ends with a simple illustration of short and long run effects of a policy shift to increase the energy industry's demand for forest fuels. The simulation results indicate that the introduction of a subsidy in the energy industry increases the demand for forest fuels and, thereby, the total demand for forest resources, and has a positive effect on all equilibrium prices. There is, however, a negative effect on the equilibrium quantities of sawtimber and of pulpwood, which can be explained by a supply substitution from sawtimber and pulpwood to forest fuels. In addition, the short run responses have the greatest magnitude, whereas in the long run they seem, generally, to reduce to roughly half the size. The results also show that the sawmill industry and the pulp industry are losers from such a subsidy, while the forest owners and the energy industry are winners.

### **Paper [III] Shadow Prices for Undesirables in Swedish Industry: Indication of Environmental Kuznets Curves?**

In this note, we estimate time series of shadow prices for Swedish emissions of CO<sub>2</sub>, SO<sub>2</sub>, and VOC for the period 1918 - 1994. The estimated shadow prices are, in a second step related to income, to explain the EKC's previously found for Swedish data on the three emissions. To estimate the shadow prices a Shephard distance function approach is used. An advantage of analyzing shadow prices rather than the actual emission levels is that, because the shadow prices reflect the firm's abatement costs of reducing the emissions, they may be used to explain the evolution path of the actual emissions. We expect to find the shadow prices to be just below zero for the lower income levels, and that the prices will become more negative for the higher levels of income. We conclude that the time series of the shadow prices obtained using this approach do not show support for EKC's in the Swedish industry.

#### **Paper [IV] A Dual Assessment of the Environmental Kuznets Curve: The Case of Sweden.**

The main objective in this paper is to analyze the relation between economic growth and pollution over a long period of time. The objective is closely linked to the hypothesis that environmental damage first increases with economic growth and then, after a turning point, decreases. This relationship is generally known as the environmental Kuznets curve (EKC). Newly constructed historical emission time series enable us to study a single country's emission paths for CO<sub>2</sub>, SO<sub>2</sub>, and VOC through different phases of economic activity. As in paper [III], the estimated shadow prices are in a second step regressed on the per capita GDP.

In this paper, we use the recently developed directional distance function approach to estimate the industry's production process in order to calculate the opportunity costs of a reduction in the emissions. As the shadow prices reflect the firm's abatement costs of reducing the emissions, they may be used to explain the evolution path of the actual emissions. According to the results, all three price series seem to fluctuate just below zero throughout the lower half of the income scale. At higher income levels the prices clearly tend to increase (become more negative). The turning point after which the shadow prices for both CO<sub>2</sub> and SO<sub>2</sub> increase appears at GDP levels of approximately 140000 SEK (\$18500), and the turning point for the VOC price, appears at approximately 80000 SEK (\$10500). This means that the turning point for the price of CO<sub>2</sub> and SO<sub>2</sub> occurs in the early 1980s, and in the beginning of the 1960s for the price of VOC. Some previous studies suggest that the link between emissions of globally important pollutants such as the greenhouse gas CO<sub>2</sub>, and a single country's wealth may not be so clear-cut, while the connection may be stronger for more regional or local pollutants such as the SO<sub>2</sub> or the VOC. Our shadow price series for CO<sub>2</sub> and SO<sub>2</sub> do not differ much from each other in this aspect. However, the regression results indicate an earlier turning point for the VOC price than for the other two prices. This result is in line with the argument that as we reach higher levels of welfare in terms of consumption, we can afford to be more concerned about the environment. Since VOC are ingredients in, e.g., smoke from combustion etc., we can immediately see the effects of our emissions. The damage from VOC emissions is also of a more local nature, which enables us to see a direct connection between a reduction in the emission of VOC and improving environmental quality. Accordingly, it is not surprising to find that, out of the three emissions, it is in the one that is most local in nature that we can first detect increasing shadow prices as a consequence of a reduction in the emission levels.

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