A Dual Assessment of the Environmental Kuznets Curve: The Case of Sweden[*]

Mattias Ankarhem
Department of Economics, Umeå University
SE-901 87 Umeå, Sweden

Abstract

In this paper, we calculate time series of shadow prices for Swedish emissions of CO_2, SO_2, and VOC for the period 1918 - 1994. Newly constructed historical emission time series enable studying a single country's emission paths through increasing levels of economic activity. The shadow prices are, in the next step, related to income to explain the environmental Kuznets curves (EKC) previously found in Swedish data for these three emissions. A directional distance function approach is used to estimate the production process for Swedish industry thus enabling the opportunity costs of a reduction in these emissions to be calculated. We attribute the annual changes in the shadow prices to the main causal factors by decomposing them into a technological effect and a substitution effect. We conclude that the time series of the shadow prices show support for EKCs for Swedish industry.

Key Words: Emissions, Historical time series, Decomposition, Directional distance function.

JEL Classification: O11, O13, Q51, Q53, Q56.

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1 Introduction

The main objective in this paper is to analyze the relationship between economic growth and pollution over a long period of time. To do this, we employ a two step procedure. In the first step, we estimate time series of shadow prices for emissions of carbon dioxide (CO_2), sulphur dioxide (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 hypothesis that environmental damage first increases with GDP per capita and then, after a turning point, decreases. This relationship is generally known as the environmental Kuznets curve (EKC)[1].

One view put forward by among others Meadows et al. (1972, 1992), is that economic growth requires greater use of energy and material and will, accordingly, 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. Another view originates from the World Bank's *World Development Report 1992* (IBRD 1992) and holds that the traditional way of relating growth to environmental damage is based on too static assumptions about technology, consumer preferences and environmental investments. It argues 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 would expect emissions to grow initially when a country with low economic activity increases its production. As economic activity continue to increase, a turning point would eventually be reached, after which pollution per capita would decrease.

A number of theoretical models have attempted to derive the EKC (Lopez, 1994; Selden and Song, 1995; Stokey, 1998; Lieb, 2002; among others). These studies use structural models to explain how changes in technology and preferences are related to changes in the environment. As noted by Stern (2002) and Panayotou (2003), these theoretical models have not yet been tested empirically. Andreoni and Levinson (2001) present a model where the relationship between income and pollution depends on the technological link between desirable consumption and an undesirable by-product. An empirical test of the model supports the notion of an EKC for some air pollutants. The bulk of the empirical literature, however, originates from the study by Grossman and Kreuger (1991) in which they estimate EKCs for SO_2, dark matter (fine smoke) and suspended particles. Since then, the empirical literature has expanded with numerous EKC-studies on emissions in different countries (see Stern, 1998, for an overview). A common approach for many of the studies is to estimate the relationship between an environmental index

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[1] The EKC is named after Kuznets (1955, 1963) who originally proposed a similar relationship between inequality in distribution of income and economic growth.

and per capita income, controlling for various other factors such as trade, energy prices, public R&D expenditures and measures of democracy. The results from the empirical studies are mixed. Generally, there seems to be support for the EKC for local airborne pollutants, whereas emissions with more global and more indirect environmental impacts, such as CO_2, have been found to either increase monotonically with income or to have very high turning points (Cole et al., 1997; Holtz-Eakin and Selden, 1995). Higher turning points for CO_2 emissions are also confirmed in studies by Schmalensee et al. (1998) and Panayotou et al. (1999). In the case of Sweden, however, Brännlund and Kriström (1998) find support for an EKC for SO_2 using data for the period 1900-1993, and, using data for the period 1900-1999, Kriström and Lundgren (2005) find indications of an EKC for CO_2. Both studies plot the emissions against the GDP per capita and use data at the national level.

The method used to calculate shadow prices in this study originates from Färe et al. (2002), who developed a directional distance function approach to obtain shadow prices for undesirables in the absence of market prices[2]. It has since been used for estimating shadow prices (abatement costs) for emissions and industrial wastes (e.g., Färe et al., 2005; Marklund, 2004), and is a generalization of the approach based on the Shephard's distance function that has been used in a number of studies (e.g., Coggins and Swinton, 1996; Hetemäki, 1996; Reig-Martinez et al., 2001).

This paper contributes to the research in this area in two ways. First, it narrows the gap between the underlying theory and the empirical assessment of the EKC in the sence that we estimate an axiomatic model of Swedish industry in order to derive the empirical shadow prices for the pollutants, and that we use the price mechanism to explain the EKC pattern found for Swedish emissions. In other words, an advantage of observing shadow prices rather than the actual emission levels is that as the shadow prices reflect the firm's abatement costs of reducing the emissions, they may be used for explaining the evolution path of the actual emissions. While the theoretical studies consist of structural models, a common feature of earlier empirical studies is that they typically estimate reduced form or ad hoc equations, and ignore the underlying production process that generates the pollutants. The model we estimate is in the spirit of the theoretical model in Brännlund and Kriström (1998) and Kriström and Lundgren (2005). While Kriström and Lundgren use a model consisting of a welfare function and the society's production function, this study uses a simplified version by estimating only the society's production possibilities. Second, by using a panel data set including newly constructed historical emission time series for the period 1913-1999, we are able to calculate long series of shadow prices

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[2] Chung et al. (1997) develop the directional distance function approach to be used as a component in a productivity index that models the joint production of goods and bads.

for a single country. The balanced panel consists of observations on inputs and observations on good and bad outputs for the sectors in the Swedish manufacturing industry. Generally, data series on emissions do not extend long enough back in time to cover the period when today's developed countries where still developing. To relate emissions to increasing economic activity, many previous studies have, therefore, used panels including a sample of countries at different levels of economic development, where almost all low-income observations come from developing countries and all the high-income observations come from developed countries. The approach entails a risk that a relation such as an EKC may then just reflect two separate findings: on the one hand, developing countries have a positive relationship between income and pollution; and on the other there is 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 are able to study how the shadow prices of emissions change as the country develops from a low-income to a high-income economy.

The rest of the paper is organized as follows; in the next section we present the theory underlying our approach and derive the theoretical shadow prices. The empirical model is specified in section 3 and the data and estimation procedure are discussed in section 4. In section 5 we present the results and finally, conclusions are offered in section 6.

2 Theory

2.1 Theoretical background

Environmental problems can be divided into global problems where carbon dioxide (CO_2) is an important pollutant, and into regional- and local problems in which sulfur dioxide (SO_2) and volatile organic compounds (VOC), respectively, are important pollutants. The basic problem here is that the production of a "good" output often is associated with an undesirable or "bad" output such as CO_2, SO_2 or VOC.

Using a framework similar to Brännlund and Kriström (1998) and Kriström and Lundgren (2005), the relationship between economic activity and environmental quality can be viewed in the following way: a representative individual's utility is increasing in consumption and decreasing in pollution, and the society's production possibilities are given by a production function that yields good output with bad output (pollution) as a by product, using labor and capital as inputs. Assuming a social optimum, at each point in time, gives that the marginal willingness-to-pay (MWTP) for environmental quality should be equal to its supply cost in terms of reduced production of the desirable good (Figure 1).

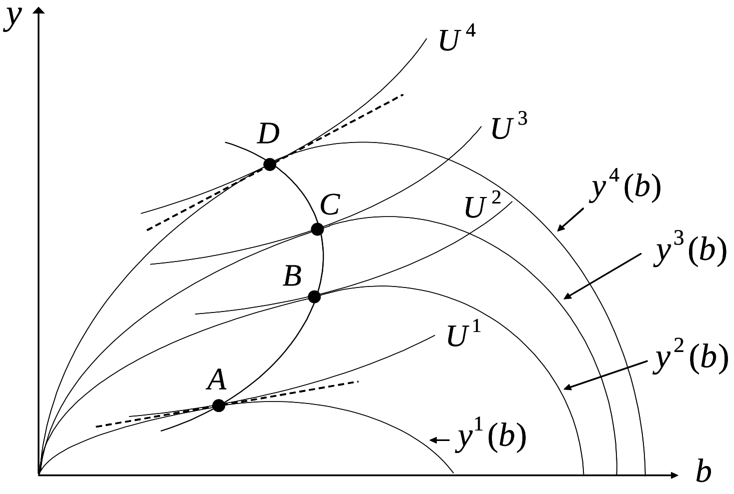

Figure 1: The EKC as an expansion path, *A*-*D*, for the equilibrium condition that MWTP for environmental quality be equal to its supply cost. The y^t , $t = 1, ..., 4$, show the production of the good as a function of the bad in four subsequent time periods and the U^i, $i = 1, ..., 4$, represent increasing utility levels. The dashed lines through *A* and *D* indicate separating hyperplanes.

The expansion path of this equilibrium over different time periods may then take the form of an EKC. Along the expansion path, the marginal willingness-to-pay for consumption is initially high. That is, the slope of the supporting hyper plane at equilibrium A is "flat". However, as economic activity increases, the marginal utility of consumption declines and the marginal disutility of pollution increases, i.e., the slope of the supporting hyper plane becomes steeper as we move through B and C to D. Technological progress enables more production at each level of emissions, which creates both substitution and income effects. The substitution effect is positive for both consumption and pollution, while the income effect tends to increase the demand for both consumption and environmental quality (i.e., reduce the demand for pollution). Accordingly, the two effects counteract each other; the former dominates at low income levels and the latter dominates at high income levels, producing the inverted U shaped relationship between income and pollution. The shape of the expansion path and where the turning point occurs, if it exists, depends on how technology and preferences interact. If no restrictions on technology and preferences are added, the path may take virtually any shape. As mentioned above, the equilibrium condition along the expansion path states that the MWTP for environmental quality equals its supply cost in forgone output. In terms of production, this is the opportunity cost of a reduction in the emissions. Studying how the opportunity cost, or shadow price, develops along the expansion path deepens the understanding of the role of the price, on the level of emissions in Sweden. For instance, if the shadow price is negative and decreasing as production increases, there is clear support for an EKC in the data.

As we have only data on the production side of the economy, we simplify the problem to a "partial analysis", in the sense that we disregard the consumer's utility function and estimate only the society's production possibilities. The shadow price is then calculated as the marginal rate of transformation, along the expansion path, between the good product and pollution. The model used for calculating the shadow prices is presented in the following section.

2.2 The model

Pollution is viewed as a by-product of 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. We assume a vector of N inputs $\mathbf{x} = (x_1, ..., x_N)$ used in the production of a vector of M good outputs $\mathbf{y} = (y_1, ..., y_M)$, together with a vector of J bad outputs $\mathbf{b} = (b_1, ..., b_J)$. 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, due to, e.g., environmental taxes on pollution, the prices of the undesirables are expected to be non-positive. Thus we define $\mathbf{p} = (\mathbf{p}_y', \mathbf{p}_b')'$ where $\mathbf{p}_y > \mathbf{0}$, for desirable outputs and $\mathbf{p}_b \leqslant \mathbf{0}$ for undesirable outputs. This implies that the firm knows the price of bads and acts accordingly. Further, the efficient production can be represented by the general "smooth" transformation function $f(\mathbf{x}, \mathbf{y}, \mathbf{b}) = 0$. For a given level of inputs, the representative firm's costs are given. Accordingly, it maximizes profit by choosing an output combination which maximizes revenues:

$$R(\mathbf{x}, \mathbf{p}) = \max_{\mathbf{y}, \mathbf{b}} \mathbf{p}_y'\mathbf{y} + \mathbf{p}_b'\mathbf{b} \quad \text{s.t.} \quad f(\mathbf{x}, \mathbf{y}, \mathbf{b}) = 0 \; .$$

The associated Lagrangian is then written:

$$\mathfrak{L}(\mathbf{y}, \mathbf{b}, \lambda) = \mathbf{p}_y'\mathbf{y} + \mathbf{p}_b'\mathbf{b} \; + \lambda(0 - f(\mathbf{x}, \mathbf{y}, \mathbf{b})) \tag{1}$$

and the first-order necessary condition with respect to good and bad output becomes $\mathbf{p}_y = \lambda \boldsymbol{\nabla}_y f(\mathbf{x}, \mathbf{y}, \mathbf{b})$, and $\mathbf{p}_b = \lambda \boldsymbol{\nabla}_b f(\mathbf{x}, \mathbf{y}, \mathbf{b})$, respectively, where $\boldsymbol{\nabla}_y$ denotes the gradient with respect to y, and $\boldsymbol{\nabla}_b$ denotes the gradient with respect to b. Here, we are interested in the shadow price of a bad output in terms of the price of a good output:

$$\frac{p_b}{p_y} = \frac{\partial f(\mathbf{x}, \mathbf{y}, \mathbf{b})/\partial b}{\partial f(\mathbf{x}, \mathbf{y}, \mathbf{b})/\partial y} \; . \tag{2}$$

That is, the relative price corresponds to the ratio of the transformation function derivatives, which allows us to retrieve the relative shadow prices we seek through a primal specification of the production, using only data on inputs and outputs. The production technology underlying the transformation function 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 as the undesirable outputs are not traded on the market and, therefore, the data we use contain only observations on inputs and outputs, and not on market prices. In this study, the distance function is preferred to the multi-output production function as the former allows us to choose a measure of efficient production that implies simultaneous expansion of the good and contraction of the bad output.

The origins of the directional distance function approach for modelling the shadow price for undesirables can be found in Färe et al. (2002). The function is defined on the output set, $P(x)$, as

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

where the solution, β^*, 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. Here, the directional vector $\mathbf{g}=(1,-1)$ is chosen for simplicity, but an alternative direction would be, e.g., $\mathbf{g}=(y,-b)$ as chosen in Chung et al. (1997), who use a non-parametric linear technique when modelling productivity. However, the choice of direction is highly important in determining the shadow price. 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. Ankarhem (2005), uses a Shephard's distance function to estimate the shadow prices of the same emissions as in this paper. Such a distance function use the directional vector $\mathbf{g}=(y,b)$ and, therefore, a proportional expansion of both the good and the bad output is rewarded as an efficiency gain. In the study, many of the price observations are positive, which is not plausible since it suggests that we would actually be willing to pay for, e.g., being exposed to acid rain. Chosing the directional vector $(1,-1)$ is, instead, in line with the view that a reduction in the bad output, given that the production of the good output is constant, or increased, is an efficiency improvment.

The distance function will take a value greater than or equal to zero if the output vector is an element of the feasible production set. The value zero applies for technically efficient output vectors on the frontier, and a value greater than zero for inefficient output vectors below the frontier, where the value increases, the more inefficient the output vector. From the definition of the distance function we can see that if $(\mathbf{y}, \mathbf{b}) \in P(\mathbf{x})$, then $(\mathbf{y} + \vec{D}_o(\mathbf{x}, \mathbf{y}, \mathbf{b}; \mathbf{g})g_y, \mathbf{b} - \vec{D}_o(\mathbf{x}, \mathbf{y}, \mathbf{b}; \mathbf{g})g_b) \in P(\mathbf{x})$. Substituting this expression into the representative firm's revenue function gives $R(\mathbf{x}, \mathbf{p}) = \mathbf{p}_y'\mathbf{y} + \mathbf{p}_b'\mathbf{b} + (\mathbf{p}_y g_y - \mathbf{p}_b g_b)\vec{D}_o(\mathbf{x}, \mathbf{y}, \mathbf{b}; \mathbf{g})$. The corresponding expression to eq. (1) may then (when allowing for inefficient production) be written as:

$$R(\mathbf{x}, \mathbf{p}) = \max_{\mathbf{y}, \mathbf{b}} \left\{ \mathbf{p}_y'\mathbf{y} + \mathbf{p}_b'\mathbf{b} + \lambda \vec{D}_o(\mathbf{x}, \mathbf{b}, \mathbf{y}; \mathbf{g}) \right\},$$

where $\lambda = (\mathbf{p}_y \cdot 1 - \mathbf{p}_b \cdot 1)$, since $\mathbf{g} = (1, -1)$. The equivalent expression to the shadow price in eq. (2) then becomes:

$$\frac{p_b}{p_y} = \frac{\partial \vec{D}_o(\mathbf{x}, \mathbf{y}, \mathbf{b}; \mathbf{g})/\partial b}{\partial \vec{D}_o(\mathbf{x}, \mathbf{y}, \mathbf{b}; \mathbf{g})/\partial y}. \tag{3}$$

Performing this calculation for each year will give a series of annual shadow price observations, and these prices may then be analyzed as follows: First, in addition to studying the evolution path of the prices, we also wish to attribute the annual price change to causal factors by decomposing them into a technological effect corresponding to technological progress, and into a substitution effect corresponding to changes in consumer preferences. In other words, both technological progress and changes in environmental preferences are assumed to lead to structural transformation in production and/or in final demand, which will influence the shadow price. For every year, we then calculate each effect's share of the total change. Second, in analogy with the EKC hypothesis, we wish to see how the prices and the shares of the causal factors are related to income, therefore we plot each year's prices, technological and substitution shares against the income level. In addition, we also run a regression of the prices on income. The decomposition of the price change is the next step and is explained in the following section.

2.3 Decomposition

In the empirical procedure, we estimate a series of sub samples (further developed in the empirical section). This allows for non-neutral technological development in the sense that the technology parameters may change from one period to another. Accordingly, the slope of the transformation function does not need to be the same in the two periods, as would be the case if the technological effect was a traditional scale effect. Instead, the technological effect is here interpreted as the shift from one estimated transformation function to a subsequent one, with a different set of parameter estimates. The slope of the transformation function can, therefore, change and we may observe changes in the shadow price due to this effect. The residual part of the total change is then interpreted as a substitution effect arising from changes in consumer preferences, realized through, e.g., regulations and green taxes etc.

When decomposing the annual price change, we follow an additive approach similar to the one used for the Luenberger productivity indicator (Färe and Grosskopf, 2004). Denoting p_b/p_g by $\widetilde{p}$, we define the total change in the shadow price as:

$$\Delta\widetilde{p}_{tot}^{t+1} = \frac{\partial\vec{D}_o^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})/\partial b}{\partial\vec{D}_o^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})/\partial y} - \frac{\partial\vec{D}_o^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})/\partial b}{\partial\vec{D}_o^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})/\partial y}, \tag{4}$$

which is the result of a movement from point A to point D in Figure 2. The $\vec{D}_o^t$, and $\vec{D}_o^{t+1}$ means that the reference technology is constructed using the data from period t and $t+1$, respectively. Within the parentheses is the input-output data for which the function is evaluated, so that $(\mathbf{x}^t,\mathbf{y}^t,\mathbf{b}^t)$ denotes the data from period t, and $(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1})$ is the data from period $t+1$.

When decomposing the total change, there are, at least, three ways to calculate the change in the shadow price arising from technological change (henceforth denoted as $\Delta\widetilde{p}_{tec}$): *(i)* with $(\mathbf{x}^t,\mathbf{y}^t,\mathbf{b}^t)$ as reference input and output vectors, *(ii)* using $(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1})$ as reference input and output vectors, and *(iii)* as the mean of the change in shadow prices obtained from *(i)* and *(ii)*. Choosing *(i)* – *(iii)* will, of course, have different effects on the size of $\Delta\widetilde{p}_{tec}$, and, in turn, it will also have an effect on the shadow price change due to change in consumer preference, $\Delta\widetilde{p}_{sub}$.

Choosing *(i)*, we see $\Delta\widetilde{p}_{tec}$ as a movement from A to B, which in turn implies that $\Delta\widetilde{p}_{sub}$ will be estimated as a movement from B to D. Choosing *(ii)*, we see $\Delta\widetilde{p}_{tec}$ as a movement from C to D, which gives $\Delta\widetilde{p}_{sub}$ as a movement from A to C. To avoid arbitrariness when calculating the measures of $\Delta\widetilde{p}_{tec}$ and $\Delta\widetilde{p}_{sub}$, we follow the third alternative, *(iii)*, and may therefore write $\Delta\widetilde{p}_{tec}$ as:

$$\begin{aligned}\Delta\widetilde{p}_{tec}^{t+1} &= \frac{1}{2}\Bigg[\left(\frac{\partial\vec{D}_o^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g}\right)/\partial b}{\partial\vec{D}_o^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{y}^{t};\mathbf{g}\right)/\partial y} - \frac{\partial\vec{D}_o^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})/\partial b}{\partial\vec{D}_o^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})/\partial y}\right) \\ &\quad + \left(\frac{\partial\vec{D}_o^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})/\partial b}{\partial\vec{D}_o^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})/\partial y} - \frac{\partial\vec{D}_o^{t}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})/\partial b}{\partial\vec{D}_o^{t}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})/\partial y}\right)\Bigg],\end{aligned}$$

where the expression in the first parenthesis is derived from alternative *(i)* and equals the shadow price at point B minus the shadow price at point A. The second parenthesis is derived from alternative *(ii)* and is the shadow price at point D minus the shadow price at point C. The change due to preferences is then written as:

$$\begin{aligned}\Delta\widetilde{p}_{sub}^{t+1} &= \frac{1}{2}\Bigg[\left(\frac{\partial\vec{D}_o^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})/\partial b}{\partial\vec{D}_o^{t+1}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})/\partial y} - \frac{\partial\vec{D}_o^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g}\right)/\partial b}{\partial\vec{D}_o^{t+1}\left(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{y}^{t};\mathbf{g}\right)/\partial y}\right) \\ &\quad + \left(\frac{\partial\vec{D}_o^{t}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})/\partial b}{\partial\vec{D}_o^{t}(\mathbf{x}^{t+1},\mathbf{y}^{t+1},\mathbf{b}^{t+1};\mathbf{g})/\partial y} - \frac{\partial\vec{D}_o^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})/\partial b}{\partial\vec{D}_o^{t}(\mathbf{x}^{t},\mathbf{y}^{t},\mathbf{b}^{t};\mathbf{g})/\partial y}\right)\Bigg],\end{aligned} \tag{5}$$

where the expression within the first parenthesis is derived from *(i)* and equals the shadow price

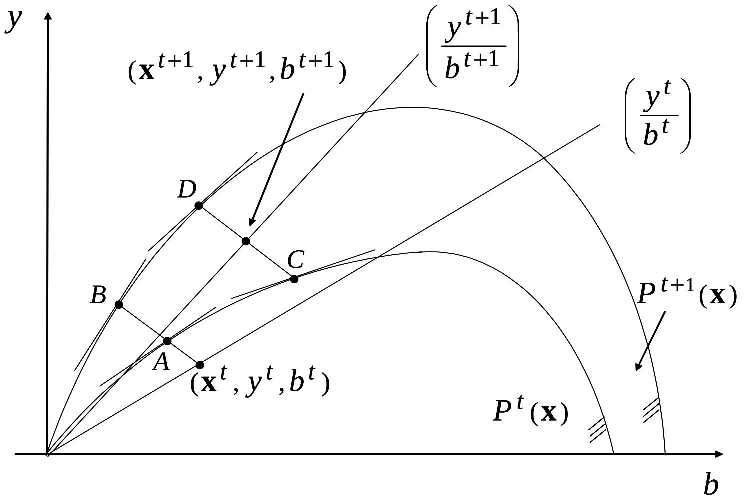

Figure 2: Decomposition of a change in the shadow price: A change from A to B or from C to D is interpreted as due to changes in technology. A change from B to D or from A to C is interpreted as arising from changes in consumer preferences.

at point D minus the shadow price at point B. The second parenthesis comes from (ii) and is equal to the shadow price at point C minus the shadow price at point A.

The $\Delta\widetilde{p}_{tec}$ share (subindexed s) of the total change is then expressed as:

$$\Delta\widetilde{p}_{tec,s} = \frac{abs(\Delta\widetilde{p}_{tec})}{abs(\Delta\widetilde{p}_{tec}) + abs(\Delta\widetilde{p}_{sub})} \quad , \tag{6}$$

which gives the $\Delta\widetilde{p}_{sub,s}$ as the remainder share, $(1 - \Delta\widetilde{p}_{tec,s})$.

3 The Empirical Model

To estimate the distance function, we follow Färe et al. (2002) and use the flexible (additive) quadratic function to approximate the underlying true transformation function. The model then has the following form (suppressing the time index):

$$\begin{aligned} \vec{D}_o(\mathbf{x}^k, \mathbf{y}^k, \mathbf{b}^k; \mathbf{g}) \quad = \quad & \alpha_0 + \sum_{n=1}^{N} \alpha_n x_n^k + \sum_{m=1}^{M} \beta_m y_m^k + \sum_{j=1}^{J} \gamma_j b_j^k \\ & + \frac{1}{2} \sum_{n=1}^{N} \sum_{n'=1}^{N} \alpha_{nn'} x_n^k x_{n'}^k + \sum_{n=1}^{N} \sum_{m=1}^{M} \delta_{nm} x_n^k y_m^k + \sum_{n=1}^{N} \sum_{j=1}^{J} \eta_{nj} x_n^k b_j^k \\ & + \frac{1}{2} \sum_{m=1}^{M} \sum_{m'=1}^{M} \beta_{mm'} y_m^k y_{m'}^k + \sum_{m=1}^{M} \sum_{j=1}^{J} \mu_{mj} y_m^k b_j^k \\ & + \frac{1}{2} \sum_{j=1}^{J} \sum_{j'=1}^{J} \gamma_{jj'} b_j^k b_{j'}^k + \kappa^k. \end{aligned} \tag{7}$$

The set of inputs with $N = 2$ has x_1^k denoting the input of labor, and x_2^k is the input of capital. The set of desirable outputs with $M = 1$ has the output (value-added) denoted by y_1^k, and the set of undesirable outputs with $J = 3$ has the outputs CO_2, SO_2, and VOC denoted by b_1^k, b_2^k and b_3^k, respectively.

Dummy variables are included to account for the industrial sectors $k = 2, ..., K$. Since we want to allow the technology parameters to change over time, we do not wish to estimate the equation for the full sample all at the same time. Instead, we estimate the equation for a series of sub-samples, or *windows*, of length T. One shadow price per undesirable and window is calculated using the window means of the variables in the equation. Ascribing the price to a year within the window, and repeating this procedure for all windows, gives a series of "year specific" shadow price observations.

We impose the following restrictions on eq. (7) to ensure that the empirical function complies with the underlying theory of the distance function. By assuming the directional vector to be $g = (1_1, ..., 1_M; -1_1, ..., -1_J)$, the parameters in eq. (7) are chosen to minimize

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\begin{array}{rl}
 & \sum_{k=1}^{K}\sum_{t=1}^{T}(\vec{D}_o(x^{kt}, y^{kt}, b^{kt}; 1, -1) - 0) \\
 & \text{subject to:} \\
(i) & \vec{D}_o(x^{kt}, y^{kt}, b^{kt}; 1, -1) \geq 0, \quad \forall\; k, t \\
(ii) & \vec{D}_o(x^{kt}, y^{kt}, 0; 1, -1) < 0, \quad \forall\; k, t \\
(iii) & \partial\vec{D}_o(x^{kt}, y^{kt}, b^{kt}; 1, -1) \;/\; \partial y_m \leq 0, \quad \forall\; k, t, m \\
(iv) & \partial\vec{D}_o(x^{kt}, y^{kt}, b^{kt}; 1, -1) \;/\; \partial b_j \geq 0, \quad \forall\; k, t, j \\
(v) & \partial\vec{D}_o(x^{kt}, y^{kt}, b^{kt}; 1, -1) \;/\; \partial x_n \geq 0; \quad \forall\; k, t, n \\
(vi) & \sum_{m-1}^{M}\beta_m - \sum_{j-1}^{J}\gamma_j = -1, \quad \sum_{m'=1}^{M}\beta_{mm'} - \sum_{j=1}^{J}\mu_{mj} = 0, \\
 & \sum_{j'=1}^{J}\gamma_{jj'} - \sum_{m=1}^{M}\mu_{mj} = 0, \quad \sum_{j=1}^{J}\eta_{nj} - \sum_{m=1}^{M}\delta_{nm} = 0, \quad \forall\; j, m, n \\
(vii) & \alpha_{nn'} = \alpha_{n'n}, \quad n \neq n', \quad \beta_{mm'} = \beta_{m'm}, \quad m \neq m', \quad \gamma_{jj'} = \gamma_{j'j}, \quad j \neq j' \;.
\end{array}
\qquad (8)
$$

The restrictions in (i), ensures that the distance function will take a value of zero or greater, i.e., producers will operate on, or below the frontier. A null-jointness restriction is imposed by (ii) stating that the production of desirable goods is not possible without also producing pollution. Monotonicity conditions are imposed by restrictions $(iii) - (v)$, ensuring that the distance function is decreasing in good output, and increasing in the bad outputs as well as in inputs. The restrictions $(i) - (v)$ are all imposed for individual observations as well as for the mean of the data at industry and sector level, respectively. Further, the restrictions (vi) impose translation properties which "translate" the observed output bundle to the frontier, and finally symmetry restrictions are imposed in (vii).

Taking the derivatives of eq. (7) with respect to the good and bad outputs, respectively, we can now write the empirical equivalence of eq. (3) as:

$$\widetilde{p}^k_{j,m} = \frac{p^k_{b_j}}{p^k_{y_m}} = \frac{\gamma_j + \sum_{n=1}^{N} \eta_{nj} x^k_n + \sum_{m=1}^{M} \mu_{mj} y^k_m + \sum_{j'=1}^{J} \gamma_{jj'} b^k_{j'}}{\beta_m + \sum_{n=1}^{N} \delta_{nm} x^k_n + \sum_{m'=1}^{M} \beta_{mm'} y^k_{m'} + \sum_{j=1}^{J} \mu_{mj} b^k_j} \ ,$$

where $j = CO_2$, SO_2, and VOC, and $m =$ value added.

3.1 Regressing the Shadow Price on GDP

Once eq. (7) is estimated subject to the restrictions and the empirical shadow prices are calculated, we estimate the possible relationship between each price, $\widetilde{p}^k_{j,m}$, and the per capita GDP. For this, a panel-data approach is used, where we allow for fixed effects and for the slope parameters to be sector dependent. To ensure that the predicted values are negative, as suggested by theory, an exponential function is used. Suppressing the subscripts, we may write the function in the following way:

$$\widetilde{p}^{k,t} = -\exp(\phi_0 + \sum_{k=1}^{K-1} \phi^k_0 z^k + (\phi_1 + \sum_{k=1}^{K-1} \phi^k_1 z^k) x^t_g + (\phi_2 + \sum_{k=1}^{K-1} \phi^k_2 z^k)(x^t_g - \overline{x}_g)^2 + \eta^{k,t}) \ . \quad (9)$$

The z^k is a dummy variable that takes the value one for observations belonging to sector k, and x_g is the GDP per capita. The t denotes time for the constructed series of the shadow prices and the GDP. For this estimation, the sample size is defined by the length of the obtained shadow price series. To reduce multicollinearity, the deviation from the mean of the GDP series, denoted $\overline{x}_g$, is used for the quadratic term. The error term η is assumed to have a zero mean and constant variance.

4 Data and Estimation

We use historical data for Swedish industry, divided into eight industrial sectors (Lindmark, 2003)[3]. The balanced panel of annual data series covers the period 1913 - 1999. The sector division follows the organization in the Historical National Accounts for Sweden (SHNA) and the classification is fairly consistent with the two-digit ISIC level. Some reclassifications have been made to ensure compatibility with older data. Labor input is expressed in working hours,

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[3] The industries are: 1) mining, basic metal industries, manufacture of fabricated metal products, etc, 2) non-metallic mineral products, 3) wood and wood products, 4) pulp, paper, printing and publishing, 5) food, beverages and tobacco, 6) textiles and clothing, 7) leather and rubber, and 8) chemicals, plastic products and petroleum.

Table 1: Descriptive Statistics. The full sample for the time period 1913-1999: covering 87 years and 8 sectors, yields 696 observations.

Variable	Unit	Mean	St. Dev.	Minimum	Maximum
Labor	K hours	17370	20683	2156	100744
Capital Stock	M SEK	2368	4376	29	26469
Value-Added	M SEK	13770	22397	191	135655
CO_2	K tons	3197	4436	2	27252
SO_2	10 tons	1603	2533	3	12239
VOC	K tons	1219	1849	3	9243
GDP/capita	SEK	86036	46499	27195	166266

Notes: The sample size for GDP equals the number of calculated shadow prices: 77 observations. Capital Stock, Value-Added and GDP are expressed at the 1990 price level.

and the capital stock, the value-added and the GDP are all given in SEK at the 1990 price level. Further, the emissions are all expressed in metric tons. Descriptive statistics of the data set are displayed in Table 1.

The estimation of the model is structured as follows; we choose the window to consist of eleven years, or 88 panel observations, and the calculated shadow prices are attributed to the sixth year (the center) in each period. The first window ranges from 1913 to 1923 and we let the window shift one year for every estimation so that the final one ranges from 1989 to 1999[4].

Sector specific fixed effects are assumed to be present, representing, e.g., differences in technology between the sectors. They are modelled by adding seven sector dummies to the restricted equation. Dummy variables are also used for the period 1914 - 1919 and 1939 - 1945 to account for the effects that World Wars I and II had on the data. For instance, the emissions of CO_2 and SO_2 drop drastically in some sectors. VOC has, instead, a positive peak, because of a change in the composition in the use of energy, where the use of biofuels has a peak especially during the World War II. We also use a dummy variable for the years 1930 - 1936 to account for the unusually large emissions of SO_2 by the large Swedish metal melting plant, Rönnskär, during its initial years of operation.

We impose restrictions (8:*i*)-(8:*vii*) on eq. (7) and use a linear programming (LP) approach to estimate the system. To avoid numerical problems in the estimation, each input and output series is divided by its mean value before estimating eq. (7). The decomposition of the shadow price changes are made according to eqs. (4) - (5) and the calculation of their shares are made according to eq. (6).

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[4] This approach produces output for 77 subsamples and the output file is large and not well suited for presentation. It is available from the author on request.

In the next step, each price is regressed on the per capita GDP as in eq. (9), where the deviation from the mean of the GDP series is used for the quadratic term to reduce possible multicollinearity. The equations are first estimated on an industrial sector level using the panel of observed prices, evaluated at the sector mean of the data in each window. The series of calculated shadow prices ranges from 1918-1994, yielding 77 observations per industrial sector and 616 panel observations. In addition, the equations are also estimated for prices at the manufacturing industry level. For this, we use 77 price observations evaluated, for each window, at one mean regarding the data observations from all sectors. We wish to constrain the predicted values to be non-positive, but still allow for an otherwise flexible specification. The relation is, therefore, specified as the negative of an exponential function, where we use a quadratic expression within the function to allow for flexibility. We also use dummy variables for these equations for the periods 1914 - 1919 and 1939 - 1945 to account for the World Wars I and II, and a dummy variable for the years 1930 - 1936 to account for the SO_2 emissions by the Rönnskär metal melting plant.

The equations are estimated using least squares and an LM-test is used for testing against heteroskedasticity, rejecting the null of homoskedasticity for all six equations. A Breusch-Godfrey test against serial correlation of the residuals indicates a serial correlation of high orders for all six equations. This is not suprising, for this type of data. Even if the price in period t is calculated independently from the subsequent price, most of the observations on the underlying variables are the same in both periods. A Wald test against fixed effects for the panel equations, accepts the null of pooled regressions. The Newey-West covariance estimator is then calculated to supply standard errors that are robust with regard to both serial correlation and heteroskedasticity. To control for other factors influencing the shadow price, it is reasonable to include more exogenous variables than per capita GDP in the equation (energy prices, public R&D expenditures, etc.). However, obtaining series of the same length as the already available series from the given data set is not easy, accordingly we focus only on the relationship between the shadow prices and per capita GDP.

5 Results

The shadow prices and their predicted values for the 77 sub-samples are shown in Figures 3a-c. They are plotted against GDP per capita, ranging from 27000 to 167000 SEK ($3500-$22500). Generally, the production/income is increasing over time, so that low GDP levels appear early and higher levels appear later in the time period. The technologically and preference driven shares of the annual total price change are also presented. The shadow prices are negative but as they correspond to opportunity costs, we will in the following refer to a price that becomes "more negative" as increasing.

In Figure 3a, we see the sequence of shadow prices for CO_2 evaluated at the corresponding window data means. Prices range between -0.4 and -0.05 for a per capita GDP level up to approximately 150000 SEK ($20000) after which the prices start to increase with the greatest values being -2.3. The spread, also increases for the prices at GDP per capita higher than 150000 SEK. In the lower graph of Figure 3a, the technology driven price change is depicted as a share, $\Delta\widetilde{p}_{tec,s}$, of the annual total price change, and the preference driven price change is then given as the remainder share, $\Delta\widetilde{p}_{sub,s}$. $\Delta\widetilde{p}_{tec,s}$ has the greatest influence on $\Delta\widetilde{p}_{tot,s}$, apart from a few observations throughout the income scale when the preference driven change dominates in magnitude. The linear approximation of the $\Delta\widetilde{p}_{tec,s}$ curve has a slightly positive slope showing that the $\Delta\widetilde{p}_{tec,s}$ tends to increase over the period. This implies that the technology driven change is gaining in importance. However, the tendency is weak so that the impression is not given that technology driven change is gaining significantly in importance with increasing levels of consumption.

In Figure 3b, we see the shadow price for SO_2 evaluated at the data mean for each window. The negative price has values close to zero (average value of approximately -0.15) for per capita GDP levels up to 150000 SEK. At higher income levels, the price starts to increase and it reaches its greatest value of -15 for a GDP of 160000 SEK, which corresponds to the years in the beginning of the 1990s.

The pattern for the $\Delta\widetilde{p}_{tec,s}$ of the annual change in the shadow price for SO_2 resembles the one in Figure 3a in that the total price change is driven primarily by technological progress, and that the consumer preferences seem to be of subordinate importance. In this case, a linear approximation of the $\Delta\widetilde{p}_{tec,s}$ curve shows that the share of technology driven changes is also increasing slightly. The main impression is, however, that the shares are fairly constant over the income scale.

The shadow price for VOC is plotted in Figure 3c. This price is also close to zero (with an average value of approximately -0.15) for the lower levels of income. However, the price starts to increase at per capita GDP levels of approximately 80000 SEK ($10500), which is a lower income level than for the other two prices. Further, it is associated with an earlier time period (the beginning of the 1960s) than was the case for the turning-points[5] for the other two prices. The fluctuations also tend to become greater as the price increases. With regard to the $\Delta\widetilde{p}_{tec,s}$ of the annual price change for VOC, the pattern resembles those for the other two emissions. The

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[5] Note that these turning points regard the shadow prices and not the actual emissions, as are usually referred to.

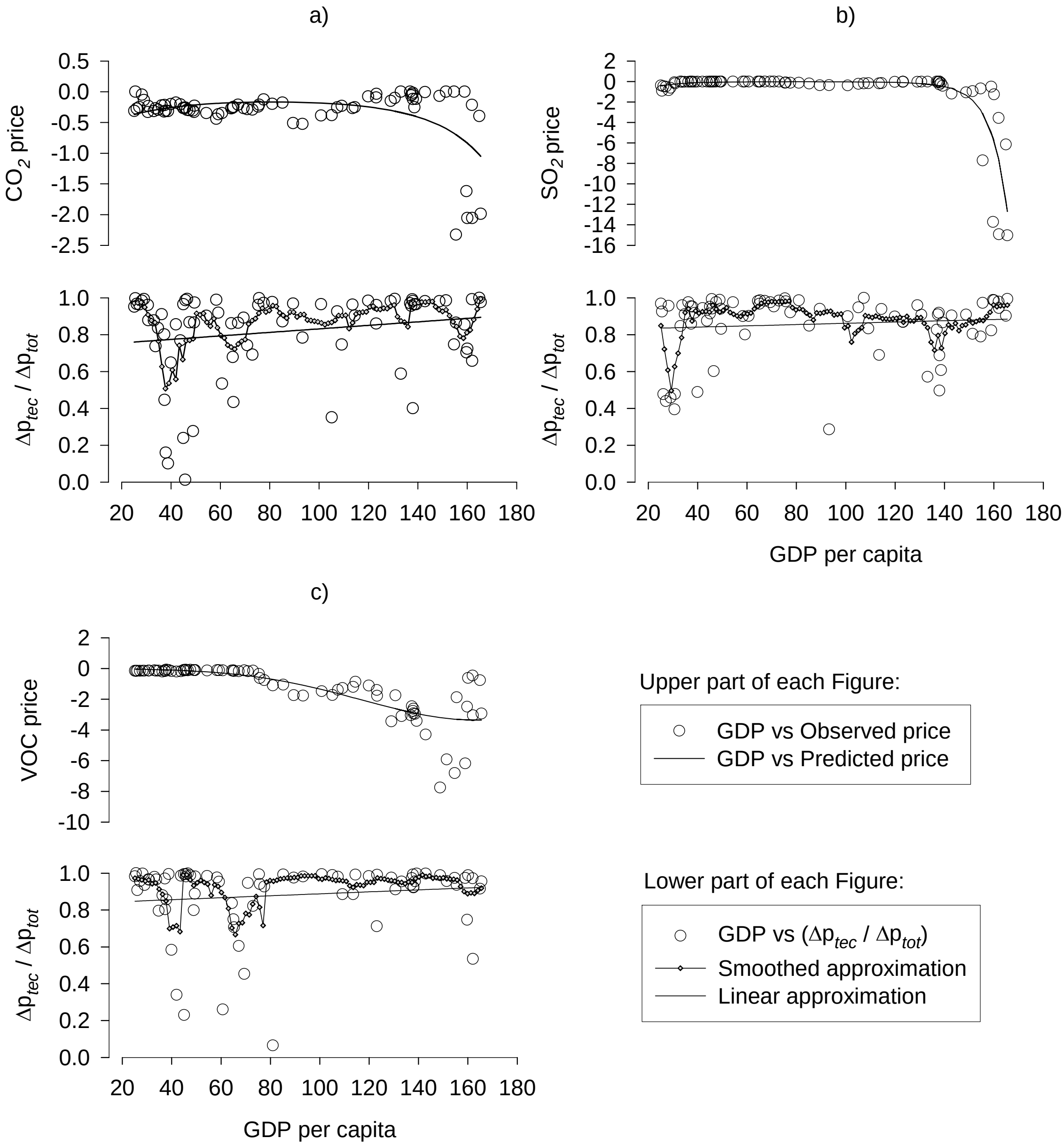

Figure 3: The upper graphes in Figures a to c show the shadow prices for CO_2, SO_2 and VOC respectively, plotted against GDP. The lower graph in each figure depicts the $\Delta\widetilde{p}_{tec}$ as a share of the $\Delta\widetilde{p}_{tot}$ yielding $\Delta\widetilde{p}_{sub,s}$ as the residual share.

technology driven change is clearly the most important part, and a linear approximation of the $\Delta\widetilde{p}_{tec,s}$ curve shows a tendency for technology driven changes to increase slightly in importance, indicating that technological development increases in importance for higher income levels.

To evaluate the robustness of these results, we compare them with the results from two alternative estimations (not reported here). First, a "grand frontier" is estimated, which means that instead of estimating a series of sub samples, we use a sample covering the entire period and dummy variables are used to model the time effects. The pattern of the calculated shadow prices seems to support the findings from the main estimation. The general impression is that they tend to have a more hump-shaped pattern, that is, they seem to decrease (i.e., have values closer to zero) in the lower part of the income scale, before increasing. Second, the distance function has also been estimated econometrically. Here, the same window procedure as described earlier, is used. In the econometric estimation we do not impose restrictions in the same manner as in the LP estimation. 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 being negative. It turns out that there are many positive observations for the CO_2 emissions, but hardly any for the other two emissions. When using the delta method to construct confidence bounds for the prices, only a few observations are significantly positive. The general impression is that the results from the econometric estimation resemble the ones from the LP estimation. This is specifically the case for the SO_2 and VOC prices.

Next, we explore the statistical relationship between each shadow price and the GDP per capita. The results from the regressions are reported in Table 2 and the predicted values from the manufacturing industry level equations are plotted in Figure 3. For the CO_2 aggregate equation, both slope parameters have positive signs, but only the quadratic term is significant at the five percent level. As the function is specified with a minus sign in front of all parameters, the effect of income on the prices will then be the opposite of the parameter sign. The predicted values show a turning point at approximately 130000 SEK, which corresponds to the years in the beginning of the 1980s. The results for the parameter estimates hold also for the panel regression. Exceptions are sectors 2 and 8 (i.e., the non-metallic minerals sector and the chemical sector) which have negative level terms. The high turning point, together with the parameter estimates, suggest that the negative effect of the quadratic term has a dominating effect in increasing the price.

The pattern for the SO_2 estimates resembles the one for CO_2. For the aggregate equation, both the level and the quadratic terms are positive but only the latter is significant. From the panel regression, we have basically the same results. Both the level and the quadratic terms are positive for all sectors, indicating that income has a negative effect on the shadow

Table 2: Parameter estimates for the price equations.

		CO_2 price		SO_2 price		VOC price	
Coefficient	Parameter	Est.	s.e.	Est.	s.e.	Est.	s.e.
Aggr. level:							
Constant	ϕ_0	-2.003	0.329*	-4.324	0.518*	-3.223	0.466*
x_g^t	ϕ_1	0.025	0.037	0.071	0.050	0.356	0.049*
$(x_g^t - \overline{x}_g)^2$	ϕ_2	0.026	0.011*	0.090	0.016*	-0.023	0.008*
	R^2_{Adj}	0.282		0.638		0.602	
	LM	39.23*		41.48*		24.63*	
	AR	4		9		8	
Sector level:							
Constant	ϕ_0	-2.167	0.139*	-5.206	0.238*	-4.450	0.285*
x_g^t	ϕ_{11}	0.104	0.035*	0.278	0.073*	0.516	0.034*
	ϕ_{12}	-0.160	0.045*	-0.162	0.088**	-0.062	0.044
	ϕ_{13}	0.006	0.048	-0.056	0.089	-0.094	0.043*
	ϕ_{14}	-0.028	0.058	-0.014	0.105	-0.264	0.056*
	ϕ_{15}	0.010	0.043	-0.036	0.089	-0.075	0.043**
	ϕ_{16}	-0.090	0.060	-0.057	0.089	-0.062	0.048
	ϕ_{17}	-0.066	0.046	-0.022	0.099	-0.088	0.057
	ϕ_{18}	-0.179	0.046*	-0.124	0.092	-0.058	0.042
$(x_g^t - \overline{x}_g)^2$	ϕ_{21}	0.179	0.011	0.032	0.013**	-0.029	0.008*
	ϕ_{22}	0.029	0.013*	0.056	0.025*	0.009	0.018
	ϕ_{23}	0.596	0.016	0.027	0.025	0.010	0.018
	ϕ_{24}	0.045	0.019*	0.019	0.030	0.032	0.018**
	ϕ_{25}	-0.002	0.014	0.020	0.025	0.013	0.018
	ϕ_{26}	0.042	0.019*	0.044	0.025**	0.021	0.020
	ϕ_{27}	0.051	0.014*	0.055	0.027*	0.046	0.022*
	ϕ_{28}	0.039	0.015*	0.038	0.025	0.003	0.017
	R^2_{Adj}	0.424		0.375		0.119	
	LM	248.16*		245.37*		88.78*	
	AR	10		10		10	

Notes: The GDP per capita, x_g, is scaled to 10000 SEK for these estimations. The * and ** indicate significance at the 5 and 10 percent level, respectively. LM is the Lagrange multiplier test against heteroskedasticity. AR denotes the number of lags used in the regression. The dummy variables are not reported. Most of them were not significant.

price. The predicted values show a turning point at approximately 140000 SEK which, together with the parameter estimates, suggests that the quadratic term has a dominating influence on determining the price after the turning point.

Turning to the final shadow price, the aggregate regression shows a positive level term and a negative quadratic term, both significant. The predicted values show a turning point at 80000 SEK after which they increase until they reach another turning point at approximately 160000 SEK, and their values seem to stabilize. In the panel regression, all parameters for the level term have positive signs, and the quadratic term is negative for all sectors except for sectors 4: pulp, paper and printing, and 7: leather and rubber. The parameter estimates and the turning points suggest that the level term has a dominating negative effect on the price for income levels above 80000 SEK, and the positive effect of the quadratic term starts to dominate at income levels around 160000 SEK.

Summing up, all three price series seem to fluctuate just below zero for the lower half of the income scale. In general, they do not deviate much from zero until the income level reaches the upper half of the scale. The turning point for VOC occurs at an income level of approximately 80000 SEK, which is associated with the mid 1960s. The CO_2 and SO_2 reach their turning points at a higher income level of approximately 140000 SEK, which occurs in the early 1980s. The regression results show that the level effect of the income dominates in increasing the VOC price, while the quadratic effect dominates in increasing the CO_2 and SO_2 prices.

6 Discussion

In this paper, we have analyzed the relationship between pollution and economic growth over a long period of time. To do this, we have first estimated the shadow prices for Swedish emissions of carbon dioxide, sulphur dioxide and volatile organic compounds, and in a second step these prices have been related to the per capita income level. An advantage of analyzing shadow prices rather than observing 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. In the results, all three price series seem to fluctuate close to zero throughout the lower half of the income scale. At higher income levels the prices clearly tend to increase. The turning point, after which the shadow prices for both CO_2 and SO_2 increase, occurs at per capita GDP levels of approximately 140000 SEK, and the turning point for the VOC price, appears at approximately 80000 SEK. This means that the turning point for the price of both CO_2 and SO_2 occurs in the early 1980s, and in the beginning of the 1960s for the price of VOC. These patterns are interpreted as indications of EKCs for these emissions and so the findings in this study seem to support the findings of the previous studies of Brännlund and Kriström (1998) and Kriström and Lundgren (2005). Both studies use data at the national level and they find indications of EKCs for Swedish emissions of CO_2 and SO_2 with turning points in the early 1970s, which in our data is equivalent to a per capita GDP of approximately 120000 SEK.

The impact of factors working as incentives for the industries to reduce the emissions are expected to result in increasingly negative shadow prices, indicating that the industries have to account for the cost of polluting. Zero shadow prices indicate that the representative firm does not, in general, associate emissions with costs when maximizing profits, and hence they maximize the output of the good irrespectively of the emissions. Our findings are in line with this argument in that we find the shadow prices to be close to zero for a period in time when there is little debate of the environmental impact of production and consumption. As environmental concerns are growing in importance, efforts are made to reduce emissions (e.g., by imposing regulations and green taxes) and to replace existing technology with more environmentally sustainable technology.

Further, shifts in technology seem to be the main causal factor driving the annual price changes, and the preference driven changes are of lesser importance. This suggests that, as economic activity increases, innovations are more important than consumer preferences for environmental quality for giving rise to new cost structures and incentives for structural transformations. The small effect of consumer preferences suggests that either growing environmental concerns have not found a way to sufficiently influence the production process so as to have an impact on the shadow prices, or that environmental concerns are still not large enough to significantly influence the production possibilities.

Further, some previous studies suggest that while the link between the emission of globally important pollutants such as the greenhouse gas, CO_2, and a single country's wealth may not be so clear-cut, the connection may be stronger for more regional or local pollutants such as SO_2 or VOC. Our shadow price series for CO_2 and SO_2 do not differ much from each other in this respect, 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, for example, such things as smoke from combustion, 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 the 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.

Summing up, previous studies find indications of EKCs for Swedish emissions of CO_2 and SO_2. The results in this study support these findings and also provides an additional possible explanation of the patterns of these Swedish emissions in terms of the price mechanism. The conclusion that we can draw from our results is that an increasing level of economic activity appears at least to some extent to lead to a reduction in these emissions, either through changes in consumer preferences or, more likely, through structural transformations arising from technological development. Our results do not, however, indicate how extensive the reduction, resulting from these effects, is in quantitative terms.

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