Annals of Public and Cooperative Economics 76:2 2005 *pp. 275–300*

SULPHUR EMISSIONS AND PRODUCTIVITY GROWTH IN INDUSTRIALISED COUNTRIES

by

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Received December 2003; final revision accepted October 2004

ABSTRACT:** *In this paper, we examine the relationship between economic and environmental performance. More specifically, we analyse the impact of SO2 reduction in the eighties (1980–1992) on productivity growth, technical efficiency and technological progress for a set of 12 OECD countries. Our timeframe roughly corresponds to the adoption and implementation of the First Sulphur Protocol signed in 1985. First, we estimate an output based Malmquist productivity index using distance functions derived from successive DEA (Data Envelopment Analysis) frontiers. This index is decomposed in two components namely technical and efficiency change. Second, we regress the change in productivity and its two components on a set of explanatory variables including annual variations in SO2 emissions. The results indicate that reductions in SO2 do not seem to have had a significant impact on productivity growth. The decomposition into*

* We benefited from useful suggestions from two anonymous referees. We are also grateful to the participants to the 13th annual meeting of the Canadian resource and environmental economics study group and to the 44ème Congrès annuel de la Société canadienne de science économique for their stimulating comments. Any remaining errors are ours. Financial support from the Communauté Française de Belgique (PAC 98/03–221) is gratefully acknowledged. E-mails: pbar@ecn.ulaval.ca; sergio.perelman@ulg.ac.be

** *Résumé en fin d'article; Zusammenfassung am Ende des Artikels; resumen al fin del artículo.*

efficiency and technology changes suggests that two countervailing effects may explain this result. On one hand, SO2 cutbacks adversely affect efficiency but on the other hand, they stimulate technical change.

1 Introduction

For the last decade, there has been an ongoing debate surrendering the economic impact of efforts for improving environmental quality. The traditional view states that there is a trade off between environmental quality and economic growth. Recently, Porter (1991) and Porter and van der Linde (1995) challenged this view arguing that environmental protection can very often stimulate economic growth by increasing efficiency and encouraging technical progress. This idea is now referred to as the *Porter Hypothesis*.[1] This debate is more than academic particularly in the context of the development of new environmental regulations addressing climate changes.

In this paper, we try to shed some light on this question by analysing the impact of SO2 reduction in the eighties (1980–1992) on productivity growth, technical efficiency and technical progress for a set of 12 OECD countries. Our timeframe roughly corresponds to the adoption and implementation of the *First Sulphur Protocol* signed in 1985. Most of the countries in our sample (except for the USA and the UK) ratified this protocol thereby committing to reduce SO2 emissions by 30 per cent in 1993 relatively to their 1980 emission level.[2] Factual evidence suggests that the implementation of this Protocol was relatively easy: most countries reached the Protocol target well before 1993 and there are indications that early reductions in SO2 were principally driven by cost saving fuel switching (see Levy 1995, Burtraw et al. 1997). The implementation of this Protocol is therefore a good candidate for finding a positive impact on economic performance.

Our empirical strategy follows the two steps approach adopted in several studies (see for example Lovell 1993, Perelman 1995, Mukherjee

1 Jaffe et al. (1995) provides an overview of the arguments used in this debate. For a critic of the Porter Hypothesis see Palmer et al. (1995). For theoretical modelling of the Porter hypothesis see Ambec and Barla (2002) and Mohr (2002).

2 Technically, the protocol concerns all emissions of sulphur oxides SOx. SO2 is however the main source of acid depositions and all the emissions are expressed in tons of SO2 per year. For simplicity, we will refer only to SO2 in the rest of this paper.

et al. 2001) to test the productivity impact of different factors (such as R&D) on technical and efficiency change.[3] In the first step, we estimate an output based Malmquist productivity index using distance functions derived from successive DEA (Data Envelopment Frontier) frontiers. Our underlining 'world' production frontiers include one output (value added) and two primary inputs (labour and capital). The Malmquist index is then decomposed in two components namely technical change – *shift of the production frontier* – and efficiency change – *shift toward the best practice frontier*. The approach in this first step closely follows Färe et al. (hereafter FGNZ,1994).

In the second step, we regress the change in productivity and its two components on a set of potential explanatory variables including annual variations in SO2 emissions. The estimated coefficient on the SO2 variable is positive suggesting that cutbacks in SO2 emissions slow down productivity growth. It is however not statistically significant. This result is therefore in line with several empirical studies showing that environmental regulations usually have a negative but limited impact on economic performance (see Jaffe et al. 1995). Our decomposition of productivity growth suggests however that the absence of a significant impact may be the result of two countervailing effects. We find that cutbacks in SO2 are associated with a statistically significant reduction in efficiency gains but at the same time, they appear to stimulate somewhat technical progress. Overall, our results provide some support to both the traditional and revisionist views concerning the impact of environmental improvements on economic performance.

In Section 2, we expose the methodology for measuring productivity growth and decomposing it into efficiency and technical changes. The data and Protocol are described in Section 3. Section 4 presents the specification and results of the model linking economic and environmental performance. We conclude in Section 5.

2 The methodology

In this paper, we adopt productivity growth as a measure of economic performance that is the ability of the economy to transform

3 This two-stage procedure is in line with traditional studies on productivity convergence across nations (Fagerberg 1994). The main difference with these studies resides upon the way productivity growth is calculated here, using a frontier analysis method.

inputs into valuable outputs. More specifically, we use the Malmquist Total Factor Productivity change index (*MTFP*) introduced by Caves et al. (1982) and adapted in FGNZ (1994) to the frontier analysis context. The index proposed in FGNZ (1994) has two main advantages: i) it can be calculated exclusively on physical quantities (without prices) and ii) it can be decomposed into the main sources of growth, efficiency and technical change.[4] Following these authors, we construct the best practice frontiers using a non parametric approach, DEA (Data Envelopment Analysis). Furthermore, these economic performance indicators are then regressed on several potential explanatory variables including SO2 emission variations.

Another avenue would be to consider pollution as either a 'bad output' (Färe et al. 1989, Färe et al. 1993, Chung et al. 1997, Hernández-Sancho et al. 2000, Reig-Martinez et al. 2001, Zofio and Prieto, 2001, Aiken and Pasurka, 2003) or as another input (Paul et al. 2002, Ball et al. 2004) in the production process and therefore compare the productivity growth scores obtained with and without controlling for emission. This comparison allows evaluating the output loss associated with regulating pollution.[5] It also allows, under some conditions, to derive shadow prices for pollution. While this methodology is theoretically appealing, we adopt in this paper the more traditional two stages approach for several reasons. First, as most countries in our sample have signed the SO2 Protocol, emissions are not entirely a control variable for these countries. Beside, economies are composed of decision-making units (especially private firms) that do not control emissions but rather are forced to meet the imposed environmental regulations.[6] Second, including emission directly in the specification of the production process is probably better suited for micro-level analysis of decision-making units operating with relatively similar production process. In a macroeconomic setting, the two steps approach provides more flexibility in introducing and testing the impact of the different factors explaining differences across countries. In other words, the results on the relationship between environmental and economic performance are less likely to

4 The possibility to decompose productivity change into efficiency and technical change was illustrated for the first time by Nishimizu and Page (1982) in a parametric frontier context.

5 The comparison may also involve computing productivity with pollution as a bad output imposing weak or strong disposability of the undesirable output.

6 It is only latter that flexible market based mechanisms have been adopted.

be driven by missing variables.[7] Finally, in our approach, we only use the variable *change* in SO2 emissions, which is less likely to be affected by methodological differences in measurement across countries than the variable *level* of SO2 emissions. Obviously, the two steps approach also suffers from limitations. Most notably, our first step productivity measure ignores the undesirable output and therefore likely bias downward the productivity growth of countries that have reduced significantly their emissions. However, it is precisely the objective of the second step to examine the importance of this bias.[8] Overall, we believe that the two approaches should be viewed as complementary.

MTFP is defined using distance functions, which allows for a very general representation of multi-outputs, multi-inputs technology without imposing full efficiency of every decision-making units (i.e. countries in our setting).[9] An output distance function characterizes the technology by considering maximal proportional expansion of outputs given a fixed quantity of inputs. We adopt the output distance for several reasons. First, this choice makes it possible to compare directly our results with those of FGNZ. Second, we believe that in a macroeconomic setting, this measure is more appealing from a public policy perspective. Indeed, it would be difficult to argue that an inefficient country can reduce its labour usage. Third, under CRS, productivity indexes computed using various directions (input, output

7 To understand the danger of applying the one step approach to a macroeconomic setting, suppose that we have data for only countries 1 and 2. Country 1 uses the same quantity of input than country 2 but produce much more desirable output and just marginally more undesirable output. The traditional frontier (ignoring the bad) will be defined by country 1 and country 2 will be judged inefficient. Introducing emissions in the modelisation of the production process will lead to the conclusion that both countries are efficient (on the frontier) and all the output difference between the two countries will be attributed to the small difference in emissions. While this may be the case (if marginal abatement cost are huge), several other factors may explain the output difference such as, for instance, a difference in efficiency or R&D investments, exposition to international competition, etc.

8 Simar and Wilson (2003) have recently shown that the two steps approach also poses serious econometric issues due to the fact that, in the second step, the residuals are not independent, identically distributed. They propose a bootstrap procedure to alleviate somewhat this difficult. We are unaware of applications that have used this procedure so far. Given the scope of our paper, we can only recognize this difficult when interpreting the results. Moreover, as we will discuss later other econometric issues plagued the analysis (such as endogeneity), which we try to address in this paper.

9 See for example Coelli et al. (1998).

or proportional distance where both input and output are adjusted) can all be related (see Zofio and Lovell 2001, Boussemart et al. 2003). Boussemart et al. (2003) show that the productivity changes from the output oriented Malmquist are approximately twice those obtained using the Luenberger index based on the proportional distance function. Using the Luenberger index would therefore only affect the constant in our second stage regression.

Formally, we begin by defining the output set for time period t, $P^t(x^t)$ as

$$P^t(x^t) = \{y^t : x^t \text{ can produce } y^t\}$$

with y^t, x^t the vector of outputs and inputs respectively. The output distance function is defined as:

$$D_0^t(x^t, y^t) = \inf\{\theta : (y^t/\theta) \in P^t(x^t)\}.$$

This function takes values less than or equal to one for all $y^t \in P^t(x^t)$, with equality implying technical efficiency.[10] Figure 1 illustrates the case of a constant return to scale technology with one input and one output. The distance function evaluated at (x^t, y^t) corresponds to the ratio y^t/y_E^t. Change in total productivity between two data points may then be defined as ratio of the distance of these points to the best practice. However, when comparing data points from different time periods such as (x^t, y^t) and (x^{t+1}, y^{t+1}), period t or $t+1$ technology could be used as reference. To avoid choosing, FGNZ (1994) propose to define the Malmquist index of productivity change as a geometric mean of two productivity index defined respectively with respect to technology t and $t+1$. That is:

$$M_o(x^t, y^t, x^{t+1}, y^{t+1}) = \left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)}\right)\left(\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^t, y^t)}\right)\right]^{1/2}$$

or equivalently as FGNZ (1994) shows

$$M_o(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \times \left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right)\right]^{1/2} \quad (1)$$

10 The output distance function corresponds to the inverse of Farell (1957) output technical efficiency measure.

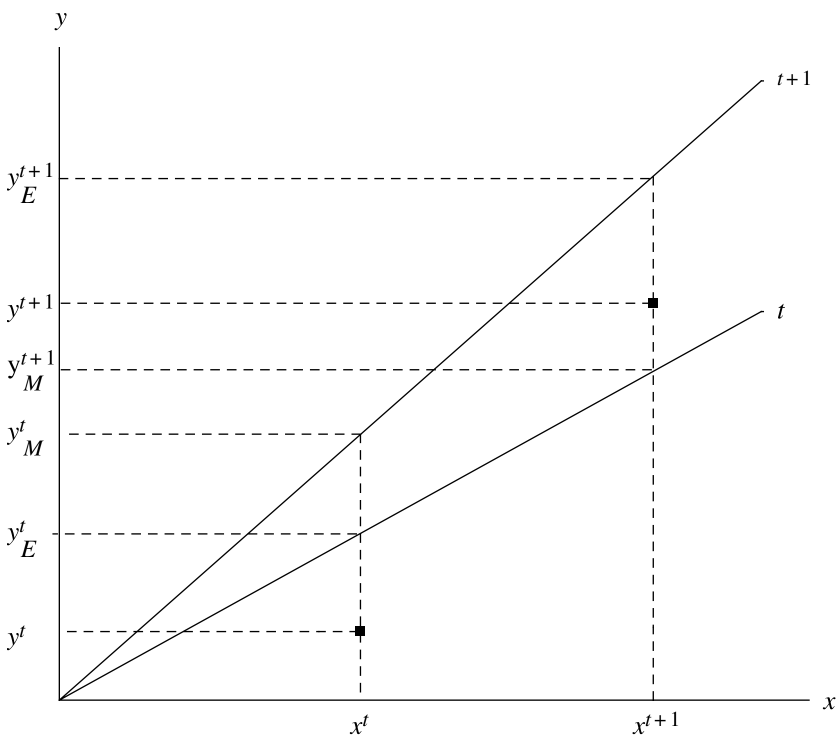

Figure 1 – Productivity, efficiency and technical change

The first term in (1) represents the change in relative efficiency *i.e.* the shift toward the best practice and the second term technical change *i.e.* shift of the frontier. For practical convenience, this relation will be expressed as following:

$$MTFP = TEC \times TC$$

Figure 1 helps illustrate this decomposition. The technical efficiency change is given by

$$TEC = \frac{y^{t+1}/y_E^{t+1}}{y^t/y_E^t} \tag{2}$$

and technical change by

$$TC = \left[\frac{y^{t+1}/y_M^{t+1}}{y^{t+1}/y_E^{t+1}} \times \frac{y^t/y_E^t}{y^t/y_M^t}\right]^{1/2} = \left[\frac{y_E^{t+1}}{y_M^{t+1}} \times \frac{y_M^t}{y_E^t}\right]^{1/2}. \tag{3}$$

Technical change is therefore represented as the geometric mean of the shift in the best practice frontier evaluated at t and $t+1$. To express productivity, efficiency and technical change in terms of growth rates, it suffices to subtract one from (1), (2) and (3) respectively. Note that to properly capture productivity change, *MTFP* requires a constant returns to scale technology, which we will assume throughout this paper.[11]

The computation of *MTFP* requires that the best practice frontiers be determined from the observed data set. Deterministic and stochastic, parametric and non-parametric, methods have been proposed in the literature (see Coelli et al. 1998 for an overview). In this paper, we adopt DEA, a deterministic non-parametric linear programming approach. Details of the different linear programs involved can be found in FGNZ (1994). The basic idea is to construct each best practice (one for each year in our case) as a piece-wise linear frontier that best envelops the data and respects some specific regularity conditions.

3 Data and background

The economic performance measures are constructed using Heston, Summers and Aten, Penn World Tables Version 5.6 (PWT 5.6) from the Center for International Comparisons at the University of Pennsylvania (CICUP).[12] The output measure is *GDP* (gross domestic product) in constant dollars express in international prices (base 1985). For inputs, labour is defined as total employment and capital corresponds to gross capital stock excluding residential structures.[13]

The SO2 emissions are those reported by the Economic Commission for Europe (1999) under the 1979 Long-range Transboundary Air Pollution Convention. The OECD environmental data Compendium provides additional information on emission sources. Finally, most of the variables used to explain economic performance beside SO2 emission

11 The CRS hypothesis is common in the literature particularly with macro-level data. Also, FGNZ (1994) analysis suggests that decomposing TEC into a pure efficiency and scale factor does not change the results very much (the scale factor is always very close to one). Furthermore, we also show that our main results are robust to introducing a scale control variable in our second step analysis.

12 This is a revised and updated version of the Mark 5 version, which was the source of data for FGNZ (1994).

13 Labour is recovered from the variable RGDPW while capital is computed using the variable KAPW in PWT 5.6.

changes were obtained either from the World Bank World Development Indicators (WDI) online database or the OECD.

The time frame of our analysis as well as the set of countries studied was primarily dictated by the availability of data.[14] Our study covers the period 1980–1992 and includes the following countries: Belgium, Canada, Denmark, Finland, France, Italy, Netherlands, Norway, Sweden, the United States, the United Kingdom and West Germany.

The time frame approximately covers the implementation of the 1985 Sulphur Protocol, which was the first Protocol signed under the 1979 Convention. This Protocol requires a 30 per cent reduction in SO2 emission by 1993 relatively the 1980 emission level. The UK and USA did not sign the Protocol even though they ratified the 1979 Convention. Note however that the UK reduced its emissions by almost 30 per cent. For the US, SO2 emission reductions have been spread over a longer timeframe: the 1990 Clean Air Act Amendments aimed at cutting emissions by about 50 per cent by 2010 compared to the 1980 level. These amendments also created the emission allowance trading system that has been credited for substantially reducing compliance cost.

As Table 1 shows, all the countries that signed the Protocol widely exceeded the required reduction, with the only exception of Canada that reduced its emissions by 32 per cent. For the whole sample, the annual average rate of SO2 reduction is not very different before and after 1985 (respectively -7.92 per cent and -6.67 per cent). However at the individual country level, we note some differences, for example France and Italy reduce their emissions mostly before 1985 while it is the opposite for Norway or West Germany. For most countries, mobile sources (essentially transportation) are only marginal contributors. For stationary sources, some countries clearly have a dominant source (powers stations for Denmark, Italy, UK, USA and West Germany and industrial processes for Canada) while other do not.

SO2 is one of the key pollutants (with NOx) responsible for acid depositions that adversely affect ecosystems such as lakes and forests. SO2 has also been linked with significant increase in asthma and bronchitis as well as other health problems.[15] The main sources of

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14 For example, SO2 emission data are not available for Japan and Australia since these two countries are not part of the Long-range Transboundary Air Pollution Convention

15 Interestingly, while health effects were considered only marginal at the time of the first protocol, they have turned out to be the main source of benefits associated with reducing emissions. See Burtraw et al. (1997) for a cost-benefit analysis of reducing acid rain.

Table 1 – SO2 emission characteristics

Country	Average SO2 ton per capita (80–92)	Per cent reduction emission (80–92)	Main emission sources (% total, 1985) Power station	Industrial combustion	Industrial process	Mobile sources
Belgium	0.047	–62	30	34	19	5
Canada	0.146	–32	20	9	65	4
Denmark	0.055	–57	59	15	n/a	7
Finland	0.071	–75	25	44	24	3
France	0.032	–62	28	14	13	7
Italy	0.039	–63	61	19	5	5
Netherlands	0.020	–65	24	38	21	10
Norway	0.020	–74	1	21	44	26
Sweden	0.030	–82	24	20	26	14
United Kingdom	0.067	–29	69	15	3	3
United States	0.087	–14	70	14	10	3
West Germany	0.031	–75	64	20	4	3

Note: 1987 and 1990 emission sources data for Norway and Belgium, respectively.

SO2 are fossil fuel burning (mostly coal) as well as smelting sulphur-containing ore (e.g. copper). Reduction in SO2 emissions has mainly been achieved by either switching fuel sources (for example using low sulphur coal in power plants) or by investing in scrubbers.[16] The latter allows significant reductions in emission (around 90 per cent) but it is costly both in terms of initial investments and operating expenses (scrubbers consume energy and produce wastes that need to be disposed).

While there are numerous researches on the impact of growth on SO2 concentration (i.e. estimation of the Kuznets curve, see for example Zaim and Taskin, 2000a, Harbaugh et al. 2002, Millimet et al. 2003), we did not find any study examining the consequences of SO2 regulations on productivity growth at the macroeconomic level.[17] However, several studies have examined the impact of SO2

16 Scrubbers use various chemical processes to extract sulphur from gas that are released into the atmosphere.

17 Zaim and Taskin (2000a, 2000b) and Zofio and Prieto (2003) examine the productivity impact of including CO2 emissions for a sample of OECD countries. Their results suggest that good output loss associated with reducing CO2 can be significant (around 5–7 per cent of total production). Using data for US state manufacturing, Weber and Domazlicky (2001) and Fare et al. (2001) show that productivity growth is significantly higher when reductions in emissions are considered in measuring productivity.

regulations (especially the 1990 Clean Air Act Amendments) on the US electric utilities. For example, Coggins and Swinton (1996) and Swinton (1998) estimate the shadow price of SO2 abatement for samples of coal burning power plants. Their estimates suggest a great variability in marginal abatement cost among plants ranging from a low 2.42$ to a high 4669$ per ton of SO2. Their results also suggest that marginal abatement costs are convex with significantly higher marginal abatement cost for plants that have installed scrubbers and thus have reduced emissions significantly.[18] Yaisawarng and Klein (1994) compute a cumulative Malmquist input-based productivity index for 61 US coal-burning power plants over the period 1985 to 1989. They include SO2 emissions as an undesirable output and the sulphur content of coal as an undesirable input. They find productivity decline over the period 1985–1987 followed by raising productivity in 1988 and 1989. Interestingly, they also find significantly lower efficiency level for plants with scrubbers when the efficiency measure is computed ignoring SO2 emissions as a bad output.

Aiken and Pasurka (2003) estimate the shadow price of SO2 and NOx abatement for 22 two digit SIC US manufacturing industries for the period 1970–1996. They also use these estimates to adjust a traditional productivity measure of total factor productivity growth to take into account reduction in emissions. Their estimates for the shadow price of SO2 range from 1,300$ to 300,300$ per ton. They also find that productivity growth is higher when adjustments are made to take into account reduction in pollution. For some industries, they find declining shadow prices over time despite more stringent regulation suggesting that induced technological change may play a role.

It is off course difficult to predict the macroeconomic consequences of SO2 reductions based on these micro-level analyses mostly focusing on the US experience. It is clear that SO2 regulation have had significant impacts on some plants and probably on some industries such as the coal burning electric utilities. It is unclear however if these impacts have been sufficiently large to have had ripple effects over the whole economy. For example, the total cost of the US 1990 Clean Air Act Amendments has been evaluated at about US$3–5 billions. It is unlikely that these costs spread over a 20-year period are sufficient to have significant macroeconomic effects. Recall

18 These estimates are based on data preceding the creation of the SO2 allowances trading system. Note that the price for the SO2 allowance is now around 300$ and is expected to increase sharply as US regulation become more stringent (see ICF, 2004).

however, that some countries have cut their emissions must more than the USA and that they have proceeded at the much faster rate without resorting to a flexible market based mechanism. Thus, these countries may have beard a much larger burden particularly given the convexity of the marginal abatement costs.

4 The empirical specification and results

4.1 Measures of economic performance

As already mentioned, we use the Malmquist TFP index (*MTFP*) and its decomposition into technical efficiency change (*TEC*) and technical change (*TC*) as measures of economic performance. We assume an underlining constant returns technology with two inputs (labour, capital) and one aggregate output (gross domestic product).[19] Table 2 provides the average changes of *MTFP* and its two components over our sample timeframe as well as the average level of efficiency (*TE*) as given by the distance to the best practice $D_0^t(x^t, y^t)$.

For our sample, average total productivity growth has been rather low at +0.85 per cent, most of it being driven by technical change (+0.92 per cent) rather than by technical efficiency change (−0.07).[20] Only very slight differences appear in these results when we compare the periods before and after 1985, as it can be observed at the bottom of Table 2. Figure 2 presents a box plot of total productivity change per year. Productivity growth appears to be pro-cycle while variability across countries in productivity growth is probably somewhat smaller during good economic conditions.

Globally, our results are in line with those of FGNZ (1994) with three noticeable exceptions. Contrary to our results, FGNZ (1994) finds a positive and significant productivity growth for Italy and a low productivity growth rate for Sweden. These disparities could be explained by: i) differences in sample structures – the periods are slightly different, 1980–1992 against 1979–1988 and the number of

19 Energy and other intermediate factors are not included as inputs since our output measure is based on value added and not on gross output (see OECD 2001).

20 Technical efficiency change can be decomposed in order to identify the effect of returns to scale changes. The results, not reported here, show that this effect is negligible for the whole sample (an annual average of 0.09 per cent over the period), with the exception of one country, Denmark, for which it corresponds to the total change in technical efficiency (0.53 per cent).

Table 2 – Average productivity changes and technical efficiency levels (Unweighted geometrical averages)

Country	Productivity change (annual %)			
	Malmquist index (*MTFP* − 1.0)	Technical efficiency change (*TEC* − 1.0)	Technical change (*TC* − 1.0)	Average technical efficiency *TE* (%)
Belgium	1.39	–0.07	1.44	84.4
Canada	1.60	0.15	1.44	92.8
Denmark	0.74	0.53	0.19	70.2
Finland	1.74	0.31	1.44	71.5
France	1.18	–0.23	1.42	82.6
Italy	–0.41	–0.28	–0.12	87.4
Netherlands	–0.23	–0.48	0.26	87.7
Norway	1.49	0.05	1.44	81.9
Sweden	1.21	–0.21	1.44	78.3
United Kingdom	0.08	0.00	0.08	100.0
United States	0.62	0.00	0.62	100.0
West Germany	0.83	–0.62	1.44	81.9
Average	0.85	–0.07	0.92	85.0
1980–1985	0.64	–0.38	1.03	85.0
1986–1991	1.00	0.15	0.84	85.0

Note: For presentation purposes the Malmquist index and its components are expressed as deviations from the unity and in percentages.

countries covered is lower, 12 against 17- and ii) revisions in the Penn World Tables.[21]

Interestingly, the two countries that did not sign the Sulphur Protocol (the USA and UK) always define the best practice in our sample (i.e. 100 per cent technical efficiency). In fact, the USA is first in terms of partial productivity of labour while the UK has the best productivity of capital. Simple correlation suggest that reductions in SO2 emissions are associated with lower economic performances both in terms of *MTFP* and *TEC*.[22] Obviously, a more careful analysis is required to confirm this relationship.

4.2 Economic performance and SO2 reductions

Testing the Porter Hypothesis would ideally require assessing the impact of regulatory pressures on economic performance.

21 FGNZ (1994) uses an earlier version of the data (Mark 5).

22 Figures not reported here.

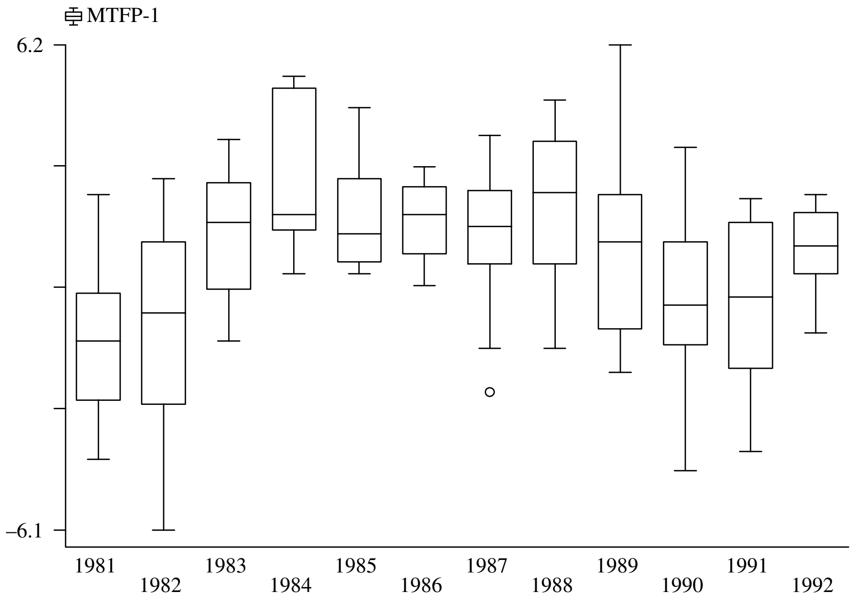

Figure 2 – Box plot of (MTFP –1) by years

Measuring regulation intensity is however difficult given data limitations particularly in an international setting. For example, several studies based on national data (see Gray 1987, Barbera and McConnel 1990, Dufour et al. 1998) have used total investment in pollution-control equipment to proxy environmental regulation. This variable is however unavailable for most of the countries in our sample. We circumvent this problem by using environmental performance as an indicator of regulation severity. The validity of this approach rests upon the maintained hypothesis that environmental regulations do improve environmental performance (for evidence on this see Dasgupta et al. 1997, Laplante and Rilstone 1996).

Since economic performance is measured at the aggregate level, environmental performance should also be measured at that level. Constructing an aggregate indicator of a country environmental performance is however well beyond the scope of this paper particularly given the severe data limitations at the international level.[23] In this paper, we focus on SO2 emissions for three reasons. First, acid rain

23 For steps in this direction, see World Economic Forum (2000).

was one of the major environmental issues in the eighties.[24] Second, there is factual evidence suggesting that initial SO2 reduction may have been privately cost reducing thereby making it a good candidate for Porter type of effects. Third, one of the requirements of the first Sulphur Protocol was the reporting of emissions[25]

The second step in our analysis consists therefore in estimating the following equations:

$$\begin{aligned} EPM_{it} = \alpha_0 + \alpha_t + \alpha_1 \Delta SO2_{it} + \alpha_2 \Delta GDP_{it} + \alpha_2 TE_{it-1} \\ + \alpha_3 (RD/GDP)_{it} + \alpha_4 \Delta (I/K)_{it} + \alpha_5 (XM/GDP)_{it} + \varepsilon_{it} \end{aligned} \quad (4)$$

Where EPM_{it} represents one of our three economic performance measures namely $MTFP_{it}$, TEC_{it} and TC_{it} with i a subscript for the country and t for the time period.[26] $\Delta SO2_{it}$ is introduced to test the impact of the annual rate of variation in SO2 emission ($\Delta SO2_{it} = (SO2_{it} - SO2_{it-1})/SO2_{it-1}$). Beside environmental performance, exogenous demand changes affect productivity growth since capital (and to some extend labour) cannot be adjusted quickly. We control for worldwide macroeconomic effects by introducing a time-specific effect (α_t). Country specific demand variations are controlled for by the current *GDP* growth rate (ΔGDP_{it}).

The lagged *level* of technical efficiency (TE_{it-1}) is included to capture the dynamics of the *catching-up process*, also called the *reversal hypothesis*.[27] The idea behind this hypothesis is that technological imitation and diffusion constitute a significant source of productivity growth. Countries with low levels of efficiency in the previous period would thus be more likely to benefit from other countries experience. This variable is therefore expected to have a negative impact on productivity (and efficiency) growth.

Another potentially significant source of productivity is the importance of country research and development activities. Unfortunately, time series statistics on total *R&D* expenditures are unavailable for several countries in our sample. We therefore use as a

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24 No major effort of reducing CO2 emissions was carried out during the timeframe of our data.

25 Note that our SO2 variable could also viewed, to some extent, as a proxy for a country general effort to improve environmental quality.

26 In fact, we use the measures expressed in terms of percentage change (i.e. *MTFP*-1, $TEC-1$ and $TC-1$).

27 See Abramovitz (1982), Soete and Verspagen (1989) and Fagerberg (1994) for a detailed discussion of the catching-up issue, and Gouyette and Perelman (1997) for an application to the service industry in an international setting.

proxy the OECD statistics on *R&D* expenditures in the business enterprise sector as a percentage of *GDP* $(RD/GDP)_{it}$.[28] While *R&D* is expected *in fine* to improve productivity, current *R&D* investments could very well have initially a depressing effect on productivity.

Investments could also improve productivity as new technology is embodied in new vintage capital. We control for this effect by introducing the rate of capital formation represented by the change in the ratio of current investment to capital $[\Delta(I/K)]_{it}$. Note however that if investments are realized in response to new regulations (such as environmental or safety regulations), this variable could capture some of the effect we are trying to isolate with $\Delta SO2_{it}$. Finally, we proxy for the effect of international competitive pressure by introducing the sum exports and imports as a percentage of total *GDP* $(XM/GDP)_{it}$ and add an error term ϵ_{it} with the usual properties. Tables 3 and 4 presents descriptive statistics for the variables in our sample and the regression results, respectively.

The results are rather mixed concerning the impact of SO2 reductions on economic performance. On one hand, reductions in emissions appear to slow down growth in technical efficiency thereby supporting the traditional hypothesis. This impact is not negligible since a 5 per cent reduction in emission (half the standard deviation) reduces *TEC* by 0.125 per cent point. On the other hand, reductions in emissions stimulate technological progress as argued by Porter. Clearly this effect is not statistically significant at the usual levels

Table 3 – Descriptive statistics (values in per cent, except for $\Delta(I/K)_{it}$)

Variable	Mean	Standard deviation	Minimum	Maximum
$MTFP_{it} - 1$	0.85	2.26	–6.09	6.20
$TEC_{it} - 1$	–0.07	2.29	–4.69	8.00
$TC_{it} - 1$	0.92	2.54	–5.29	5.40
$\Delta SO2_{it}$	–7.18	9.96	–37.35	33.51
ΔGDP_{it}	2.05	2.45	–9.15	7.30
TE_{it-1}	85.0	9.0	65.0	1.00
$(RD/GDP)_{it}$	1.61	0.63	0.76	3.32
$\Delta(I/K)_{it}$	–0.0006	0.0028	–0.0110	0.0050
$(XM/GDP)_{it}$	60.1	26.4	17.3	144.3

28 These figures include R&D carried out by business enterprises but financed by the public sector. It excludes however government and higher education R&D activities (see OECD 2000).

Table 4 – The regression results

Explanatory variables	Explained variables					
	MTFP−1		*TEC*−1		*TC*−1	
	Parameter	(Std. error)	Parameter	(Std. error)	Parameter	(Std. error)
Constant	5.19	(1.22)***	2.39	(1.25)**	3.00	(1.11)***
$\Delta SO2_{it}$	0.010	(0.011)	0.025	(0.012)**	–0.0140	(0.0106)
ΔGDP_{it}	0.755	(0.084)***	0.572	(0.086)***	0.1867	(0.0766)**
TE_{it-1}	–0.057	(0.011)***	–0.040	(0.012)***	–0.0189	(0.0104)*
$(RD/GDP)_{it}$	0.316	(0.172)*	–0.004	(0.177)	0.3300	(0.1576)**
$\Delta(I/K)_{it}$	–28.0	(68.0)	63.0	(70.0)	–90.5	(62.3)
$(XM/GDP)_{it}$	–0.003	(0.004)	–0.003	(0.004)	0.0004	(0.004)
Time effects						
1981	–2.146	(0.493)***	–0.657	(0.507)	–1.464	(0.452)***
1982	–2.018	(0.494)***	4.857	(0.508)***	–6.754	(0.452)***
1983	–0.868	(0.506)*	–1.017	(0.521)**	0.123	(0.464)
1984	–0.779	(0.526)	–2.969	(0.542)***	2.250	(0.482)***
1985	–1.302	(0.512)**	–0.056	(0.527)	–1.315	(0.469)***
1986	–1.3092	(0.5132)**	0.585	(0.528)	–1.933	(0.470)***
1987	–1.3175	(0.4959)***	–0.472	(0.511)	–0.925	(0.454)**
1988	–1.3103	(0.5125)**	–1.477	(0.528)***	0.114	(0.470)
1989	–1.8451	(0.5071)***	–0.578	(0.522)	–1.338	(0.465)***
1990	–2.3471	(0.4991)***	1.529	(0.514)***	–3.927	(0.457)***
1991	–0.8320	(0.5013)	2.689	(0.516)***	–3.552	(0.459)***
1992	Base		Base		Base	
R^2	0.76		0.75		0.84	
Observations	136		136		136	

***: significant at 1 per cent; **: significant at 5 per cent; *: significant at 10 per cent

but this may be due to the limited variability in *TC* caused by the way this variable is computed. Indeed, *TC* is only driven by the two countries defining the best practice. Overall, the impact of environmental quality improvement on productivity appears to be negative but it is not statistically significant which is relatively in line with the literature (see Jaffe et al. 1995).

As expected, overall demand conditions greatly affect productivity growth. Indeed, *MTFP* increases by 0.75 per cent point for each additional 1 per cent in *GDP* growth. Both *TEC* and *TC* are positively affected but the impact on efficiency improvement dominates. The results on the effect of TE_{it-1} support the catching-up hypothesis. Countries that are further from the best practice experience, next period, faster technical efficiency improvement. Technical progress also appears to be encouraged. Expenditures on *R&D* significantly stimulate productivity growth by speeding up technical change.

Productivity growth increases by an extra 0.19 per cent point when $(RD/GDP)_{it}$ increases by 0.63 per cent point (i.e. a one standard deviation increase). Finally, $\Delta(I/K)_{it}$ and $(XM/GDP)_{it}$ do not appear to have any significant impact.

These results are relatively robust to specification changes. First, we tested whether there may be any scale effects by introducing either the level of *GDP* or the country population. Neither variable was statistically significant and the coefficients for the other variables were very close to those in Table 4.[29] Second, we introduced country-specific effects to control for all the unobservable country characteristics. The nature of the results was unaffected except for $(RD/GDP)_{it}$ that became insignificant. This is likely due to the lack of temporal variability in this variable.[30] Also the effect of TE_{it-1} appears stronger. Third, we re-estimated the model excluding the two frontier-defining countries namely the USA and UK (for these two countries *TEC* is always zero). Fourth, we estimated the model using average values of the variables over a three years period. The conclusion on the impact of SO2 remained similar. We also added as an explanatory variable the rate of change in total energy consumption. The coefficient on this additional variable was not significant and its introduction did not change our conclusion. The results were also robust to changes in the functional form of equation (4).

Finally, several of the explanatory variables may be endogenous leading to bias in the OLS estimates. In Table 5, we present the results when instrumenting the variables $\Delta SO2_{it}$, ΔGDP_{it}, TEC_{it-1} and $\Delta(I/K)_{it}$ using a 2SLS procedure.[31] To allow comparison, the OLS estimates for the same sample are also reported.[32] Also given the likelihood of heteroscedasticity (see Figure 2), we use the Hubber-White

29 All the results in this paragraph are available to the authors upon request.

30 The introduction of the country fixed effects eliminates between country variability.

31 We use as instruments: a dummy variable when a country has signed the Protocol, a dummy for actual ratification of the Protocol, the one period lag of the pre-determined variables and their squared values, the ratio of the SO2 emission at $t-1$ over the protocol target for that country (this variable is set to zero for the USA and UK), the annual variation in international oil prices time the country consumption of energy per capita, the real short term interest rate, the squared of the last three variables and the one period lagged value of these variables (including their squared value).

32 The sample varies with respect to Table 5 since the use of lagged values eliminates some time periods.

Table 5 – OLS and 2SLS results

Explanatory variables	*MTFP*–1		*TEC*–1		*TC*–1	
	OLS	2SLS	OLS	2SLS	OLS	2SLS
$\Delta SO2_{it}$	0.009 (0.011)	–0.012 (0.035)	0.026** (0.012)	0.076** (0.030)	–0.016* (0.008)	–0.090*** (0.032)
ΔGDP_{it}	0.766*** (0.100)	0.757*** (0.247)	0.565*** (0.104)	0.363* (0.195)	0.205*** (0.068)	0.409*** (0.218)
TE_{it-1}	–0.057** (0.012)	–0.039** (0.020)	–0.047* (0.013)	–0.044** (0.017)	–0.011 (0.012)	–0.005 (0.021)
$(RD/GDP)_{it}$	0.350* (0.166)	0.374* (0.214)	–0.080 (0.165)	–0.039 (0.205)	0.438*** (0.123)	0.420** (0.197)
$\Delta(I/K)_{it}$	–64.6 (59.0)	–206.9 (212.0)	65.4 (74.7)	123.0 (167.0)	–128.4*** (61.2)	–333.0** (163.3)
$(XM/GDP)_{it}$	–0.004 (0.005)	–0.001 (0.006)	–0.002 (0.004)	–0.002 (0.005)	–0.001 (0.003)	–0.002 (0.005)

Note: In parenthesis, the Hubber–White robust standard error.
***: significant at 1 per cent; **: significant at 5 per cent; *: significant at 10 per cent

robust standard errors. Globally, the nature of the results is unaffected. Note however that the effect of $\Delta SO2_{it}$ on both *TEC* and *TC* become stronger and the stimulating effect of $\Delta SO2_{it}$ on technological change become statistically significant when 2SLS is used.

5 Conclusions

Concerns over the economic consequences of improving the environment are bound to remain a source of heated debates. Reducing greenhouse gas emissions, controlling agricultural run-offs or smog causing car emissions, all require some form of public policy intervention that may impose costs on some agents. Economists have traditionally argued that there is no 'free lunch' and that social benefits of an improved environment most often imply real private costs. A large body of empirical studies indicates that environmental regulations impose costs but, except for some high polluting industries (pulp and paper, chemical etc.), these are relatively limited. By opposition, the Porter hypothesis argues that severe but well design regulations may be a source of economic growth and improved competitiveness. Several cases studies have provided some support to this view (see Lanoie and Tanguay 1999).

In this paper, we show that at the macroeconomic level reduction in SO2 emissions appears to have had a negative impact on productivity growth. The effect does not appear however statistically significant. The decomposition of productivity growth on efficiency and technology changes suggests that two countervailing effects may explain this result. On one hand, SO2 cutbacks adversely affect efficiency but on the other hand, there are also (weak) evidences that they stimulate technical progress.

Several extensions of our analysis would be useful in order to test further its main conclusion. First, it would be useful to check for similar patterns on more disaggregate data (ideally micro level data). Our macroeconomic perspective implies for example that some benefits of SO2 reductions (e.g. increased agricultural productivity) are included thereby underestimating the real costs to some sectors. Second, reductions in SO2 may initially negatively affect efficiency but over time with learning, they may actually favour efficiency growth (see Lanoie et al. 2001). Due to the limited number of periods in our panel, it is however difficult to test properly for such dynamic effects. Third, it would interesting to measure productivity and its two components when SO2 emissions are directly included as an undesirable output.

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Emissions de sulfure et croissance de la productivité dans les pays industrialisés

Dans cet article, nous examinons la relation entre les performances économique et environnementale. Plus précisément, on analyse l'impact qu'ont eu les réductions d'émissions de SO2 au cours de la période 1980–1992 sur la croissance économique, le progrès technologique et l'efficacité technique de 12 pays membres de l'OCDE. La période analysée correspond approximativement à celle au cours de laquelle a été adopté et appliqué le Premier protocole sur le sulfure signé en 1985. Nous estimons d'abord un indice de productivité de Malmquist par la méthode des frontières DEA (Data Envelopment Analysis). Cet indice est décomposé en ses deux composantes : progrès technologique et changement d'efficacité technique. En deuxième lieu, nous testons économétriquement l'impact sur la productivité et ses composantes d'une série de variables, parmi lesquelles les taux de variations annuelles des émissions de SO2. Les résultats indiquent que les réductions d'émissions ne semblent pas avoir eu un effet significatif sur la croissance de la productivité. Mais deux effets de signe contraire peuvent expliquer ce résultat. La réduction des émissions de SO2 aurait stimulé le progrès technologique mais affecté négativement l'efficacité technique.

Schwefelemissionen und Produktivitätsgewinne in industrialisierten Ländern

In diesem Beitrag untersuchen wir die Beziehung zwischen ökonomischer und Umweltperformance. Mehr spezifisch analysieren wir die Auswirkung der SO_2*-Verminderung in den 80er Jahren (1980–1992) auf Produktivitätssteigerung, technische Effizienz und technologischen Fortschritt in 12 OECD-Ländern. Unser Zeitrahmen korrespondiert etwa mit der Annahme und Implementierung des Ersten Schwefelprotokolls, das 1985 unterzeichnet worden war. Als erstes bilden wir einen auf Output-Basis gebildeten Malmquist-Produktivitätsindex* *und verwenden hierbei aus sukzessiven DEA (Data Envelopment Analysis) Grenzen bezogene Distanzfunktionen. Dieser Index wird in zwei Komponenten aufgespalten, nämlich technische- und Effizienzveränderungen. Zweitens nehmen wir eine Regression der Produktivitätsveränderung und ihrer zwei Komponenten auf ein Set expandierender Variabler vor, einschließlich jährlicher Veränderungen der SO_2-Emissionen. Die Ergebnisse zeigen, dass SO_2-Reduktionen keine signifikante Auswirkung auf das Produktivitätswachstum zu haben scheinen. Die Aufspaltung in Effizienz- und Technologieveränderungen führt zu der Annahme, dass dieses Ergebnis mit zwei einander aufwiegenden Effekten erklärt werden kann: Einerseits wirken sich SO_2-Verringerungen negativ auf die Effizienz aus, aber andererseits stimulieren sie den technischen Wandel.*

Emisiones de sulfuro y crecimiento de la productividad en países industrializados

En este artículo se examina la relación entre resultados económicos y medioambientales. Más precisamente el impacto que tuvieron las reducciones de emisiones de SO_2 en el curso del período 1980-1992 sobre el crecimiento económico, el progreso tecnológico y la eficiencia técnica de 12 países miembros de la OCDE. Durante este período fue adoptado y aplicado el First Sulphur Protocol *firmado en 1985. Primeramente se estiman índices Malmquist de productividad utilizando la metodología de fronteras DEA (Data Envelopment Analysis) sucesivas. Este índice es descompuesto en sus dos componentes, el progreso tecnológico y el cambio de eficiencia técnica. En segundo lugar se estima el impacto sobre estos componentes de la productividad de una serie de variables, entre las cuales las emisiones de SO_2. Los resultados indican que las reducciones de emisiones no parecen haber afectado significativamente al crecimiento. Sin embargo se identifican dos efectos de signo contrario: la reducción de las emisiones de SO_2 habría estimulado el progreso tecnológico al mismo tiempo que afectaban negativamente el cambio de eficacia técnica.*