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Do environmental regulations hamper productivity growth? How accounting for improvements of firms' environmental performance can change the conclusion

Abstract:
Many economists maintain that environmental regulations hamper productivity growth. However, recently, an opposing view has gained advocates. Indeed, it has been suggested that the empirically detected inverse relationship between environmental regulations and productivity growth is an almost inevitable consequence of the current methods used to measure productivity – methods that fail to account for improvements in environmental performance. We apply a method that amends this methodological shortcoming of previous empirical studies, and perform a regression analysis of regulatory stringency and a measure of productivity growth that accounts for emission reductions. To credit a firm for emission reductions, we include emissions as inputs when calculating the Malmquist productivity index (EMI); and for the sake of comparison, we also calculate the traditional Malmquist productivity index (MI) where emissions are not included. The regression analysis shows that the sign of the relationship is positive when EMI is employed as measure of productivity growth; but not statistically different from zero when MI is applied. Hence, the present paper provides the first empirical support for the claim that evaluations or recommendations of environmental policies that are based on a traditional measure of total factor productivity can be biased.

Keywords: Environmental regulation; Productivity; Malmquist index

JEL classification: Q28, D24, Q25, L60

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1 Introduction

It is a concern to policymakers that environmental regulations hamper competitiveness and economic growth. Several economists have estimated the effect of environmental regulations on traditional measures of growth in total factor productivity, and their results suggest that the concern is not unwarranted (Christiansen and Haveman 1981, Jaffe et al. 1995). Recently, however, the opposing view, that there are opportunities available where emissions can be reduced and productivity growth improved simultaneously, has gained advocates. It has also been suggested that the empirically detected inverse relationship between environmental regulations and productivity growth is an almost inevitable consequence of the current methods used to measure productivity – methods that fail to account for improvements in environmental performance (Repetto et al. 1997).

Recently, methods that account for environmental performance when measuring productivity growth have been developed, and most empirical studies have revealed that failure to account for emissions results in understatement of productivity growth (Weber and Domazlincky 2001, Färe et al. 2001, Hailu and Veeman 2000). These studies are often motivated by the conjecture that inclusion of environmental factors in measures of productivity growth will influence the results of analysis of the *relationship* between environmental regulations and productivity growth. To our knowledge, the present paper is the first to empirically investigate this conjecture; we study the empirical *relationship* between environmental regulations and productivity growth. To credit a firm for emission reductions, we include emissions when calculating an environmental Malmquist productivity index (EMI); and for the sake of comparison, we also perform the analysis on the traditional Malmquist index (MI) where emissions are not accounted for.

Most studies of the relationship between environmental regulations and productivity growth (not accounting for emissions) employ industry- or state-level data and conclude that such regulations hamper productivity growth (Christiansen and Haveman 1981, Jaffe et al. 1995).[1] However, as regulations are usually set at the plant level, employing industry- or state-level data can be an important shortcoming. When it comes to studies of environmental regulations and traditional measures of productivity employing plant level data, the literature is scarce and the results more ambigious (Jaffe et al. 1995, Jenkins 1998): Gollop and Roberts (1983), which seems to be the only plant level study of the relationship between environmental regulations and productivity growth, investigates the effect of

[1] In the present paper, we consider one measure of economic performance; productivity growth. The literature on the relationship between regulations and other measures of economic performance is not scarce; see e.g. the frequently cited work by Jorgensen and Wilcoxen (1990) on economic growth for the overall US economy. Firm level studies of regulation and profitability or efficiency do also exist; see e.g. Brännlund et al. (1995) and Hetemäki (1996), respectively.

firm specific environmental regulations on traditional measures of productivity growth in the U.S. electric power industry. The authors conclude that environmental regulations have resulted in markedly lower productivity growth.

Similarly, Gray and Shadbegian (2002) analyze the connection between productivity and environmental regulations for plants in three US industries. When environmental regulations are measured by compliance costs, they find a negative relationship. However, when other commonly used measures of regulation are employed, like compliance status or the number of inspections by the regulatory agency, the estimated coefficients are not significant. Gray and Shadbegian (2003a) build upon Gray and Shadbegian (2002) and concentrate on the Pulp and Paper industry. Their results resemble the ones of their previous study regarding the relationship between compliance costs and productivity (see also Gray and Shadbegian 2003b). On the other hand, Berman and Bui (2001) conclude that environmental regulation can *increase* productivity in their study of US oil refineries.

All these previous firm level studies employ traditional measures of productivity (growth). We are not aware of any study that investigates the relationship between environmental regulations and a measure of productivity growth that accounts for emission reductions. The contribution of the present paper is to provide an empirical regression analysis showing how the relationship between stringency of environmental regulations and productivity growth depends on whether MI or EMI is applied. Based on empirical studies elsewhere (e.g. Magat and Viscusi 1990, Laplante and Rilstone 1996), regulatory stringency or enforcement is assumed to rise with inspection frequency. Inspection frequency serves as our measure of regulatory stringency.

The MI/EMI type of index has advantages over other measures of growth in total factor productivity, like the Törnquist or Fischer index: The MI/EMI type of index can be computed solely on the basis of quantities, getting around the problem of recovering (shadow) prices on emissions. Although implying that the EMI specified in this study cannot be directly related to changes in welfare, it does provide a more complete picture of changes in productivity, as emissions, which are of concern to society, are included. Another advantage is that MI/EMI can be computed with very few restrictions on the production technology. We use nonparametric linear programming to estimate distance functions, which are used to define MI/ EMI (see e.g. Färe et al. 1994). Based on plant specific data, we estimate a technology frontier using data envelopment analysis for each industry. The MI/EMI comprises of changes in firms' distance to the frontier and movement of the frontier. Contrary to econometric approaches used to estimate productivity (growth), like e.g. Klette (1999) or Gray and Shadbegian (2002), the approach taken in the present paper requires no assumptions of the functional form of the production function. And in addition, when estimating productivity growth, we avoid imposing the same production function structure on all firms within an industry. Finally, we do not need to impose optimizing behavior.

Norway's most energy intensive manufacturing industries are included in the present study. The Pulp and paper, Aluminum, Inorganic chemicals and Ferro alloy industries consume about 50 percent of the energy of all Norwegian manufacturing industries. These industries are major contributors to overall Norwegian emissions. In 2000, these four industries caused more than 80 percent of Norwegian manufacturing industry's emissions of SO_2, more than 50 percent of emissions of acids, and about 50 percent of the emissions of CO_2 or greenhouse gases (Statistics Norway 2003a).

In Section 2, we present the econometric model and the data, and outline how the productivity indexes are estimated. Section 3 presents the regression results for the two measures of productivity growth on regulatory stringency. Section 4 concludes.

2 Models and data

2.1 Econometric framework

In this subsection we introduce the econometric model, which is applied to test the sign of the relationship between environmental regulatory stringency and productivity growth. As mentioned in the introduction, empirical studies of the relationship between environmental regulation and productivity (growth) on firm level data are scarce, and the results ambiguous. The differing methods applied in previous studies may be one reason for ambiguous results.

Gollop and Roberts (1983) estimate a cost function to test for the impacts of regulatory stringency of sulfur dioxide emissions. Berman and Bui (2001) take another approach. They use prices on inputs and outputs to directly calculate total factor productivity. Then they compare productivity of plants in regulated US states with plants in less regulated states. Gray and Shadbegian (2002, 2003), first, let the residuals evolving from a regression of a three input production function model serve as measures of the total factor productivity levels. Then, they recognize that this measure of productivity overstates the inputs necessary to produce the conventional output because some inputs are used for abatement activity. Therefore, in an attempt to amend this "mismeasurement", they correct the estimated productivity by the share of compliance costs in total costs. It is a weakness of this procedure that the measurement of the compliance data is suspect (Berman and Bui 2001, Gray and Shadbegian 2002), and that abatement productivity and traditional productivity are treated principally differently. Second, Gray and Shadbegian (2002, 2003) regress estimated productivity on various measures of regulatory stringency.

Our approach is similar to the one taken by Gray and Shadbegian (2002, 2003): We regress productivity growth on regulatory stringency. However, we apply a measure of productivity growth that accounts for emission reductions (EMI). This enables us to account for changes in emissions in a consistent and clearly defined way; circumventing any ex post needs to amend the estimates of productivity growth. The regression model, where $Productivity\_growth_{i,t}$ for plant *i* in time *t* is either EMI or MI, is as follows:

$$Productivity\_growth_{i,t} = a + b * Stringency_{i,t-j} + Controls_{i,t-j} * c + v_i + w_t + u_{i,t} \quad , j=1,2,..,\tau \tag{1}$$

where *Stringency* is a measure of the stringency of the environmental regulation, *Controls* is a vector of control variables, v and w is plant specific and year specific effects, and u is an error term. These variables are explained more carefully in the following paragraphs.

The *stringency* or enforcement of environmental regulations may be operationalized in numerous ways. The following are examples from the abovementioned papers; compliance costs, the number of new regulations taking effect, discrepancy between non-constrained emissions and actual emissions, or the number of inspections. In the present paper we use inspections, which are a reasonable indicator of regulatory stringency or enforcement for several reasons. First, previous studies elsewhere have shown that inspections increase enforcement by reducing emissions (e.g. Magat and Wiscusi 1990, Laplante and Rilstone 1996). Second, the costs for the Norwegian Pollution Control Authority (NPCA) of inspections have to be covered by the inspected plant; and in addition, if violations are revealed, both future inspection frequency and the plant's expectation of future sanctions tend to increase (Nyborg and Telle 2004). Finally, inspections are more frequent for potentially more environmentally risky plants, and such plants are also more stringently regulated. Hence, as inspection frequency is in general higher for more regulated plants, the *Stringency* variable includes not only stringency of enforcement, but also elements of the stringency of regulation.

The *Stringency* variable is constructed as a dummy variable set to one if the plant experiences one or more inspections during the period. In studies where compliance costs or emissions are used as measures of regulatory stringency, it is commonly recognized that measurement errors may bias the estimates (Berman and Bui 2001). As our data builds on the registrations routines of the regulator (NPCA), and as the registration is crucial as documentation for future follow up or prosecution of violators, there is little reason to believe the data are not complete. Hence, it seems reasonable to say that our approach practically eliminates the problem of measurement errors faced by most previous studies.

See Nyborg and Telle (2004) for an introduction to the Norwegian regulatory system, and for a more careful presentation of these data.

What control variables (*Controls*) to include in the analysis depends on the regression model employed; we focus on the random effect model and the fixed effect model. In the fixed effect model v_i is a plant specific fixed effects and w_t is a year dummy. This model effectively controls for plant specific effects that do not vary over time. Examples of such variables are the industry that the plant belongs to, plant's location or risk class, or time invariant elements of plant vintage, technology, management, or employee motivation and education. The baseline regression will be performed on this two-way fixed effect model. As there may be e.g. differences in economies of scale across plants (and over time), we control for size by including (the logarithm of) capital stock.

To investigate the sensitivity of the results of the baseline regression, we also report results from regressions on a (two way) random effect model. In the random effect model v_i and w_t are considered randomly distributed across plants and time periods, see Greene (2000). In the random effect model, we also include industry dummies as control variables. u_{it} is the error term[2].

2.2 Productivity growth

In this subsection, we outline the calculation of EMI and MI. There is an extensive literature on the Malmquist productivity index (see e.g. Färe et al. 1994), including a growing relatively new strand where this kind of index is amended to include environmental factors (see e.g. Färe et al. 1989, Chung et al. 1997, Färe et al. 2001).

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. We use observations of x_t and y_t for all plants to define the technology set. Following Shephard (1953, 1970) and Färe and Primont (1995), we define the plant's input distance function:

[2] Endogeniety problems, which lead to biased estimates, would arise if causality runs from (low) productivity growth to (increased) inspection frequency (*Stringency*). However, there is little reason why *Stringency* in period t should influence productivity growth in the same period, as the plant will normally need some time to adjust after an inspection. Hence, we use inspections in previous periods as explanatory variables. This should be sufficient to avoid problems of endogeniety. One may also argue that our measure of size, capital stock, could be correlated with the error term. Hence, for the regressions reported in Table 2 below, we tried using the lagged value of capital stock instead of capital stock. This did not change our main qualitative result.

$$d^t(y,x) = \max_{\theta}\left\{\theta : \left(y, \frac{x}{\theta}\right) \in S^t\right\} \quad (2)$$

The value of the input oriented 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, it is clear that $d \in [1, \rightarrow)$, and that a plant is operating on the boundary of the technology set (S^t) if d=1.

The data envelopment analysis involves the use of linear programming methods to construct a non-parametric piecewise frontier (the boundary of the technology set). In the present paper we compute MI and EMI, constructing the frontier as outlined in Coelli et al. (1998).[3] These indexes measure the change in productivity computed including and excluding emissions as inputs, respectively.[4] The indexes are computed for each of the four industries individually. 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 computation difficulties, we follow the recommendation of Coelli et al. (1998) and assume constant returns to scale. We assume that inputs are strongly disposable. Annual means of each industry are weighted by production.

Following Färe et al. (1994) we specify the input oriented Malmquist productivity index for each plant as:

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

This represents the geometric mean of the two Malmquist input-oriented productivity indexes, each with period t- and t-1-technology as base technology. (3) calculated including and not including environmentally detrimental emissions in the input vector (x) defines EMI and MI, respectively.

2.3 Data

To compute MI and EMI we use a unique data set[5] consisting of an unbalanced panel of plants for each of the following industries: Pulp and paper, Aluminum, Ferro alloys and Inorganic chemicals.[6] In

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[3] The actual estimations of the indexes are performed using Onfront version 2.02, see Färe and Grosskopf (2000).

[4] This is the same approach as the one taken by Bruvoll et al. (2003).

[5] The data covers the time period 1992 to 2000, see Bruvoll et al. (2003) and Larsson and Telle (2003) for further documentation. Data on greenhouse gases are estimated using disaggregated data (from Statistics Norway 2003c) on consumption of various energy carriers within each plant, and the carrier specific emission coefficients used by Flugsrud et al. (2000). We lack data for some smaller plants. The analysis is restricted to these four industries because the data quality is generally lower for other, less regulated, industries.

[6] NACE 21.1, 27.421, 27.35, and 24.13, respectively.

2000, the plants in our samples cover about 90 percent of the production, material and man hours of the four industries, and about 95 percent of the energy use.

Output, intermediate inputs and capital are deflated to 1992 NOK. Labor is the number of man hours. Two pollutant aggregates are included. *Greenhouse gases* is an aggregate of carbon dioxide (CO_2), methane (CH_4) and nitrous oxygen (N_2O), measured in tons of CO_2-equivalents. *Acidifying substances* is an aggregate of sulfur dioxide (SO_2), nitrogen oxides (NO_x) and ammonium (NH_3), measured by the acidifying component.

Table 1 presents summary statistics for the variables used in the regression analysis. Average of the logarithm of productivity growth is positive regardless of measure, indicating productivity growth. On average, the growth rate is higher for the traditional measure (MI) than for the environmentally sensitive one (EMI)[7]. The mean of the *Stringency* variable is about 0.7, revealing that on average the plants in the sample where inspected 0.7 times a year. About a quarter of the observations stems from the Ferro and Chemicals industry, 17 percent from the Aluminum industry, and about a third from the Pulp and Paper industry.

Table 1: Summary statistics (N=332)

Variable	Mean	Std Dev
Log EMI	0.013	0.25
Log MI	0.019	0.13
Stringency	0.69	0.46
Log capital	13.7	1.08
Aluminium	0.17	0.38
Ferro	0.25	0.43
Chemicals	0.25	0.44
Pulp and paper	0.33	0.47

3 Results

3.1 Estimation results

As mentioned in the introduction, it is not clear whether we should expect a positive or negative relationship between our measure of regulatory stringency and productivity growth, i.e. whether b in (1) is

[7] See the appendix for a closer presentation of development of MI and EMI.

positive or negative. Nevertheless, since EMI also credits a firm for emission reductions, it seems reasonable to expect a more positive (or a less negative) relationship between environmental regulations and productivity growth for EMI than for MI.

The results of the regression on (1) are presented in Table 2 for EMI as the dependent variable. The effect of enforcement on EMI is positive. EMI increases if the plant was inspected one period ago, and the effect is statistically significant. We note that this holds in all the regressions. From the results of the fixed and random effect model 2, we also find a positive relationship between inspections two or three periods ago and productivity growth. However, the effect seems to decline over time - both the coefficient and the significance level falls as the lag increases. For the third lag, the effect is no longer statistically significant. We note that the main result (regarding *Stringency*) do hardly vary between the preferred (cfr. Hausman tests in Table 2) fixed effect models and the random effect models.[8] The results of the regression of EMI support a view that there is a positive relationship between stringency of enforcement and productivity growth.

Table 3 presents the results of the regression on (1) when MI is the dependent variable. The effect of enforcement on MI is not clear. The sign of the coefficient is different across model specifications. We focus on the two random effect specifications (cfr. Hausman tests in Table 3). When only one lag of the stringency variable is included in the model, the coefficient is negative - a result in line with the conclusion of Gollop and Roberts (1983). However, when three lags are included, they are all positive. In neither cases are the estimated coefficients statistically different form zero. Hence, the result on the relationship between stringency of enforcement and traditional productivity growth (MI) is not conclusive.

These results illustrate how EMI and MI can yield different results. While the analysis on EMI suggests that inspections raise productivity growth, an analysis on MI is inconclusive.

[8] First, one may argue that heteroscedasticity can influence on the level of significance reported in Table 2. To account for this possibility, we performed a GLS (on OLS) estimation on the fixed effect 2 model in Table 2. Although this yielded higher p-values for the coefficients of *Stringency_1* and *_2*, the coefficients remained significant at the .005 and .05 level, respectively. Second, one may argue that the results could be seriously biased by measurement errors in variables like e.g. emissions or capital. In an attempt to take account of this possibility, we performed a GMM estimation (cf. Arellano and Bond 1991) of the fixed effect 2 model in Table 2; allowing for both *Size* and the dependent variable as instruments. This did not change the main qualitative results: The coefficient of *Stringency_1* and *_2* increased and was significant at any conventional level (*Stringency_3* was not significant). The regressions reported in this footnote were performed using PcGive (DPD). All other regressions in the paper were performed using SAS (proc tscsreg).

Table 2: The result of the regressions. Dependent variable is (the logarithm of) EMI (standard errors in parenthesis)

	Fixed effect 1	Random effect 1	Fixed effect 2	Random effect 2
Stringency_1	0.072** (0.34)	0.072** (0.032)	0.12*** (0.040)	0.12*** (0.037)
Stringency_2			0.082** (0.040)	0.074** (0.037)
Stringency_3			0.0051 (0.034)	0.016 (0.032)
Size	0.73*** (0.20)	0.21** (0.11)	0.91*** (0.24)	0.27** (0.13)
Aluminum dummy		-0.18 (0.36)		-0.33 (0.43)
Ferro dummy		0.072 (0.30)		0.067 (0.36)
Chemical dummy		0.22 (0.31)		0.25 (0.37)
F-test of no fixed effects (F-value)	1.47**		1.32*	
Hausman test (m-value)		9.69***		9.89**
Number of observations (i,t)	332 (44, 8)	332 (44, 8)	251 (44, 6)	251 (44, 6)

*,**, and *** indicate significance at the 10, 5 and 1 percent level, respectively.

Table 3: The result of the regressions. Dependent variable is (the logarithm of) MI (standard errors in parenthesis)

	Fixed effect 1	Random effect 1	Fixed effect 2	Random effect 2$^{\Psi}$
Stringency_1	-0.013 (0.018)	-0.0074 (0.016)	-0.00018 (0.023)	0.013 (0.019)
Stringency_2			0.0067 (0.023)	0.0093 (0.019)
Stringency_3			-0.0089 (0.020)	0.0091 (0.017)
Size	0.18* (0.10)	0.20 (0.022)	0.11 (0.14)	0.0023 (0.0098)
Aluminum dummy		-0.0041 (0.065)		-0.014 (0.025)
Ferro dummy		-0.0014 (0.053)		-0.035 (0.022)
Chemical dummy		0.045 (0.055)		-0.0038 (0.023)
F-test of no fixed effects (f-value)	1.28		0.96	
Hausman test (m-value)		2.55		2.05
Number of observations (i,t)	332 (44, 8)	332 (44, 8)	251 (44, 6)	251 (44, 6)

*,**, and *** indicate significance at the 10, 5 and 1 percent level, respectively.

$^{\Psi}$ A negative variance component estimate of -0.01076 was obtained for cross sections during computations. The estimate was set to zero.

4 Conclusion

The present paper provides the first empirical support of a claim that evaluations or recommondations of environmental policies that are based on a traditional measure of total factor productivity can be biased: When using a measure of productivity growth that accounts for emissions, we find a positive and significant relationship between regulatory stringency and productivity growth (EMI). This result is consistent with a view that enforcement stringency raises productivity growth. However, we find no significant relationship between regulatory stringency and a traditional measure of productivity growth (MI).

This paper has investigated one possible aspect of the costs of environmental regulations: reduced growth in total factor productivity. Contrary to what is traditionally claimed, our result indicates that environmental regulations have *not* reduced productivity growth when measured in a way that credits firms for emission reductions.

When a firm allocates resources to abatement activities, this is conventionally believed to reduce productivity measured by ordinary outputs. However, over time the firm may accomplish the same amount of abatement by allocating fewer resources from ordinary production to abatement activities. The main point of the present paper is that this improvement in abatement technology should constitute one element of the firm's overall technical progress. We find that accounting for this element is sufficient to observe a positive relationship between productivity growth and regulatory stringency.

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Comparing MI and EMI

Figure 1 shows the development of MI in the four industries when 1992 servers as base year. All industries experienced growth in traditional productivity from 1992 till 2000. The progress was highest for Chemicals, (49 percent growth), followed by Aluminum (29 percent), Pulp and paper (19 percent), and Ferro (4 percent). This yields annual growth rates varying between about 0.5 and 5 percent.[9]

Previous studies find that ignoring firms' abatement efforts when measuring productivity growth yields lower growth than when such effort is accounted for (Weber and Domazlincky 2001, Färe et al. 2001, Hailu and Veeman 2000, 2001). One single study reaches the opposite conclusion. Bruvoll et al. (2003) investigate productivity growth in the Norwegian Pulp and Paper industry, and find that including emissions of greenhouse gas or acids in the computation *lowers* productivity growth. Figure 1 presents the development of EMI. First, we notice the replication of the results of Bruvoll et al. (2003) for the Pulp and paper industry; [10] EMI declines over the period. Second, that EMI grows less than MI does not seem as unrepresentative as the previous studies may indicate: MI grows more than EMI in the Ferro industry too, and also in the Chemical industry in the early part of the period. Only for the Aluminum industry, our results seems largely in line with previous studies elsewhere; here EMI grows more than MI, especially early in the period.

In general, the comparison of the development of EMI and MI shows that including or disregarding environmental factors when estimating productivity progress matter; however, not as unidirectional as proposed by previous studies elsewhere. Only for Aluminum, EMI has clearly improved more than MI. For the other industries, employing MI, which ignores the actual use of environmental services, tends to overstate, or be fairly similar to, the more environmentally sensitive measure of productivity progress (EMI). This indicates that more research is needed before the effects of including abatement efforts when estimating productivity change can be fully assessed.

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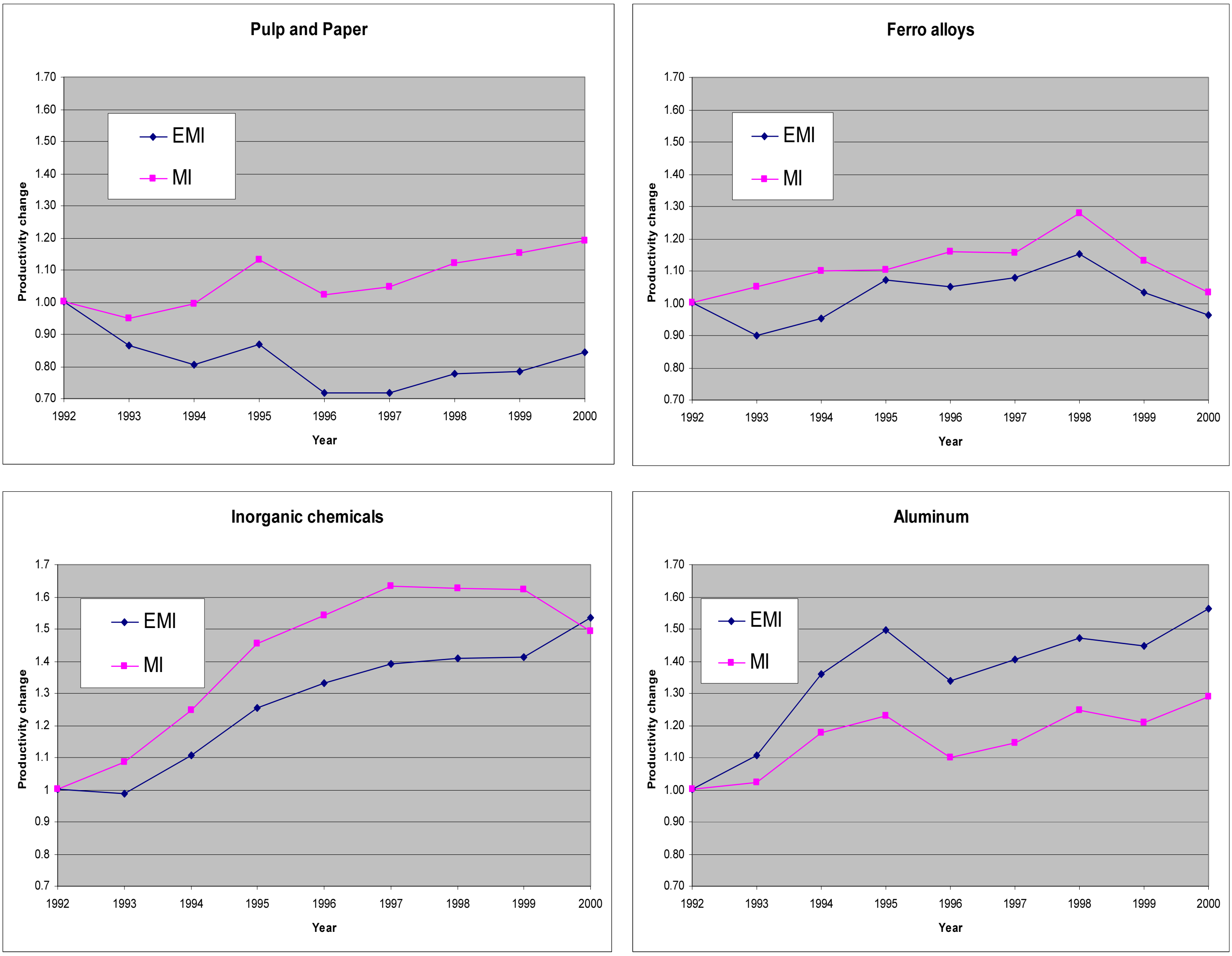
[9] Such annual growth rates are within the range of what is previously found for Norwegian manufacturing industries for the same period (Statistics Norway 2003b), but above the rates found for the 1980s (Møen 1997). Note however, that compared to our distance function approach, these studies apply a very different method to compute total factor productivity.

[10] It is not self evident that we would replicate the result of Bruvoll et al. (2003): First, while Bruvoll et al. (2003) compute EMI by including emission of greenhouse gases and acids *one by one*, we include both in one calculation. This implies slightly different samples in the two studies. Second, to avoid a disproportionate influence from small plants, we weight each plant's productivity with its production when calculating the industry average.

Figure 1: The Malmquist (MI) and environmental Malmquist (EMI) index in the industries (averages of each industry weighted by production). 1992=1



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