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Technological changes in the pulp and paper industry and the role of uniform versus selective environmental policy

Abstract:
Although environmental regulations may imply a cost increase on firm's conventional input factors, such regulations could stimulate the incentives to improve factor productivity. Productivity measures including indicators capturing environmental improvements may also show higher or lower progress than productivity measures ignoring environmental aspects. We apply a Malmquist productivity index approach on micro data for the Norwegian pulp and paper industry, and find that the overall productivity growth accounting for changes in emissions of COD to water is higher than the growth in the productivity measure including conventional inputs only. We find the opposite result when including emissions of acids and climate gases to air. This is probably due to environmental regulations with opposing effects on different emissions. A decomposition of the Malmquist index into a technical efficiency change factor and a technical change component shows that the frontier technology has changed, while the average distance to the frontier has increased.

Keywords: Emissions, Productivity change, Paper and pulp, Malmquist index, Frontier technology

JEL classification: L73, O12, O14, O33, O41, Q48, R38

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1. Introduction

An important aspect of economic growth is the negative environmental externalities caused by technology choices. Over the last two decades, producers, policy makers and researchers have paid an increasing interest in economic growth and environmental performance; see e.g. Jorgenson and Wilcoxen (1993), Bovenberg and van der Ploeg (1994), Goulder et al. (1999) and Porter and van der Linde (1995). One aim of environmental policy is to increase incentives to develop and utilize environmentally friendly technologies.

In the neoclassical literature, technology choice is modeled by production or cost functions. Jorgenson and Griliches (1995/1967) and Berndt and Khaled (1979) applies times series data to estimate technology parameters depending upon a trend variable and prices. Klette (1999) uses a panel data set and estimates productivity differences across firms. Another strand in the literature estimates the locus of a technology frontier by applying data envelopment analyses (DEA) or deterministic frontier analysis (DFA), see e.g. Zellner and Revanka (1969), Charnes et al. (1978), Banker et al. (1984) or Färe et al. (1994). Their concern is to describe the development of the technology frontier over time, while the driving forces behind the development are not in their focus. Their method enables both the calculation of firms' distance to the estimated frontier, and a decomposition of the changes in total factor productivity over time. Färe et al. (1994) show how a measure of changes in total factor productivity, the *Malmquist productivity index*, can be decomposed into movements of the technology frontier and the firms' catching up to or lagging behind the frontier. In the present article we perform such decompositions for the Norwegian pulp and paper industry.

Environmental regulations normally increase the conventional input factor costs. Increased input factor costs stimulate the incentives to improve factor productivity. Productivity measures including indicators capturing environmental improvements may show higher or lower progress than productivity measures ignoring environmental aspects. Hetemäki (1996), Tyteca (1997), Hailu and Veeman (2000; 2001) and Reinhard et al. (2000) include environmental externalities, based on a method described in Färe et al. (1989). They all conclude that measures including environmental indicators differ from traditional measures.

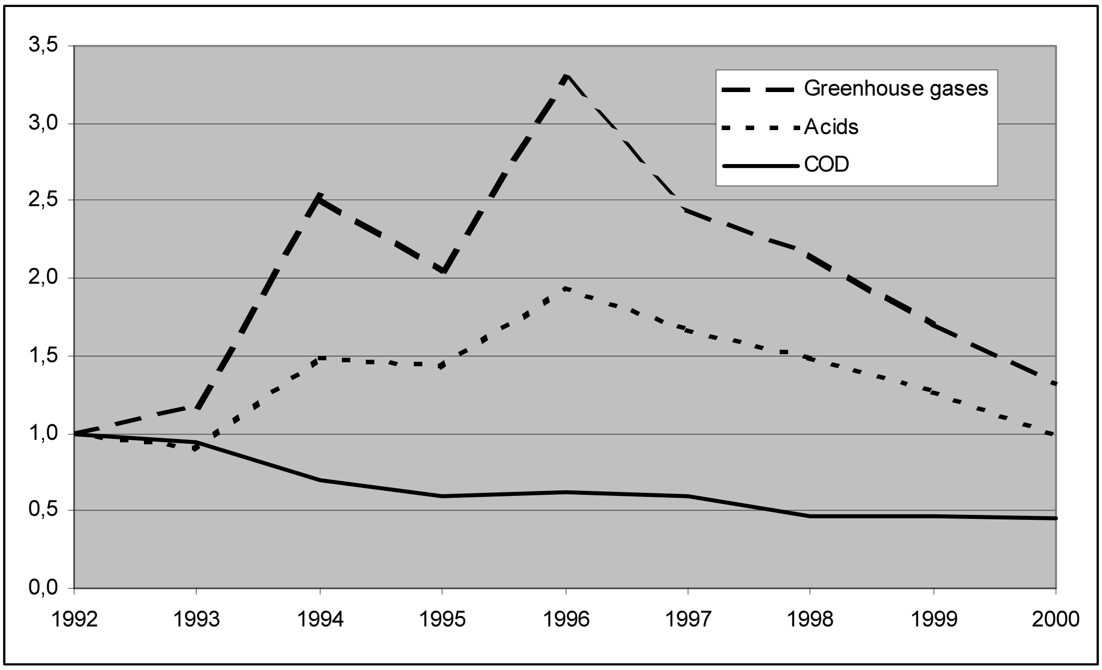
Klette and Raknerud (2002) apply a structural model of optimal supply and factor demand to decompose efficiency differences for Norwegian manufacturing industries. They decompose efficiency differences into stochastic, firm specific cumulated innovations and permanent efficiency differences, and conclude that differences seem to prevail rather than narrow. Earlier frontier studies on Norwegian manufacturing investigate the development in conventional input factors, see Førsund et al. (1980) and Førsund and Jansen (1983). Our article includes both a conventional productivity measure and a combined measure including environmental indicators in the Norwegian pulp and paper industry. The analysis focuses on the relationship between the locus of the technology frontier and the firm specific differences to the frontier, with a specific emphasis on the possible link between environmental regulations and technological changes.

To perform the comparisons, we calculate the Malmquist index with and without environmental factors. If a regulation involves a productivity gain in the environmental dimension compared to conventional input factors, this will be reflected in the extended Malmquist productivity index. The productivity measure including environmental indicators may then increase more than the conventional measure.

The decomposition of the Malmquist total productivity index into *technical efficiency changes* (diffusion) and *technical changes* (innovation) helps to illustrate the link between *uniform* and *selective* environmental policies and technological progress. Environmental policy may be taxes adding direct costs to detrimental emissions, taxes increasing the costs of the polluting input factors, or indirect cost increase through direct regulations of emissions. The environmental policy may be uniform or selective. *Uniform environmental policies*, i.e. taxes on emissions, tradable permits, and even a percentage based pollution control, aim to reduce emissions by equable movements in the technology frontier and firms towards the frontier. By including general incentives to invest in cleaner technologies, uniform environmental policy may influence innovations. *Selective environmental policies* (firm specific regulations) are normally directed towards the most intensively polluting firms. If these firms are based on old technologies, it may be only a matter of time before they invest and become more overall effective, or shut down. Hence, regulations accelerate the direction of technology change towards the frontier. Pollution intensive firms may also switch over to unregulated technologies, e.g. technologies based on hydro- or nuclear power, or to technologies with lower energy intensity. However, the new technologies may involve lower productivity with respect to unregulated inputs. Then, even though the firms pollute less, a loss in total productivity and an overall increase in the distance to the frontier may occur. On the other hand, replacement of old technologies, including *general* innovations, may involve productivity gains also for unregulated factors.

A complicating aspect is that regulating one externality may affect the productivity index including other environmental indicators. We will illustrate that such controversies may take place in the pulp and paper industry. We focus on three groups of emissions, greenhouse gases (CO_2, CH_4 and N_2O), acids to air (SO_2 , NO_x and NH_3) and chemical and biological oxygen demand (COD and BOD) to water. The main policy tool against greenhouse gases has been a relatively high carbon taxes, in addition to several measures to reduce the emissions of methane from landfills and other climate gases. The emissions of acids have constituted another environmental problem high on the policy agenda. Policy measures like regulation of sulphur content in fuels, fuel oil taxes and direct emission control have been implemented. The emissions of COD and BOD were regulated through maximum emissions per unit wastewater. Despite these policies, emissions to air per produced unit increased toward 1996, but later decreased. For COD, however, emissions per produced unit decreased continuously, c.f. Figure 1.

Figure 1. Sample emissions of greenhouse gases, acids and COD per unit of production, Norwegian paper and pulp industry, 1992=1,00



Finally in our paper, we apply a DEA approach to compute a measure of technical efficiency to illustrate the potential emission reductions, given that all firms adjust to the best available technologies. The potential technical improvements shed light on the possibilities to further reduce pollution proportionally with the conventional input factors, disregarding profitability.

The rest of the paper is organized as follows: In Chapter 2, we present the methodological and empirical framework for our estimations. Chapter 3 discusses the estimations, while Chapter 4 concludes.

2. Theoretical framework

A variety of environmental performance indexes have been proposed in the past (Tyteca, 1997), based on adjustment of conventional efficiency measures, defined by Farrell (1957). The underlying methods can be divided into those using non-parametric or parametric deterministic techniques, and those using exclusively parametric stochastic methods. Most of the non-parametric techniques are related to the

Data Envelopment Analysis, DEA, a procedure pioneered by Charnes et al. (1978) and extended by Banker et al. (1984).

Environmental impacts are treated either as output (e.g. Färe et al. 1989) or undesirable inputs (Tyteca 1997). The input oriented perspective, used in this paper, addresses the question: Without reducing output, what is the maximum proportional reduction in inputs?

Consider a production technology where an output vector, $y \in R_+^M$, is produced using a vector of inputs, $x \in R_+^{N+D}$. The input vector consists of N normal and D environmentally detrimental inputs. Let S^t be the technology set at time t, i.e. $S^t = \{ (x_t, y_t) : x_t \text{ can produce } y_t \}$. Following Shephard (1953, 1970) and Färe and Primont (1995), we define the input distance function:

$$d^t(y,x) = \max_\theta \left\{ \theta : \left(y, \frac{x}{\theta} \right) \in S^t \right\} \tag{1}$$

The value of the input distance function measures the maximum amount by which the input vector can be deflated, provided that the output vector is unchanged. In a given period $d \in [1, \rightarrow)$, and the firms operate on the boundary of the technology set, S^t, if d=1.

In line with Färe et al. (1994) and Hailu and Veeman (2000), we specify the input oriented Malmquist productivity index, MI, as:

$$MI = m(y_{t+1}, x_{t+1}, y_t, x_t) = \left[\frac{d^t(x_{t+1}, y_{t+1})}{d^t(x_t, y_t)} \frac{d^{t+1}(x_{t+1}, y_{t+1})}{d^{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \tag{2}$$

This represents the geometric mean of the two Malmquist input-oriented productivity indexes, each with period t- and t-1-technology as base technology. This index can equivalently be written as follows (see Färe et al. 1989; Färe 1992):

$$m(y_{t+1}, x_{t+1}, y_t, x_t) = \frac{d^{t+1}(x_{t+1}, y_{t+1})}{d^t(x_t, y_t)} \left[\frac{d^t(x_{t+1}, y_{t+1})}{d^{t+1}(x_{t+1}, y_{t+1})} \frac{d^t(x_t, y_t)}{d^{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \tag{3}$$

The first factor measures the change in technical efficiency from one year to the next:

$$EC = \frac{d^{t+1}(x_{t+1}, y_{t+1})}{d^t(x_t, y_t)} \tag{4}$$

The geometric mean of the two factors inside the brackets captures the change in technology between the two periods:

$$TC = \left[\frac{d^t(x_{t+1}, y_{t+1})}{d^{t+1}(x_{t+1}, y_{t+1})} \frac{d^t(x_t, y_t)}{d^{t+1}(x_t, y_t)} \right]^{\frac{1}{2}} \tag{5}$$

Hence, the total factor productivity change given by the Malmquist productivity index equals the product of *technical efficiency change* (*EC*) *and technical change* (*TC*):

$$MI = EC * TC \tag{6}$$

Improvements in *EC* correspond to catching up to the frontier, while improvements in *TC* correspond to shifts in the frontier.

We base our estimation of the potential emission reductions on the input distance function $d(y,x)$. By definition, the reciprocal of the value of the input distance function provides an input-based Farrell measure of technical efficiency (Farrell, 1957):

$$TE(y, x) = \frac{1}{d(y, x)}. \tag{7}$$

Technical efficiency, TE, measures how well a firm performs compared to the boundary of the technology set. The potential emission equals the product of the actual emission and the technical efficiency.

We estimate the Malmquist index and technical efficiency in the presence of environmentally detrimental inputs, using DEA-like linear programs outlined in Coelli et al. (1998)[1]. Grifell-Tatje and Lovell (1994) show that, in the presence of non-constant returns to scale, the Malmquist index does not accurately measure productivity change. To address this, and to avoid possible computation difficulties, we follow the recommendation of Coelli et al. (1998) and assume constant returns to scale.

When we estimate technical efficiency, we allow for variable returns to scale. We follow Tulkens and Vanden Eeckaut (1995), computing a sequential frontier: Technical efficiency is computed in year τ on the basis of all observations generated up to year τ, i.e. all former technologies are available at any time.

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[1] The actual estimations of technical efficiency and Malmquist indexes are performed using DEAP version 2.1, see Coelli (1992).

2.1. Data

We base our study on an extensive database (DEED)[2], which consists of disaggregated environmental and economic data covering the largest and potentially most polluting Norwegian firms. This database provides firm specific time series data for output, market inputs and emissions over the period 1992 to 2000.[3]

The data set consists of an unbalanced panel containing 22 plants in the pulp and paper industry[4], see Table 1. In 2000, these plants comprise more than 90 percent of the total production in the sector, and more than 95 percent of energy consumption. Firm specific output, intermediate inputs and capital are measured in current values, and deflated to 1992 NOK by industry specific price indexes and price indexes for investments, respectively. Capital estimates are based on a combination of insurance values of buildings and machinery and accumulation of net investments. Labor is measured in terms of working hours. In addition, three different (groups of) emissions are included. Greenhouse gases is an aggregate of carbon dioxide (CO_2), methane (CH_4) and nitrous oxygen (N_2O), measured in 1000 tonnes CO_2-equivalents. Acidifying substances is an aggregate of sulfur oxide (SO_2), nitrogen oxides (NO_x) and ammonium (NH_3), measured in tonnes weighed by the acidifying component (H^+). Chemical oxygen demand (COD) is measured in tonnes.

The environmental policy may have opposing effect on different pollutants. In the abatement process, COD and BOD are correlated, and COD is used as a proxy for these emissions. COD abatement turns parts of the component into a solid that may be utilized as energy in the production process, which again contributes to increased emission of acids (SO_2). If the abated COD substitutes electricity, a regulation of COD then increases acidification. If substituting oil, however, a net decrease in acidification may be possible, and emissions of CO_2 will be reduced. The number of observations is not sufficient to address all these problems simultaneously. However, by analyzing the pollutants one by one, we compare the findings and discuss the effect of policy due to dependency between the pollutants.

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[2] DEED - Database for Disaggregated Environmental and Economic data, see Larsson and Telle (2003a) for further documentation.

[3] On the international level, similar data is scarce. For time series data in EU, see Berkhout et al. (2001). EPA provides data for US (Toxic release inventory).

[4] NACE code 21.1

Table 1. Descriptive statistics. Yearly mean, standard deviation, minimum and maximum for the entire sample

Variables	Mean	Std. dev.	Minimum	Maximum
Firms	20	1.48	18	22
Production (million 1992-NOK)	628	705	7	2899
Capital (million 1992-NOK)	1466	1650	42	7037
Intermediates (million 1992-NOK)	490	530	6	2066
Labor (1000 working hours)	491	396	16	1446
Green house gases* (1000 tonnes CO_2)	23	28	0.05	132
Acid equivalents** (tonnes acidifying effects)	5	6	0.003	29
COD*** (tonnes)	7759	8621	201	42177

*) Whole sample, 22 plants, measured in CO_2 equivalents.
**) Subsample, 17 plants.
***) Subsample, 16 plants.

3. Results

3.1. With or without the environment: what is the technological progress?

Brännlund et al. (1995) apply a non-parametric programming approach to study whether environmental regulations have influenced profits in the Swedish paper and pulp industry. Their conclusions are ambiguous; for some mills, profits increased, while for others, profits decreased. Hetemäki (1996) also studies the Finnish paper and pulp industry in a stochastic front analysis. His main finding is that an increase in the regulative intensity leads to a decrease in productivity. However, the first order effect of *general technological progress* motivated by profit maximizing behavior is more productive market factors.

The question is whether the conventional Malmquist productivity index (MI_{conv}) is greater than, equal to or smaller than the Malmquist index including environmental factors (MI_{env}). If the productivity gain for environmental factors, due to the regulation, overrides the gain for conventional factors, then the relative measure, i.e.

$$MI_R = \frac{MI_{env}}{MI_{conv}} \tag{8}$$

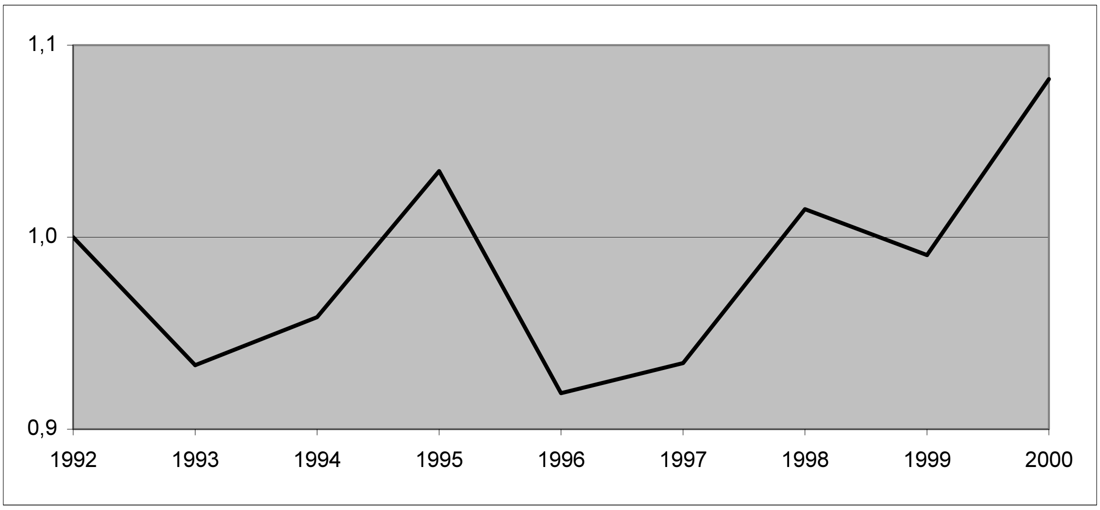
is larger than one.[5] This is in line with the results of Hailu and Veeman (2000) for the Canadian pulp and paper industry. Based on time series data, they estimated a parametric distance function with both

[5] See Färe et al. (1996) for a similar measure.

traditional inputs and output, and a pollution output. Their main conclusion is that a measure including the pollution output shows a significantly higher overall productivity change than when just accounting for traditional inputs and output. Hailu and Veeman also find little if any conventional progress in the Canadian pulp and paper industry, which may well be caused by the extra costs from the environmental regulations.

The conventional Malmquist productivity index in our sample of the Norwegian pulp and paper industry is depicted in Figure 2. From 1992 to 2000 the MI_{conv} increased by 8 percent, i.e. an annual average progress about one percent.[6]

Figure 2: The conventional Malmquist index, 1980=1.00



Within the rather short data period, business cycles may cause variation in the capacity utilization that disturbs the calculation of technical progress. Figure 3 shows the variation in output in the paper and pulp industry in Norway from 1980 to 2000. The peak in production in 1995 coincides with the peak in the technical frontier described in Figure 2. However, over the entire nine year period, it seems as the business cycle movement is less important for the overall conclusion. Assume that full capacity utilization is defined by the continuous linear development between the peaks of production over time. Then 1995 was all time high utilization. In 1992, 84 percent of the capacity is utilized and in 2000 96 percent were utilized.[7] If capacity has not increased since 1995, this indicates that our measure may overestimate the technology improvement over time by a magnitude of 10 percent, dependent upon the productivity effect of capacity utilization.

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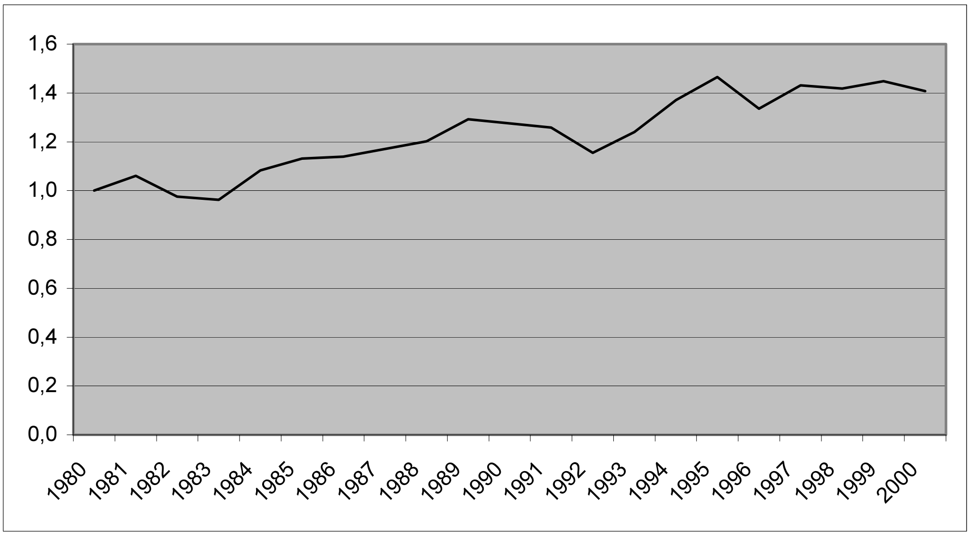
[6] Such an annual growth rate is a bit above what is previously found for Norwegian manufacturing industry for the same period (Statistics Norway 2003), and clearly above the rate found for the 1980s (Møen 1998). Note that, compared to ours, both these studies apply a different method to compute total factor productivity.

[7] Since 1995 is the top year, the capacity utilization is 2000 is defined relative to the 1995 level.

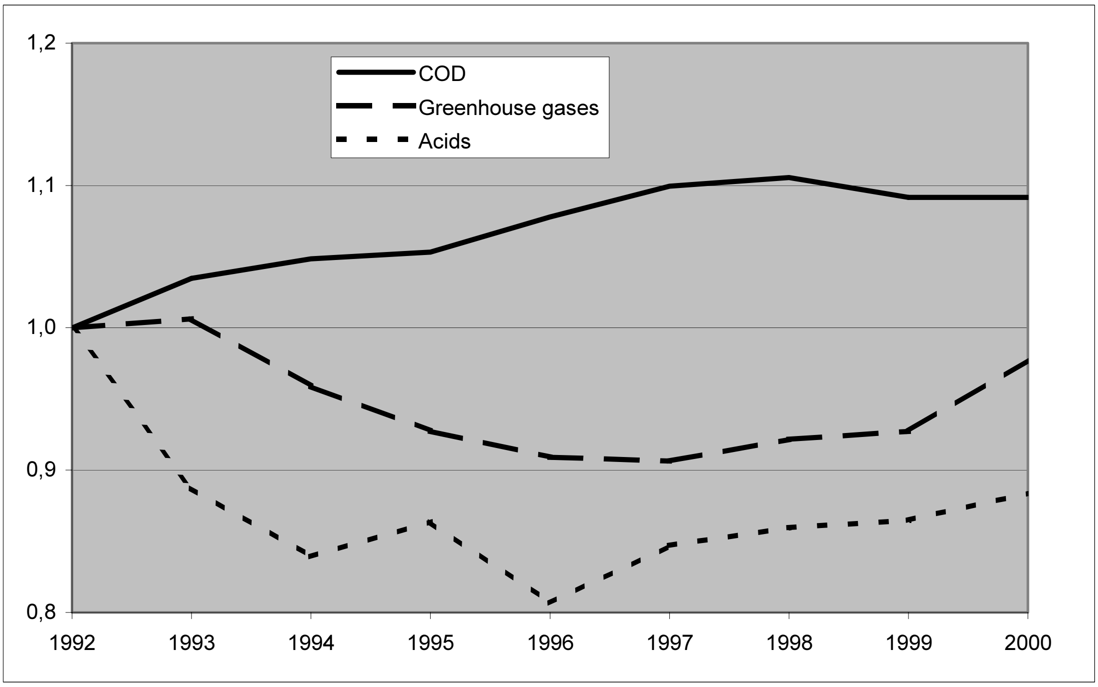
Figure 3. Development of production in Norwegian Pulp and paper industry. Index 1980=1.00



In Figure 4, we see that total factor productivity including COD increases relative to the conventional measure. This follows the prime suggestion that regulations imply productivity changes in the environmental dimension that exceed the productivity change in conventional inputs *ex post* the regulation.

We further find that the MI_R is below one for both greenhouse gases and acids, i.e. the mean productivity of conventional factors increased more than the productivity measure including emissions. Despite the extensive use of taxes on carbon emissions and sulfurous oils and regulations against methane and N_2O emissions, the plants have become less productive when taking emissions into consideration. This corresponds to the picture depicted in Figure 1, which shows that emissions of greenhouse gases and acids per produced unit increased over the period as a whole, but declined after 1996.

Figure 4. The Mamquist productivity index including emissions, relative to the index based on conventional factors, 1992=1.00



One explanation may be that COD regulations are more forcefully imposed than the regulations towards acids and greenhouse gases. Adding filters to the waste liquid from the plants can abate COD emissions. This is a partial end treatment that does not influence significantly on conventional factor productivity.

Another explanation may be a "substitution" between emissions to water and air. When reducing COD from the waste liquid, solid fuel from the BOD can be produced. These sulfur-containing solids may be utilized as energy in the heating process, and when they substitute electricity in boilers, emissions of acids increase. If the solids substitute other fossil fuels, the effect on acids are unclear, but probably positive, while the net greenhouse gas emissions will be reduced.

A third reason for the relative decrease in environmental productivity may be that regulations have not been binding. If the average plant already complies with the emission target before the regulation, emissions may increase despite the regulations, hence the environmentally adjusted productivity measure will be reduced.

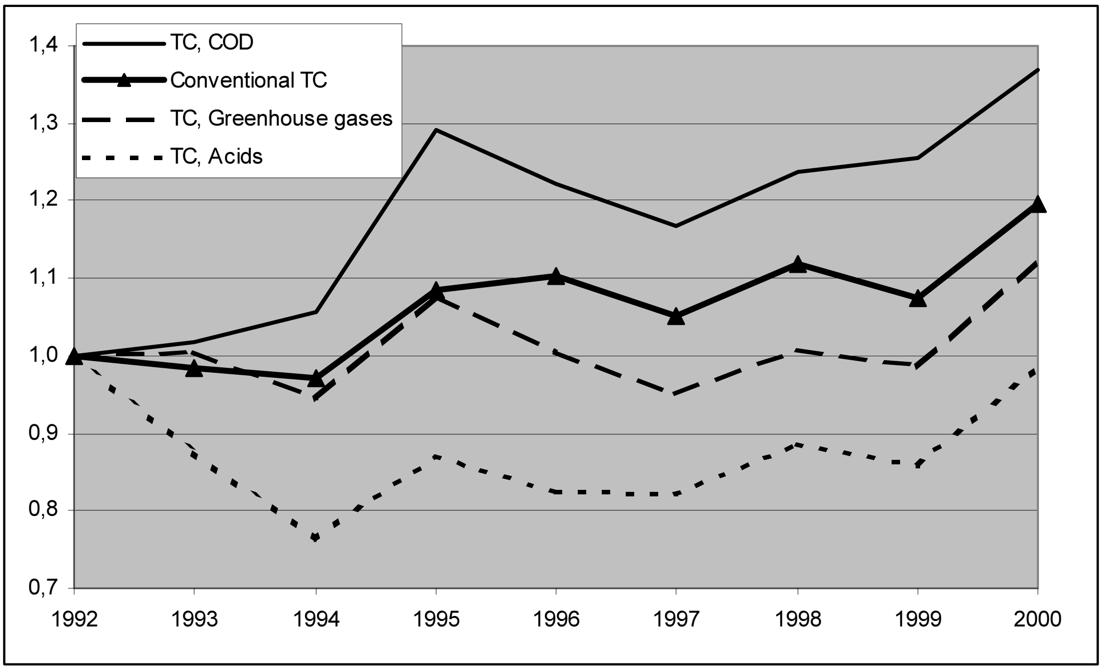
Finally, the total factor productivity measure disregards economic efficiency. Simultaneously with the reductions in the total factor productivity measure including fossil fuel related emissions (greenhouse gases and acids) around 1996, the prices of fossil fuels relative to electricity were low. The electricity prices increased by almost 50 percent from 1993 to 1997. A relative decrease in the costs of using fossil fuels must have induced substitution in fossil fuels for electricity and increased fossil fuel related emissions. Since the pulp and paper industry holds boilers where electricity and fuel oil are perfect substitutes, such substitution is simple.

The differing paths for water and air emissions depicted in Figure 4 may also mirror the findings in the EKC (Environmental Kuznets Curve) literature. This literature refers to observations that emissions imposing local costs (e.g. COD) are most likely to be treated first, while emissions of regional and global impact, such as acids and greenhouse gases, typically are less exposed to efficient regulations (see e.g. Bruvoll and Medin 2003).

3.2. Movements of and behind the frontier

The decomposition of the Malmquist index reveals substantial *technical changes, TC*, i.e. the frontier moved approximately 20 per cent over the period, see Figure 5. Taking into account the higher capacity utilization over the period, we may deduct about 10 per cent from this estimated technical change. Besides, the higher capacity utilization in 2000 compared to 1992 may have caused firm specific productivity effects. An upward change in the total business capacity utilization could influence the most effective production units first, as these plants may have a greater potential of increasing productivity as capacity utilization increases.

Figure 5. Decomposition of the Malmquist index including emissions, technical changes (TC), 1992=1.00

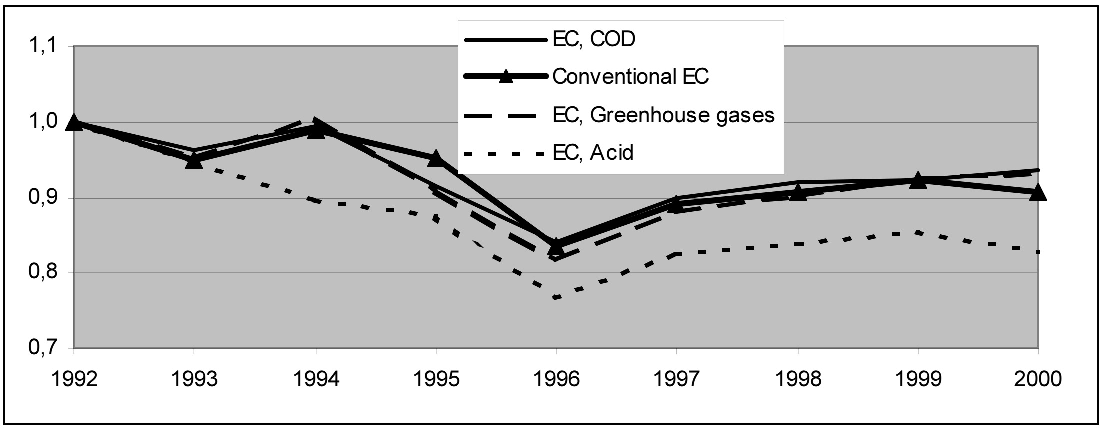


The positive technical change in Figure 5 applies both for the conventional measure, and for COD and greenhouse gases. The regulations against COD and greenhouse gases are typically uniform, i.e. the regulations should foster innovation and move all the firms in the same direction. Carbon taxes and maximum emissions per unit wastewater both involve shifts in technology for all less productive plants towards the existing frontier, and a shift in the frontier. COD regulations are relatively inexpensive, and the effect on the general productivity with respect to other input factors is probably limited. Thus, as anticipated, *TC* including COD increases, and more than the conventional *TC*. For greenhouse gases, however, *TC* is lower than for the conventional factors, which may mirror that CO_2 emissions cannot be abated. CO_2 reductions require substitution in energy use or lower production (reduced energy use). Hence, productivity improvements are relatively costly.

Despite regulations, the frontier movements including acids have been smaller than the conventional *TC.* This may be due to several reasons. First, we have already mentioned the dependency between the regulation of COD and BOD, and acid through the production and burning of solids. Secondly, during this period, the taxes on the sulfur content in fuels have rather decreased (in fixed prices). This means a step backwards in the regulation of acids. Finally, the reason may be that the general technological progress has improved the effectiveness regarding conventional inputs, but the new technologies have induced increased acid emissions.

In Figure 6, we present the general *technical efficiency changes, EC*. We find that over the period there has been a firm specific movement away from the technology frontier. This applies for both the conventional measure and the measures including environmental factors. This is an even stronger conclusion than in Klette and Raknerud (2002), who claimed a prevailing difference in firm efficiencies over time. Several explanations may be launched to explain our result. First of all, we refer again to the development in capacity utilization. Increased business capacity utilization may reflect that the most productive firms increase the capacity utilization first. If the less productive firms are less inclined to increase capacity utilization, an increase in total business capacity utilization, biased distributed, may be depicted as a movement away from the technology frontier in Figure 5. Second, even though most of the policy regulations seem uniform, they could hit some firms harder than other firms. Thirdly, some of the regulations have actually been firm specific, cf. the regulation of COD, which often depend upon the firm specific processes (cf. chemical or mechanical pulp production). And finally, the firm specific regulation may imply firm specific dependency between emissions as described above.

Figure 6. Decomposition of the Malmquist index including emissions, technical efficiency changes (EC), 1992=1.00

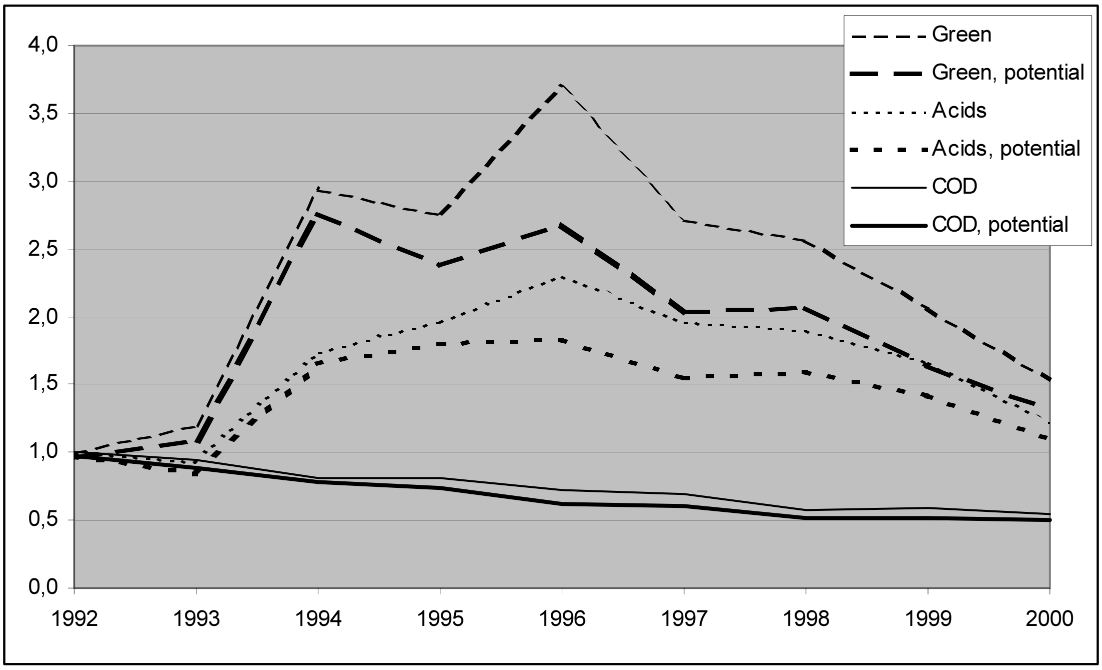


3.3. The potential for additive environmental improvements

In this chapter, we illustrate the environmental improvements that are technically possible, assuming that all firms adjust to the best available technologies over all factors. This illustration is purely hypothetical, based on *technical efficiency* only. When the alternative costs related to reducing inputs and emissions and implementing new technologies are accounted for, *economic efficiency* may prevail. Thus, such hypothetical emission reduction estimates may serve as information to the policy makers evaluating e.g. potential sources for regulations to achieve certain goals of emission reductions given in international treaties or Pigou taxes.

Figure 7 shows the actual emissions in the pulp and paper industry, and the estimated *potential emissions* given that all inputs and emissions are proportionally decreased at constant output. In the mid 90ies, the average firm showed less efficient relative to the best available technology for all *TE* measures including emissions, and particularly for greenhouse gases and acids. This coincides with the relative fall in prices on fossil fuels. However, the *TE* measure picked up towards the end of the period, although at a lower level than in 1992. While the average firm utilized about 96-98 percent of the technology potential in 1992, only 85-92 percent of the existing potential was utilized in 2000. In other words, if the best available technologies were applied in all firms in 2000, all inputs and the emissions of greenhouse gases could have been reduced by about 8-15 percent without reducing production. Over time, emissions could have been both significantly lower and more stable, if the best available technologies had been applied.

Figure 7. Emissions and potential total emissions for the firms in the sample, 1992=1,00



4. Conclusions

Technical change is considered to reduce environmental problems. Given an initially optimal adjustment, regulations of detrimental emissions, either by direct and selective regulations or by imposing uniform economic instruments, generally imply cost increases in conventional input factors. We compare a Malmquist productivity index for conventional inputs and output with an index including environmental indicators, and find that accounting for the environment may both increase or decrease the productivity estimate.

For the emissions to water, our results confirm the results in Hailu and Veeman (2000, 2001), who find that the environmentally sensitive productivity change measure is higher than the conventional one. The regulation may have reduced the productivity for conventional factors in the Norwegian pulp and paper industry, but the Malmquist index still reveals a change in conventional productivity. When accounting for the productivity gain in COD emissions, the Malmquist index unveils that the environmental improvement is larger than conventional factor input progress.

Including emissions to air, the productivity measure is lower than the pure conventional measure. Indicators of the overall productivity gain in an economy may then be overestimated if relying on conventional measures alone. We argue that the different results regarding emissions to air and water may stem from policy effect and dependency between emissions. Regulating COD creates solids, which may next substitute electricity in heating processes that creates emissions of SO_2 (acids), or fossil fuels that reduce the emissions of CO_2 (greenhouse gases). The discrepancy between conventional productivity measures and measures including environmental factors illustrates the importance of the ongoing efforts to widen the traditional market indicator sets to include environmental indicators in a welfare context (see e.g. European Commission and Eurostat 1999).

Further, we find that the main reason for the overall productivity is from movement of the frontier. This may imply that uniform environmental policies create impulses to simultaneous technology shifts among firms, keeping the relative distance to the frontier unchanged. At the same time, selective environmental policies (regulations) seem to have increased the distance to the frontier for several firms.

Finally, from a policy perspective, we find it interesting that there is a potential of about 10 percent decrease in all inputs, without reducing production. It is important to note that these estimates only concern technical efficiency. Status quo may be optimal in the economic perspective, when the alternative costs related to reducing inputs and emissions and implementing new technologies are also accounted for. However, this information is relevant if taxes and regulations creating the shadow prices on the externalities are un-optimal.

Extensions of this project are comparisons across more industries[8], econometric analyzes of the causal relationship between actual policy instruments and the productivity measures (endogenous technical change). Other extensions may be further investigations of the effects of different policies (uniform versus selective) and the inclusion of several environmental aspects into the productivity measure.

[8] Larsson and Telle (2003b) compare the aluminum, ferro, chemical industries and the pulp and paper industry, for acids and greenhouse gases.

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