Efficiency, productivity and environmental policy: a case study of power generation in the EU*

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Preliminary: please do not quote

This version: June 21, 2010

Abstract

This study explores whether the European Union's CO_2 Emissions Trading Scheme (EU ETS) could provide incentives for the public power plants responsible for about one third of EU-27 CO_2 emissions, to improve their environmental and productive performance. This paper employs an approach for measuring the overall impact of the EU ETS on the public power plants of the EU member states during 1996-2007. Firstly, it measures environmental efficiency and total factor productivity growth taking into account environmental variables. For this purpose, Data Envelopment Analysis is used as the principle methodological base. Secondly, the impacts of the EU ETS and other variables on the environmental efficiency and productivity indicators are estimated by using econometric techniques. Two findings emerge from this analysis: i) the EU ETS had a positive effect on the environmental efficiency and technical change of the public power plants; however, ii) the looseness of this policy reflected in the overallocation of the grandfathered permits led to the deteriorating performance.

JEL Classification: Q41, Q48, Q54, Q58

Keywords: Climate change, Data envelopment analysis, Emissions trading, Power generation, Total factor productivity

1 Introduction

Reducing the risk of catastrophic climatic change requires the stabilization of the concentration of green-house gases (GHGs) to 450-550 parts per million (ppm) of carbon dioxide equivalent - a level considered consistent with an increase in average temperatures not exceeding 3 degrees centigrade (IPCC, 2007). There is little doubt that achieving such a target is a daunting task that requires a complete paradigm shift in the long-run. In particular, the transition towards carbon-free energy sources is paramount if this objective is to be achieved. In the short and medium run, however, an effective climate change

*The authors would like to thank Dr Ian Lange for helpful suggestions. Jūratė Jaraitė is also grateful to the financial support provided by the Irish Research Council for the Humanities and Social Sciences (IRCHSS) and the Irish Research Council for Science, Engineering and Technology (IRCSET).

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mitigation strategy calls for the production of energy in the most efficient possible way. Therefore, the role of mitigation policies is to create incentives to follow carbon reducing practices, to develop and adopt new technologies, and to increase the overall efficiency of power generation. The latter is the focus of this paper.

We study the productive and environmental efficiency of fossil-fuel based public power plants across member states (henceforth MS, for brevity) of the European Union (EU) over the twelve-year period (1996-2007) that spans the ratification of the Kyoto Protocol and the introduction of the European Union's CO_2 Emissions Trading Scheme (EU ETS). The main focus of our analysis is whether there has been any improvement in terms of environmental efficiency and productive performance in the energy generating sector in the EU, and if so, whether it is possible to attribute such changes to climate change mitigation policies, controlling for other contributing factors.

We focus on the EU ETS as it represents the largest cap-and-trade system currently operating in the world, and it constitutes the centrepiece of the EU climate policy. As more efforts are underway to introduce similar policies in other countries, answering the questions posed above is of fundamental importance to inform the debate on the design of effective policies aimed at reducing the carbon footprint of energy generation. The fossil-fuel based power generating sector is also a natural choice as it is the largest sector in the EU ETS, being responsible for roughly one third of GHG emissions in the EU. Power generation is also particularly interesting for other reasons. As discussed by Ellerman et al. (2010) and Widerberg and Wråke (2009), the perception that more low-cost abatement opportunities were available in power generation than in other sectors, and the fact that the sector is not directly exposed to international competition were the main reasons why power generation received relatively fewer allowances than other sectors elsewhere in the EU ETS. This suggests that if any emissions abatement occurred, and efficiency gains were realized, the power generating sector would be a natural place to look for them.

Few studies document the early emissions abatement in the EU ETS. Ellerman and Buchner (2008) and Anderson et al. (2009) provide ex post analyses of the first trading phase of the EU ETS. Ellerman and Buchner (2008) find that between 130-200 Mt of CO_2 were abated in 2005 and 140-220 Mt in 2006 for all EU member states. Anderson et al. (2009) improve on these results using more refined data for 2005-2007 and estimate overall abatement at 247 Mt CO_2 over the entire pilot phase. Delarue et al. (2008) and Widerberg and Wråke (2009) focus explicitly on abatement in power generation. Delarue et al. (2008) analyse the European power sector's CO_2 short-term abatement possibilities through fuel switching. Using both a non-calibrated and a historically calibrated simulation models the authors' estimates of abatement range between 34.4 and 63.6 Mt of CO_2 in 2005, and 19.2 and 35 Mt in 2006. Widerberg and Wråke (2009) look at the effect of the carbon price on the CO_2 emissions intensity of the Swedish electricity sector for the period 2004-2008. They find no statistically significant link between the price of EUAs and CO_2 emissions, and conclude that it is unlikely that there are significant volumes of low-cost CO_2 abatement measures with short response times in the Swedish electricity sector, which might be explained by the peculiar characteristics of the Swedish system.

Our paper contributes to this sparse empirical literature by assessing the impact of the EU ETS on the power generation sectors of 24 European countries. In order to do so, we develop measures of environmental efficiency and total factor productivity (TFP) using Data Envelopment Analysis (DEA) methods. We then use econometric techniques to estimate the effect of the EU ETS (in terms of carbon price and policy stringency at the national level) on both indicators, controlling for other relevant variables. We find that the EU ETS had a positive effect on the environmental efficiency of the European public power generation but that the laxity of the policy, as measured by the degree of overallocation of permits, reduces such positive impact by allowing the use of more carbon intensive fuels. Our results also show that although the EU ETS didn't seem to affect the overall TFP of public power plants, it significantly affects its two components: technological change and technical efficiency change. The EU ETS triggers an upward shift in the power production function, while, the windfall profits from selling the surplus of the allowances encourage the inefficient use of all inputs in power production. Overall, our analysis points out that the theoretical expectations about the first phase of the EU ETS as being performance improving are met through the emissions trading nature of the programme but tend to be softened due to the allocation design.

The rest of the paper proceeds as follows, in Section 2 we present our measures of environmental efficiency and total factor productivity change and briefly discuss the results. Section 3 describes the conceptual framework and the data employed to analyse the determinants of changes in environmental efficiency and TFP over time and presents the results. Finally, Section 4 concludes.

2 Measurement of environmental efficiency and total factor productivity

To measure the environmental efficiency and the total factor productivity of the power generating sector across EU member states, we develop measures based on data envelopment analysis (DEA) techniques. Our use of DEA is dictated by the flexibility and the robustness of this methodology. DEA assigns scores to decision-making units (or, in our case, to entire productive sectors) on a scale between 0 and 1, depending on how efficiently they convert inputs into outputs. In other words, DEA estimates a 'best-practice' frontier given the available information, and then places each observation on or below the frontier, based on its relative efficiency. This has several advantages from our point of view. First, DEA, as a nonparametric method, only needs to assume that the available observations belong to the same production possibility set, which is a prerequisite for comparability, without imposing any additional structure. This is clearly an advantage as the diversity of the power generating industries across the EU with respect to the type of installed technology, the fuel mix, and the extent of cogeneration, for example, would pose serious classification problems within a parametric framework. Secondly, as DEA highlights best rather than average practice, it is better suited to analyse a semi competitive sector such as power generation where average performers may be well in the interior of the production possibility set. The multi-input/multi-output specification of the technology also increases the informational value of the benchmarking, in addition to the avoidance of a priori assumptions on the production possibility set. Thirdly, DEA allows for a variety of substitution possibilities among inputs and outputs that cannot be captured by parametric methods. In particular, by allowing the inclusion of negative outputs like pollution, DEA is extremely useful when discussing environmental performance, given that the same level of efficiency can be achieved by increasing good-outputs or reducing bad ones. Finally, the nonparametric models are easy to compute and most of their statistical properties are well established through use of bootstrap methods.[1]

[1] See Fried et al. (2008) for a thorough review of DEA and other methods of productivity analysis.

2.1 Using DEA to measure relative efficiency

Consider a production process in which desirable and undesirable outputs are jointly produced by consuming inputs. Let $\mathbf{x}$, $\mathbf{y}$ and $\mathbf{u}$ be the vectors of inputs, desirable outputs and undesirable outputs (pollutants), respectively. The production possibility set for this technology is

$$T = \{(\mathbf{x}, \mathbf{y}, \mathbf{u}) | \mathbf{x} \text{ can produce } (\mathbf{y}, \mathbf{u})\}. \tag{1}$$

T provides a complete description of all technologically feasible production plans, and is assumed to be a closed and bounded set, which guarantees output closeness, implying that finite amounts of inputs can only produce finite amounts of outputs. In addition, inputs and desirable outputs are assumed to be strongly disposable. Given the joint production of both desirable and undesirable outputs, we assume null-jointness in production[2] and, at least initially, weak disposability of the undesirable output. The latter assumption proves not to hold in our dataset and we hence opt for strong disposability also for the undesirable inputs in what follows.

Observing a sample of K entities whose environmental efficiency and overall technical efficiency are to be measured, and letting the observed data on inputs, desirable and undesirable outputs be $\mathbf{x}_k$=(x_{1k},...,x_{Nk}), $\mathbf{y}_k$=(y_{1k},...,y_{Mk}) and $\mathbf{u}_k$=(u_{1k},...,u_{Jk}), respectively, (1) can be expressed within a DEA framework as

$$T = \left\{ (\mathbf{x}, \mathbf{y}, \mathbf{u}) \middle| \begin{array}{l} \sum_{k=1}^{K} \lambda_k y_{mk} \geq y_m,\ m = 1, \ldots, M,\ \sum_{k=1}^{K} \lambda_k u_{jk} \leq u_j,\ j = 1, \ldots, J, \\ \sum_{k=1}^{K} \lambda_k x_{nk} \leq x_n,\ n = 1, \ldots, N,\ \lambda_k \geq 0,\ k = 1, \ldots, K \end{array} \right\} \tag{2}$$

Note that the convexity constraint $\sum_{k=1}^{K} \lambda_k = 1$ is not included in the above model, as we assume constant returns to scale (CRS), and that, as discussed above, undesirable outputs are assumed to be strongly disposable. We assume that the returns to scale are constant given that we focus on aggregate data at the sectoral level across different countries over time and assuming variable returns to scale doesn't seem meaningful (See Coelli and Rao, 2005, for a more detailed discussion on this aspect).

On the basis of (2), we introduce the following non-radial DEA-type programming model for calculating the environmental efficiency performance index for entity '0':

$$\begin{aligned} ENV(\mathbf{x}_0, \mathbf{y}_0, \mathbf{u}_0) = \min \quad & \tfrac{1}{J} \textstyle\sum_{j=1}^{J} \theta_j \\ s.t. \quad & \sum_{k=1}^{K} \lambda_k y_{mk} \geq y_{m0},\ m = 1, \ldots, M, \\ & \sum_{k=1}^{K} \lambda_k u_{jk} \leq \theta_j u_{j0},\ j = 1, \ldots, J, \\ & \sum_{k=1}^{K} \lambda_k x_{nk} \leq x_{n0},\ n = 1, \ldots, N, \\ & \lambda_k \geq 0,\ k = 1, \ldots, K; \end{aligned} \tag{3}$$

[2] Null-jointness simply captures the idea that the only way to completely eliminate undesirable outputs is to cease production altogether. Formally, it is defined as: if $(\mathbf{x}, \mathbf{y}, \mathbf{u}) \in T$ and $\mathbf{u} = 0$, then $\mathbf{y} = 0$.

where the λ_k's are coefficients representing the intensity levels for entities in the construction of the reference efficiency frontier. This model can be seen as a Russell-type DEA model in the context of environmental efficiency measurement Färe et al. (1985). Examples of similar models in the context of environmental or energy efficiency measurement include Picazo-Tadeo and García-Reche (2007) and Zhou and Ang (2008).

It is worth noting that (3) non-proportionally adjusts undesirable outputs for given levels of the inputs and the desirable outputs. As a result, it allows some undesirable outputs to increase so that other undesirable outputs achieve larger reductions in order to reach its ideal bench-marking point on the best-practice frontier. Since ENV is essentially the minimum average of the ratios of the expected undesirable outputs to the actual undesirable outputs, we may refer to ENV as an average environmental performance index.

In this programme the input constraints guarantee that, at the optimum, entity '0' will make use of no fewer inputs than the efficient productive entity it is compared with. The desirable output constraints ensure that under its environmentally efficient production plan, entity '0' produces no more desirable outputs than the technological reference at the frontier, while the undesirable output constraints make sure that, at the optimum, entity '0' does not pollutes less than the efficient productive entity it is compared with. The inequality constraints on the desirable-outputs side and on the undesirable-outputs side finally imply that these outputs are freely disposable.

To measure the overall technical efficiency, we make use of the following input-oriented DEA model:

$$\begin{aligned}
ECON(\mathbf{x}_0, \mathbf{y}_0, \mathbf{u}_0) = \min \quad & \theta \\
s.t. \quad & \sum_{k=1}^{K} \lambda_k y_{mk} \geq y_{m0},\ m = 1, \ldots, M, \\
& \sum_{k=1}^{K} \lambda_k u_{jk} \leq \theta u_{j0},\ j = 1, \ldots, J, \\
& \sum_{k=1}^{K} \lambda_k x_{nk} \leq \theta x_{n0},\ n = 1, \ldots, N, \\
& \lambda_k \geq 0,\ k = 1, \ldots, K;
\end{aligned} \tag{4}$$

which attempts to proportionally contract the amount of inputs and undesirable outputs as much as possible for a given level of desirable outputs. Programme (4) adopts a radial efficiency measure, which provides an index of purely technical efficiency for the energy industries.

2.2 Using DEA to measure productivity changes

While (4) measures performance at given points in time, and thus only conveys information as refers to the distance from the frontier (i.e. relative technical efficiency), it is desirable to also have information about the shift of the efficient frontier over time, in order to capture technological change. Several indexes are available to this end, in the present context, however, given the assumption of CRS and the fact that the data support the strong disposability of the pollutants at the aggregate level, we will use the Malmquist productivity index developed by Caves et al. (1982) and extended by Färe et al. (1994). The MPI provides information on TFP over time and makes it possible to decompose TFP changes into the two components mentioned above, namely technical efficiency and technological change.

The input-orientated Malmquist TFP change index between periods s (the base period) and period t is given by[3]

$$M_t^I(y_t, x_t, y_s, x_s) = \left[\frac{D_s^I(y_t, x_t)}{D_s^I(y_s, x_s)} \times \frac{D_t^I(y_t, x_t)}{D_t^I(y_s, x_s)} \right]^{1/2}, \tag{5}$$

where the superscript I indicates an input-orientation, M is the productivity of the most recent production point (x_t, y_t) (using period t technology) relative to the earlier production point (x_s, y_s) (using period s technology), D are input distance functions, and all other variables are as previously defined. Values greater than unity indicate positive TFP growth between the two periods. Following Färe et al. (1994), an equivalent way of writing this productivity index is

$$M_t^I(y_t, x_t, y_s, x_s) = \frac{D_t^I(y_t, x_t)}{D_s^I(y_s, x_s)} \left[\frac{D_s^I(y_t, x_t)}{D_t^I(y_t, x_t)} \times \frac{D_s^I(y_s, x_s)}{D_t^I(y_s, x_s)} \right]^{1/2}, \tag{6}$$

where the ratio outside the square brackets measures the change in the input-oriented measure of technical efficiency between periods s and t. That is the efficiency change is equivalent to the ratio of the technical efficiency in period t to the technical efficiency in period s. The remaining part of the index in equation (6) is a measure of technical change or technical progress as measured by shifts in the frontier measured at period t and period s (the geometric mean of the two ratios in the square bracket).

Given that suitable panel data are available, the distance measures for the Malmquist TFP index can be calculated using DEA-like linear programs as discussed, for example in Färe et al. (1994).

We measure two productivity indices: the first one, which is the focus of our analysis, includes pollutants among the inputs. We call this the environmental TFP change (ENV TFP). The second one omits pollutants and is a conventional-economic TFP change (ECON TFP). By comparing these two measures we can better understand the implications of including pollutants in DEA estimates of productivity. Examples of recent studies employing a similar approach include Färe et al. (2001) and Jeon and Sickles (2004).[4]

2.3 Issues to be considered when estimating DEA models

Before calculating environmental efficiency scores and TFP change, the influence of atypical observations should be tested. We have checked that efficiency scores do not depend upon one or two countries repeatedly enveloping other countries, but rather upon the set of efficient countries. Also, we followed the procedures suggested by Wilson (1995) which allows detecting whether an observation in the efficient subset is really efficient relative to other observations in the sample, and, at the same time, testing how much the presence of this observation in the efficient subset affect the measured efficiency of other observations.

[3]Input-orientation refers to the emphasis on equiproportionate reductions of inputs for a given level of outputs. Note that the subscripts denoting the variety of inputs and outputs are excluded, and that undesirable outputs are treated as inputs.

[4]These studies compare the Malmquist productivity index without undesirable outputs with the Malmquist-Luenberger productivity index that credits a producer for simultaneously reducing the production of the undesirable output and increasing the production of the desirable output. As we assume that pollutants in power generation can be treated as inputs, and we find them strongly disposable, we employ the traditional Malmquist productivity index.

The statistical inference of the nonparametric DEA Malmquist productivity indices is another important aspect which should be considered. Although the nonparametric MPI measures are taken to be deterministic, they measure performance relative to an estimate of the true and unobservable production frontier. Since estimates of the production frontier are based on finite samples, efficiency and productivity measures based on these estimates are subject to sampling variation of the frontier. It is therefore necessary to assess the sensitivity of MPI with respect to the sampling variation by bootstrapping the indices. We apply the bootstrapping algorithm developed by Simar and Wilson (1999) to estimate the sampling distribution and confidence intervals for the Malmquist productivity indices. Simar and Wilson (2008) have the comprehensive discussion about the statistical inference in nonparametric frontier models.

2.4 Variables used to measure environmental efficiency and TFP

The following are some of the main features of the data series used (see Table 1 for descriptive statistics).

Country and time coverage

The study includes 24 EU member states. Cyprus, Luxembourg and Malta are excluded due to unavailability of some data series and due to the fact that these countries are very small compared to other countries in the sample. Results are presented for the period 1996 to 2007.

Output series

We restrict our attention to public power plants - public thermal power plants and district heating plants - that mostly rely on combustible CO_2-intensive fuels, such as oil, solid fuels and gas.[5] Gross electricity generation of public thermal power plants and gross heat production from public thermal power plants and district heating plants is aggregated into one output variable and measured in thousands tonnes of oil equivalent (TOE).

Input series

Given the constraints on the number of input variables that can be used in a DEA analysis, this analysis considers three groups of input variables: labour, fuel inputs, and net installed electrical capacity.

Labour data refers to the economically active population in electricity, water and gas supply industry (ISIC-68, division 4), and is measured in thousands of employees. The more disaggregated data, which could correspond to the number of employees in public thermal power plants and district heating plants, is not available. Therefore, we have made some adjustment for the available labour data (see Appendix A).

Fuel is measured in TOE, and includes all varieties of fuel utilised by the public power plants: coal, oil, gas and renewable fuels. As fuel input data are available in the same measurement units, we aggregated them into one indicator.

Net installed electrical capacity of thermal power plants is measured in Megawatts

[5] According to the Eurostat definitions, public thermal power stations generate electricity and/or heat for sale to third parties, as their primary activity. District heating plants produce heat used for process or space heating in any sector of economic activity including the residential sector. Only heat sold to third parties is included.

Table 1: Descriptive statistics of outputs and inputs

Variable	Unit	Mean	Std. dev.	Min	Max	No. of obs.	Data source
Power generation	TOE	7318	506	569	39679	288	Eurostat
Fuel	TOE	15346	1128	996	89896	288	Eurostat
Installed capacity	MW	15382	1080	569	71072	288	Eurostat, IEA
Labour	No. in thousands	58	4	5	255	288	Euromonitor International
CO_2 emissions	Thousands of tonnes	55214	4245	1910	345673	288	EEA
SO_2 emissions	Thousands of tonnes	241	18	1	1361	280	EEA

(MW).[6] The Eurostat provides the net installed electrical capacity data for thermal power plants only, that is there is no separation between *public* thermal power plants and *autoproducer* thermal power plants. This distinction is made by the IEA, but it is available only for the OECD countries. See an Appendix B for details of how the net installed electrical capacity of thermal power stations is allocated between public thermal power plants and autopoducer thermal power plants for the remaining non-OECD countries in the sample. Generating capacity of power stations is used as a proxy for capital. However, some studies use capital expenditure to find out not only the generating capacity of a plant, but also the extent to which plants have invested in equipment to reduce pollution (Yaisawarng and Klein, 1994). Unfortunately, disaggregated capital expenditure or capital stock data are not available for electricity and heat industry alone. Likewise, it should be noted that the capacity data are not available for district heating plants.

Environmental variables

CO_2 emissions from public electricity and heat production are available from the European Environmental Agency (EEA). According to the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1996), these emissions correspond to a sum of emissions from public electricity generation, public combined heat and power generation, and public heat plants. Public utilities are defined as those undertakings whose primary activity is to supply the public. They may be in public or private ownership. CO_2 are measured in thousands of tonnes.

When measuring environmental efficiency we also take into account SO_2 emissions that influence climate change indirectly. These are available from the EEA and are measured in thousands of tons. SO_2 emissions are not available for Poland and Slovenia for the period 1996-1999.

2.5 Environmental efficiency and TFP measures

2.5.1 Environmental efficiency scores

The average environmental efficiency scores for CO_2 and SO_2 emissions for period 1996 to 2007 are reported in Table 2. The environmental efficiency scores for CO_2 and SO_2 separately are reported in Appendix C in Table 9, and Table 10, respectively. The countries are listed according to the magnitude of the average environmental efficiency scores in 2007. Figure 1 shows an average performance of these scores.

The results suggest that substantial reductions in CO_2 and SO_2 emissions are possible in most of the countries. In 2007, the average CO_2 and SO_2 environmental efficiency is

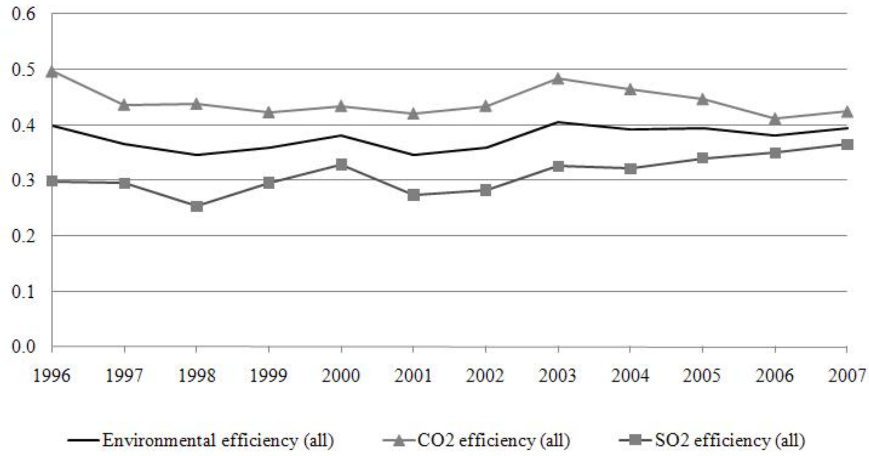
[6]The net capacity is the maximum power assumed to be solely active power that can be supplied, continuously, with all plant running, at the point of outlet to the network.

Table 2: Average environmental efficiency scores, 1996-2007

	Base fuel	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Austria	Other	1.000	0.747	0.935	0.770	0.649	1.000	0.936	1.000	1.000	1.000	0.858	1.000
Finland	Coal	0.526	0.601	0.391	1.000	1.000	0.349	0.384	1.000	1.000	1.000	1.000	1.000
Latvia	Gas	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Netherlands	Gas	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Sweden	Other	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Denmark	Coal	1.000	1.000	0.385	0.373	1.000	1.000	1.000	1.000	0.853	0.865	0.716	0.699
Hungary	Gas	0.186	0.168	0.182	0.162	0.143	0.162	0.183	0.199	0.210	0.337	0.431	0.452
Lithuania	Gas	0.409	0.390	0.335	0.306	0.327	0.345	0.400	0.503	0.469	0.442	0.439	0.431
Italy	Gas	0.216	0.178	0.177	0.155	0.164	0.213	0.248	0.290	0.313	0.365	0.348	0.429
Belgium	Gas	0.223	0.185	0.215	0.235	0.209	0.235	0.267	0.298	0.266	0.260	0.278	0.338
Germany	Coal	0.219	0.186	0.226	0.205	0.215	0.237	0.263	0.303	0.284	0.276	0.263	0.268
United Kingdom	Coal	0.182	0.161	0.171	0.183	0.156	0.165	0.189	0.201	0.197	0.194	0.180	0.205
Slovakia	Coal	0.298	0.231	0.255	0.202	0.150	0.224	0.218	0.247	0.238	0.223	0.195	0.203
Ireland	Gas	0.180	0.142	0.152	0.132	0.128	0.136	0.163	0.199	0.191	0.167	0.171	0.187
Slovenia	Coal	n/a	n/a	n/a	n/a	0.104	0.109	0.123	0.142	0.133	0.129	0.163	0.174
Czech Republic	Coal	0.242	0.207	0.224	0.341	1.000	0.202	0.187	0.209	0.195	0.172	0.153	0.155
Portugal	Coal	0.170	0.139	0.158	0.141	0.129	0.135	0.153	0.167	0.170	0.157	0.145	0.146
Poland	Coal	n/a	n/a	n/a	n/a	0.147	0.146	0.148	0.163	0.154	0.143	0.128	0.129
Estonia	Coal	0.163	0.139	0.149	0.130	0.117	0.127	0.146	0.146	0.146	0.144	0.135	0.127
Spain	Coal	0.132	0.112	0.117	0.101	0.092	0.098	0.113	0.129	0.130	0.129	0.129	0.127
Romania	Coal	0.229	0.194	0.218	0.176	0.153	0.155	0.147	0.162	0.145	0.127	0.118	0.113
Bulgaria	Coal	0.179	0.119	0.137	0.117	0.100	0.104	0.116	0.128	0.118	0.107	0.099	0.097
France	Other	0.079	0.056	0.079	0.083	0.087	0.098	0.115	0.124	0.116	0.107	0.094	0.095
Greece	Coal	0.117	0.092	0.101	0.090	0.083	0.089	0.100	0.108	0.102	0.092	0.089	0.093
Mean		0.398	0.366	0.346	0.359	0.381	0.347	0.358	0.405	0.393	0.393	0.380	0.394
Mean coal-based		0.288	0.265	0.211	0.255	0.318	0.224	0.235	0.293	0.276	0.268	0.251	0.252
Mean gas-based		0.459	0.438	0.437	0.427	0.424	0.442	0.466	0.498	0.493	0.510	0.524	0.548
Mean coal/net long		0.336	0.313	0.238	0.299	0.401	0.268	0.276	0.352	0.330	0.321	0.295	0.294
Mean coal/net short		0.143	0.122	0.130	0.125	0.109	0.115	0.131	0.145	0.141	0.136	0.140	0.150
Mean gas/net long		0.649	0.640	0.629	0.617	0.618	0.627	0.646	0.675	0.670	0.695	0.717	0.721
Mean gas/net short		0.206	0.168	0.182	0.174	0.167	0.195	0.226	0.262	0.256	0.264	0.266	0.318

Note: "Base fuel" shows what fuel was dominant (the share larger than 50%) in fuel mix in 2007.

Figure 1: Mean environmental efficiency scores



0.42 and 0.37, respectively, implying that, on average, it is possible to reduce these air pollutants by a maximum of 58% and 63% while still maintaining inputs and desirable outputs. This potential of emissions reduction in fossil fuel based power generation is confirmed by the statements of the European Commission on that that the largest GHG emission reductions can be achieved in power generating industry: "...the power generation sector is the one, at global scale, that would experience most of the fuel switch [...] due to its relatively high technological flexibility (CEC, 2009, p. 65)."

The environmental efficiency scores vary across countries reflecting the fuel mix (gas vs. coal) used in power generation. For instance, in 2007, the average relative environmental efficiency for gas-based (the share of gas in fuel mix is larger than 50% in 2007) power generation is twice as big as the relative environmental efficiency of coal-based (the share of solid fuels in fuel mix is larger than 50% in 2007) power generation (see Table 2). The average environmental efficiency of gas-based power generation has been increasing since 1996.[7] It visibly improved in the years of the first trading period of the EU ETS, while the opposite is true for coal-based power generating industries.

2.5.2 Malmquist Productivity Index (MPI)

We measure two Malmquist productivity indices: the first index, which is at the centre of this analysis, takes into account CO_2 emissions (ENV TFP), while the second one omits CO_2 emissions (ECON TFP). As we said above, by comparing these two indices we can better understand the implications of including CO_2 emissions in DEA estimates of productivity.

Tables 3 and 4 present the annual ENV TFP and ECON TFP changes for all countries during the 1997-2007 period, respectively (see Tables 11-14 in Appendix D for the technical efficiency changes (hereafter efficiency changes (EC)) and technological changes (TC)). The countries in all tables are presented in the descending order of the magnitude of the twelve-year cumulative ENV TFP and ECON TFP changes in 2007, respectively. The confidence intervals derived from the bootstrap show that the annual changes are

[7] A direct comparison between years is not straightforward, since efficiency scores are relative to the best performing power generating industries in each year. The fact that some of the countries remain on the frontier over the period of interest let us do some comparison like this.

Table 3: ENV TFP annual change and cumulative change for the 24 countries

Country	Base fuel	97-96	98-97	99-98	00-99	01-00	02-01	03-02	04-03	05-04	06-05	07-06	Cumulative 1996-2007
Finland	Coal	0.944*	0.955*	1.111*	1.001*	1.134*	1.060*	1.213*	0.972*	0.887*	1.205*	1.018*	1.547
Sweden	Other	1.030*	1.064*	0.998*	1.018*	1.103*	1.053*	0.950*	1.029*	1.027*	1.018*	0.991*	1.308
Slovakia	Coal	0.915*	1.133*	0.957*	1.037*	1.282*	0.992*	1.036*	0.979*	0.986*	0.944*	1.047*	1.293
Portugal	Coal	1.010*	1.234*	1.221*	0.925*	0.968*	1.142*	0.807*	1.078*	1.164*	0.854*	0.950*	1.277
Spain	Coal	1.159*	1.040*	1.140*	1.041*	0.933*	1.132*	0.814*	1.019*	1.044*	0.976*	0.998*	1.277
Netherlands	Gas	1.048*	1.078*	0.991*	1.013*	1.054*	1.003*	1.019*	1.034*	1.029*	0.936*	1.018*	1.238
Italy	Gas	1.003*	1.002*	0.990*	0.940*	1.175*	1.049*	0.954*	1.146*	0.979*	1.000*	0.997*	1.231
Belgium	Gas	0.979*	1.008*	1.124*	1.003*	0.966*	1.114*	0.956*	1.003*	0.987*	1.026*	1.031*	1.199
Greece	Coal	1.014*	1.091*	0.957*	1.131*	1.045*	0.943*	0.980*	1.000*	0.917*	0.998*	1.093*	1.156
Austria	Other	0.963*	1.040*	1.012*	0.975*	1.141*	0.971*	1.035*	1.009*	1.064*	0.979*	0.951*	1.135
United Kingdom	Coal	0.992*	1.029*	1.104*	1.002*	1.000*	1.030*	1.000*	0.967*	0.993*	0.986*	1.022*	1.124
Germany	Coal	0.968*	1.041*	0.961*	1.005*	1.052*	0.960*	1.071*	1.014*	1.034*	0.983*	1.032*	1.120
Estonia	Coal	0.993*	0.919*	0.998*	1.010*	1.172*	1.041*	1.079*	0.935*	1.039*	0.981*	0.951*	1.098
Slovenia	Coal	1.075*	1.115*	0.963*	0.959*	0.910*	1.057*	1.033*	1.000*	1.007*	1.010*	0.979*	1.095
Hungary	Gas	1.014*	1.039*	1.043*	0.925*	1.033*	0.946*	1.057*	0.974*	1.023*	0.989*	1.019*	1.055
Ireland	Gas	1.038*	1.012*	1.088*	1.011*	1.045*	0.854*	0.996*	1.005*	0.940*	1.034*	0.985*	0.989
Czech Republic	Coal	0.983*	0.974*	0.966*	1.092*	1.004*	0.956*	1.052*	0.981*	0.968*	0.977*	1.039*	0.985
Lithuania	Gas	1.019*	0.956*	0.967*	0.979*	1.000*	1.021*	1.012*	0.969*	0.983*	1.038*	1.026*	0.966
France	Other	0.926*	1.019*	1.036*	0.950*	0.985*	1.040*	1.002*	1.004*	1.113*	0.906*	0.985*	0.949
Poland	Coal	0.956*	0.979*	0.968*	0.972*	1.024*	0.970*	1.034*	1.008*	0.994*	1.019*	0.972*	0.898
Bulgaria	Coal	0.783	0.968*	0.952*	0.974*	0.897*	0.979*	1.091*	0.988*	1.013*	1.037*	1.246*	0.870
Romania	Coal	1.063*	0.997*	0.930*	1.000*	0.999*	0.959*	0.992*	0.981*	1.014*	0.967*	0.961*	0.867
Latvia	Gas	1.006*	0.936*	0.901*	0.961*	1.080*	0.949*	1.036*	0.935*	1.014*	1.034*	0.986*	0.837
Denmark	Coal	0.886*	0.817*	1.044*	1.086*	1.067*	1.012*	1.083*	0.864*	0.942*	1.096*	0.956*	0.818
Mean		0.990	1.019	1.018	1.000	1.045	1.010	1.013	0.996	1.007	1.000	1.011	1.097
Mean new MS		0.981	1.002	0.965	0.991	1.040	0.987	1.042	0.975	1.004	1.000	1.023	0.997
Mean old MS		0.997	1.031	1.056	1.007	1.048	1.026	0.991	1.010	1.008	1.000	1.002	1.169
Mean coal-based		0.981	1.021	1.020	1.017	1.035	1.017	1.020	0.985	1.000	1.002	1.019	1.102
Mean gas-based		1.015	1.004	1.015	0.976	1.050	0.991	1.004	1.010	0.993	1.008	1.009	1.074
Mean coal/net long		0.950	1.002	1.011	1.010	1.060	1.007	1.046	0.980	1.004	1.006	1.017	1.077
Mean coal/net short		1.060	1.069	1.041	1.033	0.972	1.040	0.957	0.997	0.990	0.993	1.023	1.163
Mean gas/net long		1.022	1.002	0.976	0.970	1.042	0.980	1.031	0.978	1.012	0.999	1.012	1.024
Mean gas/net short		1.007	1.007	1.067	0.985	1.062	1.006	0.969	1.052	0.969	1.020	1.004	1.140

Note: * denotes significant differences from unity at 0.01. "Base fuel" shows what fuel was dominant (the share larger than 50%) in fuel mix in 2007.

significant for most of the countries.

Figure 2 below shows the mean cumulative TFP measures and their components - TC and EC during 1996-2007. On average, the ENV TFP change and ECON TFP change in the European public power generating industry were positive: the average twelve-year cumulative ENV TFP growth across all countries is 9.7% (0.8% per annum). When CO_2 emissions are excluded from this measure, the average cumulative growth across all countries is 8.5% (0.7% per annum) - slightly lower than CO_2 emissions are taken into account. This occurs because the DEA TFP measure without CO_2 emissions capture the benefits in terms of lower input use, but not the benefits in terms of lower pollution. Both, EC and TC almost equally contributed to these productivity improvements. The difference between ENV EC and ECON EC is negligible, therefore, the TC component explains the disparity between ENV TFP and ECON TFP: the cumulative twelve-year ENV TC change (5.5%) is higher than the cumulative ECON TC change (4.3%).

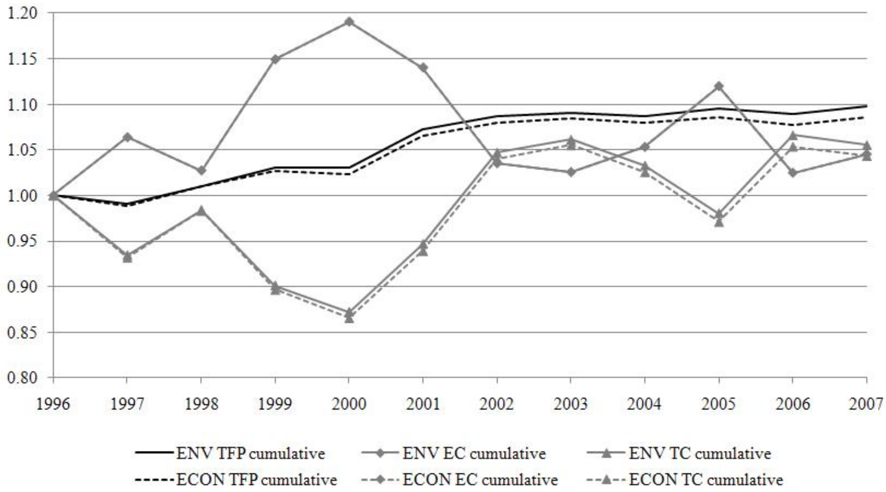
The similarity between ENV TFP and ECON TFP can be explained by the fact that fuel use in power generation expressed in energy units (in TOE, in our case) partly reflects CO_2 content of fuels. For example, natural gas is more energy and CO_2 emissions efficient, while coal is less energy and CO_2 emissions efficient. However, this symmetrical relationship between energy content and CO_2 emissions is not true for bio-renewable fuels which are less energy efficient, but more CO_2 efficient (or even treated as CO_2-free).

Table 4: ECON TFP annual change and cumulative change for the 24 countries

Country	Base fuel	97-96	98-97	99-98	00-99	01-00	02-01	03-02	04-03	05-04	06-05	07-06	Cumulative 1996-2007
Finland	Coal	0.944*	0.955*	1.111*	1.001*	1.134*	1.060*	1.213*	0.970*	0.887*	1.205*	1.018*	1.543
Slovakia	Coal	0.913*	1.133*	0.957*	1.043*	1.281*	0.992*	1.036*	0.979*	0.986*	0.944*	1.047*	1.296
Portugal	Coal	1.010*	1.234*	1.221*	0.925*	0.970*	1.142*	0.807*	1.078*	1.164*	0.854*	0.950*	1.279
Spain	Coal	1.159*	1.040*	1.140*	1.041*	0.933*	1.132*	0.814*	1.019*	1.044*	0.976*	0.998*	1.277
Netherlands	Gas	1.048*	1.078*	0.991*	1.013*	1.054*	1.003*	1.019*	1.034*	1.029*	0.936*	1.018*	1.238
Italy	Gas	1.003*	1.002*	0.990*	0.940*	1.174*	1.049*	0.954*	1.147*	0.979*	1.000*	0.997*	1.231
Belgium	Gas	0.979*	1.008*	1.124*	1.003*	0.966*	1.114*	0.956*	1.003*	0.987*	1.026*	1.031*	1.199
Greece	Coal	1.014*	1.091*	0.957*	1.131*	1.045*	0.943*	0.980*	1.000*	0.917*	0.998*	1.093*	1.156
Austria	Other	0.963*	1.040*	1.012*	0.975*	1.141*	0.971*	1.035*	1.009*	1.064*	0.979*	0.951*	1.135
United Kingdom	Coal	0.992*	1.029*	1.104*	1.002*	1.000*	1.030*	1.000*	0.967*	0.993*	0.986*	1.022*	1.124
Germany	Coal	0.968*	1.041*	0.961*	1.005*	1.052*	0.960*	1.071*	1.014*	1.034*	0.983*	1.032*	1.120
Estonia	Coal	0.993*	0.919*	0.998*	1.010*	1.172*	1.041*	1.079*	0.935*	1.039*	0.981*	0.951*	1.098
Slovenia	Coal	1.075*	1.115*	0.963*	0.959*	0.910*	1.057*	1.033*	1.000*	1.007*	1.010*	0.979*	1.095
Sweden	Other	0.998*	1.096*	0.935*	0.970*	1.097*	1.080*	0.956*	1.020*	0.990*	0.954*	0.998*	1.081
Hungary	Gas	1.014*	1.039*	1.043*	0.925*	1.033*	0.946*	1.057*	0.974*	1.023*	0.989*	1.019*	1.055
Ireland	Gas	1.038*	1.012*	1.088*	1.011*	1.045*	0.854*	0.996*	1.005*	0.940*	1.034*	0.985*	0.989
Czech Republic	Coal	0.983*	0.974*	0.966*	1.094*	1.004*	0.956*	1.052*	0.981*	0.968*	0.977*	1.039*	0.987
Lithuania	Gas	1.019*	0.956*	0.967*	0.979*	1.000*	1.021*	1.012*	0.969*	0.983*	1.038*	1.026*	0.966
France	Other	0.926*	1.019*	1.036*	0.950*	0.985*	1.040*	1.002*	1.004*	1.113*	0.906*	0.985*	0.949
Poland	Coal	0.956*	0.979*	0.968*	0.972*	1.024*	0.970*	1.034*	1.008*	0.994*	1.019*	0.972*	0.898
Bulgaria	Coal	0.783*	0.968*	0.952*	0.974*	0.897*	0.979*	1.091*	0.988*	1.013*	1.037*	1.246*	0.870
Romania	Coal	1.063*	0.997*	0.930*	1.000*	0.999*	0.959*	0.992*	0.981*	1.014*	0.967*	0.961*	0.867
Denmark	Coal	0.885*	0.817*	1.044*	1.086*	1.067*	1.012*	1.083*	0.864*	0.942*	1.096*	0.956*	0.817
Latvia	Gas	0.986*	0.936*	0.888*	0.951*	1.080*	0.943*	1.036*	0.916*	1.012*	1.034*	0.986*	0.778
Mean		0.988	1.020	1.015	0.998	1.044	1.011	1.013	0.994	1.005	0.997	1.011	1.085
Mean new MS		0.978	1.002	0.963	0.991	1.040	0.986	1.042	0.973	1.004	1.000	1.023	0.991
Mean old MS		0.995	1.033	1.051	1.004	1.047	1.028	0.992	1.010	1.006	0.995	1.002	1.153
Mean coal-based		0.981	1.021	1.020	1.017	1.035	1.017	1.020	0.985	1.000	1.002	1.019	1.102
Mean gas-based		1.012	1.004	1.013	0.975	1.050	0.990	1.004	1.007	0.993	1.008	1.009	1.065
Mean coal/net long		0.950	1.002	1.011	1.011	1.060	1.007	1.046	0.980	1.004	1.006	1.017	1.077
Mean coal/net short		1.060	1.069	1.041	1.033	0.972	1.040	0.957	0.997	0.990	0.993	1.023	1.163
Mean gas/net long		1.017	1.002	0.972	0.967	1.042	0.979	1.031	0.973	1.012	0.999	1.012	1.009
Mean gas/net short		1.007	1.007	1.067	0.985	1.061	1.006	0.969	1.052	0.969	1.020	1.004	1.140

Note: * denotes significant differences from unity at 0.01. "Base fuel" shows what fuel was dominant (the share larger than 50%) in fuel mix in 2007.

Figure 2: Mean cumulative TFP change, efficiency change and technical change



Finland, Slovakia, Portugal and Spain have experienced the biggest growth in ENV TFP and ECON TFP since 1996. The cumulative twelve-year ECON TFP measures for these countries do not differ much from the ENV TFP measures. This is not true for Sweden where ENV TFP of public power plants has grown by 30.8% since 1996, while ECON TFP - only by 8.1%. This is explained by the fact that, in Sweden, the share of renewable energy and bio fuels has increased from approximately 38% in 1996 to 74% in 2007. Denmark, Finland, Italy and Latvia are the other countries where the twelve-year cumulative ENV TFP change is higher than the corresponding ECON TFP change.

Tables 3 and 4 also indicate country variation in the TFP indices. There appears to be significant country variation. We can clearly observe that most of the ENV TFP and ECON TFP improvements occurred in the EU-15 member states (the average cumulative ENV TFP and ECON TFP growth of 16.9% and 15.3%, respectively) rather than in the new MS (on average, ENV TFP and ECON TFP did not increase in these countries).[8] From one side, this might reflect the fact that in some new MS public power generation is based on gas (Hungary, Latvia and Lithuania) meaning that these countries are already on or close to the frontier. On the other hand, this might mirror the different structure and developments of power markets between the EU-15 MS and the new MS. The regulated power markets in some new EU MS might not provide enough incentives to increase productivity. For example, the Baltic states, Hungary, Poland persist in maintaining the co-existence of a regulated end-user prices for electricity (CEC, 2008). Whereas, Jamasb and Pollitt (2005) conclude that electricity market opening in the EU-15 countries led the productivity of electricity companies to increase.

The developments of the average cumulative ENV TFP and ECON TFP measures presented in Figure 2 reveal that the major improvements in ENV TFP and ECON TFP occur during 1999-2002. As said above, this can be solely attributed to the EU-15 member states. The dynamics of cumulative ENV TC and ECON TC signify that there have been periods of technological progress (an upward shift in the frontier technology) and technological regress (an inward shift in the frontier technology) since 1996. As short-term and long-term fuel switching is incorporated by using fuels and capacity as one of the inputs in

[8]The EU-15 MS are the countries which were in the EU before 2004, the new MS are the countries which accessed the EU in 2004 or 2007.

power generation, it is not surprising to see these dynamics. In addition to that, the fact that a set of countries, responsible for shifting the frontier, changes over time can explain the dynamics of both, the technological change and efficiency change, components.[9]

The main implication of this ENV TFP and ECON TFP comparison is that, in the context of the increasing regulation of power generation, pollutants should be taken into account when measuring the productivity of public power plants. Therefore, the below analysis, on variation in TFP, focuses on the productivity measure which takes into account the CO_2 emissions, although we provide the results for ECON TFP too.

3 Analysis of environmental efficiency and TFP

3.1 Factors of environmental efficiency and TFP

Many factors can explain the variation in the environmental efficiency measures and TFP growth. They can be broadly grouped into five categories: (1) fossil fuel abundance; (2) the technological characteristics such as fuel mix and technology used; (3) the dynamics of fossil fuel prices; (4) economic growth; and (5) the participation in climate policies directed to mitigate pollution.

The tremendous variation in fossil fuel abundance across countries is presumed to be one of the principal causes that explains the dominance of the technology and fuels in public power generation. Usually, fossil fuel abundance is associated with inefficiencies. For instance, Hoffmann and Voigt (2009) analyse an effect of resource abundance on a efficiency of hard coal fueled electricity generation, which is measured as a ratio of electricity and thermal output to hard coal input. Their empirical results suggest that the more hard coal resources a country possesses, the less efficient is its electricity generation.

Fossil fuel abundance or an access to fossil fuel resources determines a choice of fuel mix and technology of public power generation. The gas-based power generation is more efficient in terms of emissions and energy than coal or oil based power generation (Graus and Worrell, 2009). Likewise, the dominance of the specific power generation technology might also explain the environmental and productivity differences in power generation across countries. Countries that specialise in public power generation could be more productive than countries that produce only a small share of power by public power plants. Also we expect that the higher share of cogeneration (CHP) leads to more productive exploitation of resources. CHP typically converts 75-80% of the fuel source into useful energy. In contrast, in conventional separate electricity and heat generation, overall efficiency is only 60% (IEA, 2008).

The fuel choice in public power plants responds to the changes in fuel prices. Fuel costs account for approximately 40% of power generating costs for coal-fired power plants and 60% for gas-based power plants (Graus and Worrell, 2009). According to this, to meet the power demand at the lowest cost, power plants are ranked following a merit order. The variation in fuel prices is an incentive to both short-term fuel switching and installation of new technologies. If public power sector has a possibility to switch to more energy efficient and less-dirty fuels in the short run, we can expect the environmental efficiency and productivity improvements. While the gains from installing new

[9] Although, based on the set of criteria defined by Färe et al. (1994) and used by Färe et al. (2001) and Zhou et al. (2010), it is possible to exactly identify which and when countries were the "innovators", we do not do that as this is not a focus of our analysis.

power generating capacity might be postponed for few years.

Söderholm (2001) considers various short-run fuel substitution possibilities in the Western Europe power generation. Fuel switching can occur within a day in dual- or multi-fuel fired plants if the alternative fuel is available. Also, switching is easy within a firm which owns several power generating units, which burn different fuels. Likewise, he points out that some conversions of electric plants are relatively easy and cheap. An oil-fired plant that is converted to burn gas, or a coal to oil/gas conversion are examples of this. However, all these fuel switching opportunities can be limited. In the current context, climate policies might be one of the reasons.

In the short run, climate policies rearrange production merit order by forcing power generators to take pollutants costs into account. In the long run, they are expected to drive power generation toward less carbon-intensive technologies (Chen and Tseng, 2008). A CO_2 price of 20€/t adds roughly 40% to power generating costs for coal and 20% to power generating costs for gas (Graus and Worrell, 2009). Due to internalisation of the CO_2 emission cost, there might be a possible change in the merit order, for instance, between coal-fired and gas-fired plants. In the case of the EU ETS, the final impact of carbon emission constraints depends heavily on the allocation of the EUAs. For instance, the windfall profits received from selling the surplus of the EUAs or from successfully passing-through the opportunity costs of the EUAs into the final consumer prices could encourage "stickiness" to carbon-intensive fuels and an inefficient use other resources.

Economic growth might affect both environmental efficiency and productivity of power generation in different ways. Firstly, it might encourage an adoption of technological innovations and thus implement more sophisticated and more efficient plants, or it might stimulate more efficient employment of resources in order to meet the increasing energy demand. On the other hand, an economic-led increase in energy demand might be met by an utilisation of less efficient peak load capacity. Inflows of foreign direct investments (FDI) might lead to knowledge transfers and thus to knowledge spillowers. In the case of power generation this might initiate the introduction of more productive and more emissions and energy efficient technologies.

3.2 Modelling approach and data sources

3.2.1 Econometric specification for environmental efficiency

To statistically investigate the EU ETS effects on the environmental efficiency of public power generation we estimate a regression model. Until recently a common practice to analyse such relationship was to employ Tobit regression. However, Simar and Wilson (2007) have shown that DEA efficiency coefficients are biased and serially correlated in a complicated, unknown way, which makes Tobit estimators not appropriate methods for inference. Instead they propose to use bootstrapped truncated regression and show its good performance in Monte Carlo experiments.

Here we follow this approach. After inverting the environmental efficiency estimates obtained in the first stage, we perform the truncated maximum likelihood regression analysis.[10] We use the inverted environmental efficiency scores as dependent variable in a truncated regression with a truncation point at 1 to explain environmental efficiency

[10] Then the environmental efficiency scores range from one to positive infinity. The larger the value of the transformed environmental efficiency score the smaller the country's environmental efficiency.

Table 5: Overview of data sources for variables

Group of factors	Variable	Data source
Fossil fuel abundance	Export-TPES ratio	IEA
Technological characteristics	CHP dummy	Eurostat
	Specialisation	Eurostat
	Solid fuel share	Eurostat
	Oil fuel share	Eurostat
	Gas fuel share	Eurostat
Fuel prices	Coal price	Euromonitor International
	Crude oil price	Euromonitor International
	Natural gas price	Euromonitor International
Economic growth	Industrial production index	Eurostat
	FDI to GDP ratio	Eurostat
The EU ETS	CO_2 price	Point Carbon
	Allocation to verification ratio	Community Transaction Log

due to a number of country specific variables:

$$\frac{1}{\theta_k} = z_k \beta + \epsilon_k, \tag{7}$$

where $\frac{1}{\theta_k}$ are left-truncated environmental efficiency indicators, z_k are the sets of explanatory variables. This truncated regression ignores the (unknown) correlation pattern among the residuals ϵ_k. We also include dummies for countries as they are shown to be significantly different from zero after performing Wald test.[11]

As Hoffmann and Voigt (2009), we use a ratio of fossil fuel exports to total primary energy supply (TPES) to represent the fossil fuel abundance. Fossil fuels include coal and coal products, peat, crude oil, natural gas liquids and feedstocks, and natural gas. TPES of a natural resource results from production of the respective resource plus imports, stock changes, and reserves stored in bunkers etc. minus exports.

To measure the extent of gas-based, coal-based and oil-based power generation, respectively, we use a proportion of gas, coal and oil fuel, respectively, in total fuel used in power generation by public power plants. The share of electricity produced by public thermal power plants in total electricity generation is used as a measure of specialisation. In order to account for CHP generation we create a dummy variable, which is equal to 1 if a portion of heat of total power generated by public thermal power plants is more than a third, and 0 if it less than one third.[12]

We use the annual growth rates in the real market prices for coal, crude oil and natural gas.[13] We also want to test the relationship between the prices of fossil fuels and the shares of fossil fuel used in power generation. We include these variables to the model in which they are multiplied. The presence of a significant interaction indicates that the effect of one predictor variable is different at different values of the other predictor variable. That is we believe that increases in certain fuel price will have a bigger effect for

[11]Note that Stata does not allow to perform truncated regression for panel data.

[12]The available data does not give a possibility to distinguish between power produced by traditional power plants and CHP plants. However, it distinguishes the portions of electricity and heat produced by all (traditional and CHP) power plants. Since only CHP produce heat, we use its share in total production of power by all power plants as a proxy of the extent of CHP.

[13]The country-level fossil duel price data was not available for all countries for the period of interest. Delarue et al. (2008) state that the assumption of uniform prices holds for coal and petroleum products, but it might be questioned for natural gas. However, on a longer time frame and considering yearly data, evidence of converging prices throughout Europe can be shown.

industries which rely on the higher share of this fuel.

Growth in industrial production index is used to measure economic growth and a ratio of total economy's FDI inflows to gross domestic product (GDP) is used to measure an extent of foreign knowledge transfers and spillowers.

To represent the EU ETS, we use the average annual CO_2 market price as an indicator of the overall stringency of the EU ETS, while a ratio of the initial permit allocation to verified-actual emissions is used to represent a country-level stringency of the EU ETS.

Table 5 lists the variables and the sources from which the respective data for the variables were retrieved.[14]

3.2.2 Econometric specification for TFP

To explain the TFP change and the dynamics of its components we estimate the linear panel regression equations. After performing a simple F-test, the Breusch-Pagan test and the Hausman test, we select a fixed effects model. We estimate this model for the TFP change, the efficiency change and the technological change separately:

$$MPI_{k,t} = \alpha_k + z_{k,t}\beta + \epsilon_{k,t}, \tag{8}$$

where $MPI_{k,t}$ represents either the TFP change, the efficiency change or the technological change, α_k are the individual country-level effects, z_k are the sets of explanatory variables which are the same as in the environmental efficiency model (see Table 5).

3.3 Results

3.3.1 What factors explain environmental performance differences between power generating industries?

To what extent the latest developments in the environmental efficiency might be attributed to the EU ETS? By simply looking at the environmental efficiency scores for the countries with the net long position of the EUAs and the net short position, respectively, it is difficult to draw any insights. However, we can observe that, on average, the environmental efficiency of the coal-based power generating industries with the net long position of the EUAs (10 out of 14 coal-based power industries) deteriorated in 2005-2007 (see Table 2). This might suggest that the net long positions of the EUAs is a consequence of the overallocation rather than emissions abatement. On average, the environmental efficiency of the remaining 4 coal-based countries (Greece, Slovenia, Spain and the UK) with the net short positions of the EUAs somewhat improved but most of this improvement occurred in SO_2 efficiency rather than CO_2 efficiency (see Tables 9 and 10). The somewhat similar pattern might be observed in the environmental efficiency for gas-based power generating countries with the net long positions of the EUAs: the environmental efficiency for these countries did not improve in 2005-2007, on average. For the countries with the short positions (Belgium, Ireland and Italy) we observe a slight improvement. However, it occurred only in 2007 after a slight deterioration in 2006. This drop might

[14]There are other explanatory variables that may be included. However, a problem we faced is that these additional variables are not available or are incomplete for all the EU member states included in the analysis.

Table 6: Determinants of environmental efficiency

Dep. Var. Environmental efficiency (inverse)	Estimated parameter	Confidence intervals 99% lower	99% upper	95% lower	95% upper
CO_2 price	-0.0316***	-0.0456	-0.0192	-0.0424	-0.0222
Allocation to verification ratio	0.0043***	0.0023	0.0060	0.0030	0.0056
Coal price (log difference)*Coal share	-0.0118***	-0.0217	-0.0031	-0.0188	-0.0045
Crude oil price (log difference)*Crude oil share	0.0426***	0.0237	0.0612	0.0283	0.0570
Natural gas price (log difference)*Natural gas share	0.0081	-0.0041	0.0205	-0.0012	0.0175
Coal price (log difference)	0.5512**	-0.0558	1.2076	0.0889	1.0227
Crude oil price (log difference)	0.1291	-0.3931	0.5853	-0.2244	0.4647
Natural gas price (log difference)	0.4056**	-0.0998	0.8722	0.0582	0.7379
Industrial production index (log difference, lagged)	3.8706***	2.0573	5.2681	2.5557	5.0934
FDI inflow share (lagged)	0.0228***	0.0053	0.0435	0.0094	0.0373
Export-TPES ratio (lagged)	-0.0309***	-0.0449	-0.0187	-0.0409	-0.0225
Specialisation	-0.0341***	-0.0466	-0.0196	-0.0450	-0.0231
CHP dummy	0.0538	-0.4702	0.4389	-0.3287	0.3526
Solid fuel share	0.1049***	0.0597	0.1419	0.0726	0.1308
Oil fuel share	0.1015***	0.0621	0.1346	0.0727	0.1256
Gas fuel share	0.0316	-0.0110	0.0647	-0.0002	0.0574
Constant	-7.5533**	-0.9579	7.5813	0.1106	6.3279
No. of obs.	144				
R-squared	80.6				

Note: 'Truncreg' command in Stata does not produce R^2, thus, we compute a rough estimate of the degree of association by correlating the dependent variable with the predicted value and squaring the result. The variables indicated with **, and *** show significance at 5% and 1% levels, respectively. Greece, Ireland and the Netherlands are dropped from the estimation since some of the data was missing for these countries. The number of the observations does not include the observations at the truncation point.

be supported by the low price of CO_2, while the improvement by the movement to a less emission intensive fuel-mix.

Table 6 displays the estimated parameters and their confidence intervals computed according to the single bootstrapping Algorithm 1 of Simar and Wilson (2007). We analyse whether fossil fuel abundance and fuel prices, technological characteristics, economic growth and the EU ETS have influenced the environmental efficiency of the European public power plants.

Controlling for all factors, and given the fact that the CO_2 price collapsed in the first phase of the EU ETS we find that, with a 99% confidence level, the price of CO_2 statistically and positively influences the environmental efficiency. This is in line with our expectations and confirms the findings of the earlier studies mentioned above which show that there was some emissions abatement in the first carbon trading period. The design of the EU ETS - the free allocation of the EUAs - has received most of the criticism. Moreover, many countries received more EUAs than was needed meaning that firms in the EU ETS not only had no incentives to reduce their emissions, but also had room to increase them, for instance, by burning more fuel intensive fuels. Indeed, we find that overallocation, which we measure as the ratio of the allocated EUAs to the verified EUAs, had a negative effect on the environmental performance of the public power plants.

In terms of fossil fuel prices, natural gas and coal price has a negative and significant effect on the environmental efficiency. The increasing price of natural gas and coal might encourage power generation to switch to cheaper but more carbon intensive fuels. However, the coefficient for the interaction term between coal price and solid fuel share is positive. This implies that the increase in coal price have the higher positive impact on the environmental efficiency the larger the share of coal-based power generation.

Apparently, the EU member states that rely on coal-based power generation have a potential to substitute for more CO_2-friendly fuels. The interaction term between the price of crude oil and the share of oil used in power generation is also significant but negative: the increase in crude oil price have the higher negative impact on the environmental efficiency the larger the share of oil-based power generation. This might suggest that a major switch from oil based power generation to less carbon-friendly fuels happens only in the countries where the share of oil-based power generation is solid. In most of the EU countries, the share of oil-based power generation has been declining and in most of the cases the oil-based power generating capacity is utilised as a peak-load capacity rather than a base-load capacity.

The coefficients for economic growth variables are negative. The negative coefficient for industrial production growth confirms our expectations about the possibility that the economic-led increase in energy demand can be met by the utilisation of less efficient power generating capacity. In this case it is inefficient in terms of CO_2 emissions. The negative coefficient for the total economy's FDI inflow is probably reflecting the consequences of economic growth too rather than technology transfers and spillowers.

The estimated parameter for resource abundance has a significant and positive sign - opposite than expected - meaning that the more fossil fuel resource abundant country is the more environmentally efficient it is. It might suggest that fuel abundant countries utilise more advanced power generation technologies in terms of emissions. Likewise, fuel abundant and rich countries might have more pressures from the society to upgrade their technologies if it is clear that fossil fuel based power generation will be brought in the future.

The coefficient for specialisation in thermal power production is significant and positive. This is in line with our expectations that the thermal power production is more efficient the larger its share in the overall country's power production. We can illustrate this argument with the following example. In France, where most of the power is produced by the nuclear power plants and the share of electricity produced by thermal power plants is around 7% (EU-24 average is near 60%), the environmental efficiency of public thermal power generation is the lowest after Greece in the EU-24. The low dependence on thermal power generation does not provide sufficient incentives to improve the performance of thermal power plants at national level.

The coefficients for the share of solid and oil fuels are negative and significant in explaining the environmental efficiency scores. The countries with the large share of coal- and oil-based power generation are less environmentally efficient.

3.3.2 Analysis of variation in total factor productivity

Could we explain any recent developments of the ENV TFP change and its components by the EU ETS? An increase in ENV EC in 2006 might be attributed to oil and gas price increases and to the existence of the EU ETS. However, the dynamics of the ENV TFP change and its components, differently than in the case of environmental efficiency, do not differ much between the countries with the net long positions of the EUAs and the countries with the net short positions (see Tables 3, 11 and 12). Only gas-based power industries with the net short positions of EUAs experienced a positive ENV TFP change in 2006 and 2007, while, at the same time, technical regress occurred for the gas-based industries with EUAs surplus. When we look at the annual ENV TFP changes country by country, we observe that the ENV TFP growth was positive for the countries with the

Table 7: Determinants of ENV TFP change and its components

	Model (1) ENV TFP	Robust s.e.	Model (2) ENV EC	Robust s.e.	Model (3) ENV TC	Robust s.e.
CO_2 price	0.0006	0.0007	-0.0023**	0.0010	0.0029***	0.0010
Allocation to verification ratio	-0.0003***	0.0001	-0.0000	0.0001	-0.0002**	0.0001
Coal price (log difference)*Coal share	-0.0010	0.0007	0.0004	0.0008	-0.0013***	0.0004
Crude oil price (log difference)*Crude oil share	-0.0009	0.0014	-0.0011	0.0022	0.0002	0.0020
Natural gas price (log difference)*Natural gas share	0.0011	0.0011	0.0006	0.0010	0.0005	0.0011
Coal price (log difference)	0.0315	0.0436	-0.0087	0.0556	0.0407*	0.0218
Crude oil price (log difference)	0.0038	0.0453	0.1985***	0.0582	-0.1951***	0.0542
Natural gas price (log difference)	-0.0331	0.0500	-0.0034	0.0562	-0.0302	0.0390
Production index (log difference, lagged)	0.3223**	0.1345	0.6241***	0.2077	-0.3034*	0.1642
FDI inflow share (lagged)	0.0024*	0.0013	-0.0024	0.0023	0.0047**	0.0017
Export-TPES ratio (lagged)	0.0032***	0.0010	0.0018*	0.0010	0.0013***	0.0004
Specialisation	0.0078***	0.0020	0.0071**	0.0031	0.0008	0.0018
Solid fuel share	0.0005	0.0018	0.0005	0.0020	0.0000	0.0011
Oil fuel share	0.0010	0.0017	0.0015	0.0022	-0.0005	0.0016
Gas fuel share	0.0002	0.0011	-0.0003	0.0018	0.0005	0.0015
CHP dummy	-0.0464*	0.0236	-0.1265***	0.0397	0.0802***	0.0230
Constant	-0.4417**	0.1636	-0.3673	0.2373	-0.0742	0.1533
No. of obs.	181		181		181	
R-squared	0.28		0.26		0.33	

Note: The dependant variables are in logs. Standard errors are displayed in italics. Variables indicated with *, ** and *** show significance at 10%, 5% and 1% levels, respectively. Greece, Ireland and the Netherlands are dropped from the estimation since some of the data was missing for these countries.

net short positions of the EUAs. For instance, in Belgium, the annual ENV TFP growth was 2.6% and 3.1% in 2006 and 2007, respectively. In 2006, this growth was driven by EV TC, while, in 2007, by ENV EC. The larger improvements in ENV TFP in the first phase of the EU ETS also occurred for the countries with the net long positions of the EUAs, such as Bulgaria, Finland, Germany and Lithuania. However, the answer to the question whether these improvements were induced by the EU ETS or other factors is not that straightforward, and is answered by performing regression analysis.

Tables 7 and 8 summarise the estimation results for ENV TFP and ECON TFP and their components. Although, the results somewhat differ between ENV TFP and ECON TFP, we place more emphasis on the results for the productivity measures that take into account CO_2 emissions.

For the ENV TFP growth CO_2 price has an insignificant effect, while it is significant in the ENV EC model and the ENV TC models. The sign in the ENV EC model is negative, while in the ENV TC model it is positive. This shows that the presence of the EU ETS encouraged an inefficient use of the existing resources in power generation. This would be true for the countries that could generate profits from selling the surplus of the EUAs. For instance, Sijm et al. (2006) show that at a CO_2 price of 20€/t, EU ETS induced windfall profits in the power sector in the Netherlands are estimated at €300-600 million per year. In the ENV TC model the coefficient for CO_2 price is positive and significant meaning that CO_2 price, despite its variation in 2005-2007, has played an important role in shifting upwards the production function of power generation. Given the dynamics of ENV TC described above, we believe that most of this positive technical change might be explained by the short-term fuel switching rather than by the adaptation of new technology.

The country-level stringency variable, measured as the ratio of the allocated EUAs to the verified EUAs, had a negative effect on the ENV TFP change and ENV TC. As in the case of the environmental efficiency analysis, the higher initial permit allocation relative

Table 8: Determinants of ECON TFP change and its components

	Model (4) ECON TFP	Robust s.e.	Model (5) ECON EC	Robust s.e.	Model (6) ECON TC	Robust s.e.
CO_2 price	0.0011	0.0011	-0.0010	0.0015	0.0021**	0.0010
Allocation to verification ratio	-0.0003	0.0002	0.0004	0.0002	-0.0006***	0.0002
Coal price (log difference)*Coal share	0.0006	0.0006	0.0006	0.0005	0.0000	0.0005
Crude oil price (log difference)*Crude oil share	0.0034	0.0025	-0.0032	0.0030	0.0067***	0.0013
Natural gas price (log difference)*Natural gas share	-0.0002	0.0008	-0.0005	0.0011	0.0002	0.0007
Coal price (log difference)	-0.0663*	0.0344	0.0288	0.0261	-0.0951***	0.0326
Crude oil price (log difference)	-0.0730	0.0640	0.2368***	0.0629	-0.3098***	0.0476
Natural gas price (log difference)	0.0231	0.0407	0.0174	0.0511	0.0056	0.0429
Production index (log difference, lagged)	0.1692	0.1412	0.6868***	0.2291	-0.5166***	0.1467
FDI inflow share (lagged)	-0.0019	0.0021	-0.0039	0.0025	0.0020	0.0018
Export-TPES ratio (lagged)	-0.0010**	0.0005	-0.0012	0.0008	0.0002	0.0005
Specialisation	0.0036*	0.0018	0.0042*	0.0023	-0.0006	0.0011
Solid fuel share	-0.0002	0.0027	0.0034	0.0023	-0.0036*	0.0019
Oil fuel share	0.0012	0.0025	0.0069**	0.0026	-0.0057***	0.0017
Gas fuel share	0.0018	0.0028	0.0057**	0.0024	-0.0039**	0.0017
CHP dummy	0.0129	0.0602	-0.0527**	0.0200	0.0657	0.0454
Constant	-0.2113	0.2771	-0.6336**	0.2930	0.4238**	0.1692
No. of obs.	181		181		181	
R-squared	0.13		0.31		0.45	

Note: The dependant variables are in logs. Standard errors are displayed in italics. Variables indicated with *, ** and *** show significance at 10%, 5% and 1% levels, respectively. Greece, Ireland and the Netherlands are dropped from the estimation since some of the data was missing for these countries.

to the actual emissions did not encourage the productivity improvements in the pilot phase of the EU ETS. The overallocation allowed the use of less emissions and energy efficient fuels that led to technical regress in the power industry (the same effect is found for ECON TC).

In terms of fossil fuel prices, increases in coal price positively influence ENV TC. The signs are negative and significant for ECON TFP and ECON TC. This might suggest that increasing coal price encouraged switching to cheaper and less carbon intensive, but less energy efficient fossil fuels. The sign is negative and significant for the interaction term between coal price and the share of the solid fuel used in power generation in the ENV TC model. This shows that while switching to more energy efficient and less carbon polluting fuels is easy in the countries with smaller share of solid-fuel based power generation, it does not happen with ease in the countries where power production mainly relies on solid fuels. For instance, in Poland the share of solid fuels has remained at 95% since 1996. The negative sign for this interaction might also suggest that, in the periods of increasing demand for power, the countries based on solid-fuel power generation would have to exploit other less efficient solid-fuel based power plants. That the peaks in the power demand might be met by the utilisation of less efficient fuels seems to be confirmed by the negative coefficient for the industrial production index in the ENV TC model. The coefficient for crude oil price is positive in the ENV EC model, but negative in the ENV TC model. This suggest that increasing crude oil price encourages more efficient use of resources in public power production, but, at the same time, it encourages switching to less efficient fuels such as coal.

As mentioned above, the coefficient for the industrial production index growth is negative in the ENV TC model, but it is positive in the ENV TFP change and the ENV EC models. This implies that economic growth increases efficiency of resources used in power generation in order to meet the increasing energy demand. The coefficient for the inflow of FDI is positive and significant in the ENV TFP and the ENV TC models, and, differently than in the case of the analysis of the environmental efficiency scores, supports the hypothesis of foreign technological transfer.

The abundance variable, as in the environmental efficiency model, is significant and positive in all three environmental productivity models and suggests that fossil fuel abundant countries are more likely to experience growth in total factor productivity led by efficiency change and technical change. However, resource abundance has a negative effect in the ECON TFP model. This result confirms the findings of the earlier studies, but, at the same time, shows the importance of including pollutants in productivity measurement.

The coefficient for specialisation in thermal power plants is significant and positive implying that the more power generating industry is specialised the more productive it is. The shares of fuels are not significant in explaining ENV TFP and its components. The coefficient of CHP dummy variable is significant in explaining ENV EC and ENV TC. Though, the signs of these coefficients are different. The sign is negative in the efficiency change equation, while it is positive in the technical change model. The positive coefficient shows that in general CHP plants are more advanced because most of them are gas-based and therefore are more energy efficient and ecological. Also, the new additions to CHP capacity have been more advanced in the last years (Graus and Worrell, 2009).

4 Discussion and conclusions

This paper contributes to the scarce ex post research on the performance of the first phase of the EU ETS. The public power generating sector is the largest scheme's participant that received the most stringent CO_2 permit allocation, and hence, it was expected to deliver most of improvements in terms of CO_2 emissions and overall productivity. However, the first trading period delivered quite mixed results: the market price of CO_2 collapsed after 16 months and there were a number of installations with more allowances than they needed. This could suggest that the EU ETS has not generated any significant reduction of CO_2 emissions and has not improved the overall productivity of the European power generation sector during 2005-2007.

Our findings from the analysis of the environmental efficiency and productivity of fossil-fuel based public power plants across EU member states support both, the EU ETS praising and criticising arguments. We find that, although the emissions trading nature of this European climate change policy was performance improving, the allocation design of the EU ETS - the free allocation of permits - moderated some of these achievements.

Even the unstable carbon price in the first phase of the EU ETS, had the positive impact on the environmental efficiency. However, the overallocation alleviated some of these improvements by "facilitating" the use of more carbon intensive and less energy efficient fuels. We can expect that this latter effect will vanish in the second trading phase of the EU ETS (2008-2012) as most of the power plants are expected to be short of permits. A situation is likely to be exacerbated from 2013 when power generators will need to buy all permits in the auctions to cover their pollutions levels.

The similar findings are in the case of the TFP change that takes into account CO_2 emissions. Although the carbon price did not influence the overall productivity of the public power plants, it had the negative effect on the efficiency change, and the positive impact in the measure of technological change. The inefficient use of the resources in power generation could be encouraged by the windfall profits from selling the surplus of the allowances or from successfully internalising the carbon costs into the consumer prices. We believe that, due to the dynamics of the technological change, most of the occurred technical change in fossil-fuel based public power generation reflects the short-term abatement through fuel switching rather than the long-term abatement achieved through investments in capital stock.

The temporal nature of the technical change is strengthen by the negative effect of country-level stringency variable - the ratio of the allocated to verified emissions - on the technical change and the TFP change. As in the case of the environmental efficiency, the overallocation could encourage switching to dirtier power generation.

The effect of fossil fuel prices also confirms the switching potential in the European public power plants. In addition, in the case of the overall productive performance, we find that this effect is not evident for coal reliant power generation suggesting that for the EU member states, locked-in with coal use, the transition towards cleaner power production might be longer than for countries where coal-based production is not dominant. However, we do not find that fossil fuel resource abundance could encourage the lavish use of these resources and, hence prevent environmental productivity improvements. We find an opposite effect for the productive performance that does not considers CO_2 emissions as one of the production factors. This implies the importance of combining all the relevant indicators into productivity measurement.

The European Commission has recently forecasted that fossil fuels will continue to be one of the main inputs in energy production (CEC, 2009). Thus, the existing and future climate policies including the EU ETS need to ensure that fossil fuels are used as productively as possible. The ultimate goal should be a movement towards frontier, not the one shaped by the already utilised technologies, but the one built from the best available technologies.

A Disaggregation of labour data

The sufficiently disaggregated labour data are not available neither from the public data sources nor from the national statistics offices. The Eurostat, the ILO and the Eurominotor International provide employment data according to the economic activities. The classification of activities is either based on NACE or ISIC classifications. The employment data of our interest is covered under the section Employment in electricity, gas and water supply (a division E, according to the NACE, and a division 4 according to the ISIC). We have decided to adjust these aggregated data by a proportion of electricity and heat generation by public power plants in total electrical energy and derived heat output. This decision is based on the fact that the largest share of employees ascribed to the division E (or 4) belongs to the subdivision Production and distribution of electricity.

We use the employment data from the Euromonitor International as it provides the consistent data series from 1996 to 2007 for all EU member states.

B Adjustment of net installed electrical capacity for 6 (if Malta and Cyprus is excluded) EU member states

The IEA data is used for EU 18 countries. For the rest 6 EU member states (Bulgaria, Estonia, Latvia, Lithuania, Romania, Slovenia) the net installed capacity of *all* thermal power stations is used as a proxy for the net installed capacity of *public* thermal power plants. This data is taken from the Eurostat. This is reasonable as a share of electricity generation of public thermal power plants in electricity generation of all thermal power plants is very high for these countries. We adapt this approach in this paper.

The capacity data for Bulgaria are not available for the period 1996-1997. However, electricity data are available for all period of interest. The electricity generation data suggests that there were no significant variations in the electricity production in 1996 and 1997. We use the capacity data from the first available year (1998) for the missing years.

Table 9: Carbon dioxide efficiency scores, 1996-2007

	Base fuel	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Austria	Other	1.000	0.494	0.870	0.539	0.375	1.000	0.872	1.000	1.000	1.000	0.716	1.000
Finland	Coal	0.523	0.579	0.459	1.000	1.000	0.426	0.458	1.000	1.000	1.000	1.000	1.000
Latvia	Gas	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Netherlands	Gas	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Sweden	Other	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Denmark	Coal	1.000	1.000	0.477	0.439	1.000	1.000	1.000	1.000	0.705	0.729	0.432	0.404
Hungary	Gas	0.347	0.314	0.343	0.309	0.272	0.301	0.338	0.364	0.367	0.381	0.390	0.386
Lithuania	Gas	0.714	0.646	0.608	0.552	0.548	0.572	0.669	0.765	0.735	0.642	0.621	0.646
Italy	Gas	0.343	0.291	0.280	0.246	0.251	0.313	0.345	0.359	0.385	0.361	0.358	0.365
Belgium	Gas	0.307	0.260	0.295	0.290	0.258	0.278	0.300	0.335	0.317	0.289	0.301	0.314
Germany	Coal	0.296	0.247	0.269	0.233	0.200	0.211	0.229	0.260	0.247	0.225	0.215	0.213
United Kingdom	Coal	0.313	0.275	0.295	0.310	0.266	0.270	0.306	0.321	0.301	0.272	0.241	0.253
Slovakia	Coal	0.565	0.440	0.481	0.384	0.253	0.380	0.373	0.423	0.408	0.381	0.331	0.342
Ireland	Gas	0.292	0.242	0.262	0.230	0.216	0.224	0.260	0.300	0.295	0.250	0.247	0.259
Slovenia	Coal	n/a	n/a	n/a	n/a	0.196	0.196	0.221	0.253	0.235	0.217	0.201	0.192
Czech Republic	Coal	0.359	0.308	0.306	0.280	1.000	0.269	0.264	0.297	0.281	0.244	0.218	0.221
Portugal	Coal	0.292	0.243	0.279	0.248	0.229	0.236	0.264	0.279	0.290	0.261	0.236	0.241
Poland	Coal	n/a	n/a	n/a	n/a	0.235	0.237	0.243	0.262	0.256	0.230	0.215	0.213
Estonia	Coal	0.273	0.237	0.255	0.229	0.205	0.220	0.251	0.254	0.250	0.242	0.228	0.217
Spain	Coal	0.244	0.209	0.218	0.188	0.169	0.179	0.207	0.234	0.236	0.232	0.230	0.224
Romania	Coal	0.387	0.338	0.374	0.311	0.270	0.274	0.261	0.288	0.257	0.236	0.218	0.205
Bulgaria	Coal	0.344	0.231	0.265	0.228	0.196	0.203	0.225	0.247	0.228	0.208	0.191	0.187
France	Other	0.124	0.089	0.124	0.130	0.135	0.144	0.163	0.182	0.171	0.153	0.128	0.129
Greece	Coal	0.203	0.161	0.176	0.160	0.145	0.155	0.175	0.191	0.180	0.162	0.156	0.163
Mean		0.497	0.436	0.438	0.423	0.434	0.420	0.434	0.484	0.464	0.446	0.411	0.424
Mean coal-based		0.400	0.356	0.321	0.334	0.383	0.304	0.320	0.379	0.348	0.331	0.294	0.291
Mean gas-based		0.572	0.536	0.541	0.518	0.506	0.527	0.559	0.589	0.585	0.561	0.560	0.567
Mean coal/net long		0.449	0.403	0.352	0.372	0.459	0.346	0.357	0.431	0.392	0.376	0.328	0.324
Mean coal/net short		0.253	0.215	0.229	0.219	0.194	0.200	0.227	0.250	0.238	0.221	0.207	0.208
Mean gas/net long		0.765	0.740	0.738	0.715	0.705	0.718	0.752	0.782	0.775	0.756	0.753	0.758
Mean gas/net short		0.314	0.264	0.279	0.255	0.242	0.271	0.302	0.331	0.332	0.300	0.302	0.313

Note: "Base fuel" shows what fuel was dominant (the share larger than 50%) in fuel mix in 2007.

C Carbon dioxide and Sulphur dioxide environmental efficiency scores

Table 10: Sulphur dioxide environmental efficiency scores, 1996-2007

	Base fuel	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Austria	Other	1.000	1.000	1.000	1.000	0.924	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Finland	Coal	0.529	0.622	0.323	1.000	1.000	0.273	0.311	1.000	1.000	1.000	1.000	1.000
Latvia	Gas	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Netherlands	Gas	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Sweden	Other	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Denmark	Coal	1.000	1.000	0.294	0.307	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.994
Hungary	Gas	0.025	0.021	0.020	0.016	0.015	0.023	0.027	0.034	0.054	0.293	0.472	0.517
Lithuania	Gas	0.103	0.135	0.062	0.060	0.106	0.119	0.130	0.240	0.204	0.242	0.256	0.215
Italy	Gas	0.090	0.065	0.075	0.064	0.076	0.113	0.150	0.222	0.241	0.369	0.338	0.492
Belgium	Gas	0.140	0.110	0.136	0.181	0.160	0.192	0.234	0.261	0.215	0.231	0.255	0.362
Germany	Coal	0.143	0.124	0.183	0.178	0.230	0.264	0.296	0.347	0.320	0.327	0.310	0.323
United Kingdom	Coal	0.051	0.046	0.048	0.056	0.046	0.061	0.073	0.081	0.093	0.116	0.119	0.156
Slovakia	Coal	0.031	0.023	0.029	0.021	0.047	0.067	0.063	0.071	0.067	0.065	0.059	0.064
Ireland	Gas	0.067	0.042	0.042	0.033	0.040	0.049	0.067	0.098	0.087	0.084	0.095	0.116
Slovenia	Coal	n/a	n/a	n/a	n/a	0.012	0.023	0.024	0.030	0.031	0.041	0.126	0.157
Czech Republic	Coal	0.125	0.107	0.141	0.403	1.000	0.135	0.110	0.120	0.108	0.100	0.089	0.089
Portugal	Coal	0.048	0.034	0.036	0.034	0.030	0.033	0.042	0.056	0.049	0.053	0.053	0.051
Poland	Coal	n/a	n/a	n/a	n/a	0.059	0.054	0.054	0.063	0.053	0.056	0.041	0.045
Estonia	Coal	0.054	0.041	0.042	0.032	0.029	0.035	0.040	0.039	0.042	0.046	0.042	0.036
Spain	Coal	0.020	0.015	0.017	0.015	0.015	0.016	0.019	0.023	0.024	0.026	0.028	0.029
Romania	Coal	0.070	0.051	0.062	0.042	0.036	0.036	0.033	0.036	0.033	0.019	0.018	0.021
Bulgaria	Coal	0.013	0.008	0.008	0.006	0.005	0.006	0.007	0.008	0.008	0.007	0.007	0.008
France	Other	0.033	0.023	0.033	0.036	0.040	0.051	0.066	0.066	0.062	0.060	0.059	0.061
Greece	Coal	0.031	0.023	0.027	0.020	0.021	0.023	0.025	0.025	0.024	0.022	0.022	0.024
Mean		0.299	0.295	0.254	0.296	0.329	0.274	0.282	0.326	0.321	0.340	0.349	0.365
Mean coal-based		0.176	0.175	0.101	0.176	0.252	0.145	0.150	0.207	0.204	0.206	0.208	0.214
Mean gas-based		0.346	0.339	0.334	0.336	0.342	0.356	0.373	0.408	0.400	0.460	0.488	0.529
Mean coal/net long		0.224	0.223	0.124	0.225	0.344	0.190	0.196	0.274	0.268	0.267	0.262	0.263
Mean coal/net short		0.034	0.028	0.031	0.030	0.023	0.031	0.035	0.040	0.043	0.051	0.074	0.091
Mean gas/net long		0.532	0.539	0.520	0.519	0.530	0.535	0.539	0.569	0.564	0.634	0.682	0.683
Mean gas/net short		0.099	0.072	0.084	0.093	0.092	0.118	0.150	0.194	0.181	0.228	0.229	0.323

Note: "Base fuel" shows what fuel was dominant (the share larger than 50%) in fuel mix in 2007.

Table 11: Efficiency change component for ENV TFP

Country	Base fuel	97-96	98-97	99-98	00-99	01-00	02-01	03-02	04-03	05-04	06-05	07-06	Cumulative 1996-2007
Finland	Coal	1.033*	1.014*	1.027*	1.000	0.983*	0.988*	1.029*	1.000	1.000	1.000	1.000	1.075
Sweden	Other	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000*	1.000	1.000
Slovakia	Coal	0.895*	1.093*	1.085*	1.098*	1.173*	0.924*	1.026*	1.029*	1.034*	0.887*	1.053*	1.287
Portugal	Coal	1.035*	1.141*	1.394*	0.953*	0.898*	1.005*	0.807	1.113*	1.254*	0.775	0.950*	1.175
Spain	Coal	1.308*	0.941*	1.230*	1.124*	0.834*	0.935*	0.821*	1.036*	1.037*	1.015*	0.993*	1.179
Netherlands	Gas	1.180*	0.937*	1.140*	1.091*	0.945*	0.825*	1.052*	1.055*	1.114*	0.854*	1.020*	1.156
Italy	Gas	1.119*	0.874*	1.137*	0.998*	1.063*	0.871*	1.019*	1.171*	0.998*	0.997*	0.995*	1.216
Belgium	Gas	1.082*	0.910*	1.198*	1.054*	0.852*	1.004*	0.953*	1.022*	1.036*	0.981*	1.031*	1.085
Greece	Coal	1.155*	1.022*	1.094*	1.139*	0.997*	0.809*	0.907*	1.074*	1.034*	0.812	1.155*	1.119
Austria	Other	0.922*	0.979*	1.060*	1.034*	1.052*	0.939*	1.101*	1.043*	1.082*	0.950*	0.952*	1.100
United Kingdom	Coal	1.123*	0.888*	1.269*	1.074*	0.898*	0.853*	1.036*	0.987*	1.051*	0.927*	1.023*	1.062
Germany	Coal	1.099*	0.927*	1.104*	1.065*	0.953*	0.797	1.035*	1.044*	1.178*	0.806	1.085*	1.012
Estonia	Coal	1.102*	0.866*	1.138*	1.050*	1.103*	0.900*	1.008*	1.005*	1.161*	0.810*	1.001*	1.080
Slovenia	Coal	1.198*	1.042*	1.103*	0.982*	0.854*	0.909*	1.008*	1.032*	1.109*	0.873*	0.994*	1.049
Hungary	Gas	1.082*	1.037*	1.180*	0.983*	0.929*	0.869*	1.092*	1.020*	1.014*	1.014*	1.022*	1.229
Ireland	Gas	1.180*	0.907*	1.249*	1.070*	0.951*	0.709	1.012*	1.028*	0.989*	0.963*	0.986*	0.942
Czech Republic	Coal	1.112*	0.940*	1.100*	1.087*	0.976*	0.852*	0.976*	1.058*	1.081*	0.799*	1.102*	1.021
Lithuania	Gas	0.985*	0.909*	1.017*	0.993*	0.978*	1.047*	1.066*	0.953*	0.992*	1.084*	1.021*	1.032
France	Other	0.930*	1.112*	0.970*	0.936*	0.898*	1.039*	0.932*	0.966*	1.218*	0.733	0.940*	0.662
Poland	Coal	1.067*	0.969*	1.099*	0.993*	0.962*	0.896*	0.961*	1.097*	1.092*	0.847*	1.028*	0.974
Bulgaria	Coal	0.888*	0.916*	1.085*	1.019*	0.823*	0.842*	1.152*	1.022*	1.044*	0.979*	1.284*	0.963
Romania	Coal	1.036*	0.952*	0.977*	1.011*	0.978*	0.935*	1.040*	0.988*	1.009*	0.995*	0.959*	0.882
Latvia	Gas	1.000	1.000	1.000	1.000	1.000	1.000	1.000*	1.000	1.000*	1.000	1.000	1.000
Denmark	Coal	1.000	0.851*	1.089*	1.079*	1.000	1.000	0.931*	0.860*	0.955*	1.073*	0.957*	0.786
Mean		1.064	0.968	1.114	1.035	0.962	0.914	0.999	1.025	1.062	0.924	1.023	1.045
Mean new MS		1.036	0.972	1.078	1.022	0.978	0.917	1.033	1.020	1.054	0.929	1.046	1.052
Mean old MS		1.083	0.964	1.140	1.044	0.952	0.912	0.974	1.029	1.068	0.920	1.006	1.041
Mean coal-based		1.075	0.969	1.128	1.048	0.959	0.903	0.981	1.025	1.074	0.900	1.042	
Mean gas-based		1.090	0.939	1.131	1.027	0.960	0.904	1.028	1.036	1.021	0.985	1.011	
Mean coal/net long		1.027	0.967	1.110	1.036	0.985	0.914	0.997	1.022	1.081	0.897	1.042	
Mean coal/net short		1.196	0.973	1.174	1.080	0.896	0.876	0.943	1.032	1.058	0.907	1.041	
Mean gas/net long		1.062	0.971	1.084	1.017	0.963	0.935	1.053	1.007	1.030	0.988	1.016	
Mean gas/net short		1.127	0.897	1.195	1.041	0.955	0.862	0.995	1.074	1.008	0.980	1.004	

Note: * denotes significant differences from unity at 0.01. "Base fuel" shows what fuel was dominant (the share larger than 50%) in fuel mix in 2007.

D ENV TFP and ECON TFP components: technical efficiency change and technical change

Table 12: Technological change component for ENV TFP

Country	Base fuel	97-96	98-97	99-98	00-99	01-00	02-01	03-02	04-03	05-04	06-05	07-06	Cumulative 1996-2007
Finland	Coal	0.915*	0.942*	1.082*	1.001*	1.154*	1.073*	1.178*	0.972*	0.887*	1.205*	1.018*	1.439
Sweden	Other	1.030*	1.064*	0.998*	1.018*	1.103*	1.053*	0.950*	1.029*	1.027*	1.018*	0.991*	1.308
Slovakia	Coal	1.023*	1.036*	0.883*	0.944*	1.093*	1.074*	1.010*	0.952*	0.954*	1.064*	0.995*	1.005
Portugal	Coal	0.976*	1.082*	0.876*	0.971*	1.078*	1.136*	0.999*	0.969*	0.928*	1.102*	0.999*	1.087
Spain	Coal	0.886*	1.106*	0.927*	0.926*	1.119*	1.212*	0.991*	0.984*	1.007*	0.962*	1.005*	1.083
Netherlands	Gas	0.888*	1.151*	0.870*	0.929*	1.116*	1.215*	0.968*	0.980*	0.923*	1.096*	0.997*	1.071
Italy	Gas	0.896*	1.146*	0.871*	0.942*	1.105*	1.204*	0.937*	0.979*	0.981*	1.003*	1.002*	1.012
Belgium	Gas	0.905*	1.108*	0.938*	0.952*	1.134*	1.109*	1.003*	0.982*	0.953*	1.046*	1.000	1.105
Greece	Coal	0.878*	1.067*	0.875*	0.993*	1.049*	1.165*	1.080*	0.931*	0.887*	1.229*	0.946*	1.033
Austria	Other	1.045*	1.062*	0.955*	0.943*	1.085*	1.034*	0.940*	0.967*	0.983*	1.030*	0.999*	1.032
United Kingdom	Coal	0.883*	1.160*	0.869*	0.933*	1.113*	1.208*	0.965*	0.980*	0.945*	1.064*	0.999*	1.058
Germany	Coal	0.881*	1.123*	0.871*	0.943*	1.104*	1.206*	1.035*	0.971*	0.878*	1.220*	0.951*	1.107
Estonia	Coal	0.901*	1.061*	0.877*	0.962*	1.063*	1.157*	1.070*	0.930*	0.895*	1.211*	0.950*	1.017
Slovenia	Coal	0.898*	1.070*	0.874*	0.977*	1.066*	1.163*	1.025*	0.969*	0.907*	1.158*	0.985*	1.044
Hungary	Gas	0.937*	1.002*	0.885*	0.940*	1.111*	1.089*	0.968*	0.956*	1.009*	0.975*	0.997*	0.859
Ireland	Gas	0.880*	1.116*	0.871*	0.945*	1.098*	1.205*	0.984*	0.978*	0.950*	1.074*	0.999*	1.049
Czech Republic	Coal	0.884*	1.036*	0.878*	1.005*	1.029*	1.123*	1.078*	0.927*	0.896*	1.222*	0.943*	0.964
Lithuania	Gas	1.034*	1.052*	0.951*	0.987*	1.022*	0.975*	0.949*	1.017*	0.991*	0.957*	1.005*	0.936
France	Other	0.995*	0.916*	1.068*	1.014*	1.097*	1.001*	1.075*	1.039*	0.914*	1.235*	1.047*	1.433
Poland	Coal	0.896*	1.011*	0.881*	0.979*	1.065*	1.082*	1.076*	0.919*	0.910*	1.204*	0.946*	0.922
Bulgaria	Coal	0.881*	1.057*	0.877*	0.956*	1.090*	1.163*	0.947*	0.967*	0.970*	1.059*	0.970*	0.903
Romania	Coal	1.026*	1.047*	0.952*	0.989*	1.022*	1.025*	0.954*	0.994*	1.005*	0.972*	1.002*	0.983
Latvia	Gas	1.006*	0.936*	0.901*	0.961*	1.080*	0.949*	1.036*	0.935*	1.014*	1.034*	0.986*	0.837
Denmark	Coal	0.886*	0.961*	0.958*	1.007*	1.067*	1.012*	1.162*	1.005*	0.986*	1.021*	0.999*	1.042
Mean		0.935	1.055	0.916	0.967	1.086	1.110	1.016	0.972	0.950	1.090	0.989	1.055
Mean new MS		0.949	1.031	0.896	0.970	1.064	1.080	1.011	0.957	0.955	1.085	0.978	0.947
Mean old MS		0.925	1.072	0.931	0.965	1.102	1.131	1.019	0.983	0.946	1.093	0.997	1.133
Mean coal-based		0.915	1.054	0.906	0.970	1.079	1.128	1.041	0.962	0.932	1.121	0.979	
Mean gas-based		0.935	1.073	0.898	0.951	1.095	1.107	0.978	0.975	0.974	1.026	0.998	
Mean coal/net long		0.927	1.036	0.914	0.976	1.076	1.105	1.051	0.961	0.931	1.128	0.977	
Mean coal/net short		0.886	1.101	0.886	0.957	1.087	1.187	1.015	0.966	0.936	1.103	0.984	
Mean gas/net long		0.966	1.035	0.902	0.954	1.082	1.057	0.980	0.972	0.984	1.015	0.996	
Mean gas/net short		0.894	1.123	0.893	0.946	1.113	1.173	0.975	0.979	0.961	1.041	1.000	

Note: * denotes significant differences from unity at 0.01. "Base fuel" shows what fuel was dominant (the share larger than 50%) in fuel mix in 2007.

Table 13: Efficiency change component for ECON TFP

Country	Base fuel	97-96	98-97	99-98	00-99	01-00	02-01	03-02	04-03	05-04	06-05	07-06	Cumulative 1996-2007
Finland	Coal	1.033*	1.014*	1.027*	1.000	0.983*	0.988*	1.029*	1.000	1.000	1.000	1.000	1.075
Slovakia	Coal	0.897*	1.093*	1.085*	1.098*	1.173*	0.924*	1.026*	1.029*	1.034*	0.887*	1.053*	1.290
Portugal	Coal	1.035*	1.141*	1.394*	0.950*	0.901*	1.005*	0.807*	1.113*	1.254*	0.775*	0.950*	1.175
Spain	Coal	1.308*	0.941*	1.230*	1.124*	0.834*	0.935*	0.821*	1.036*	1.037*	1.015*	0.993*	1.179
Netherlands	Gas	1.180*	0.937*	1.140*	1.091*	0.945*	0.825*	1.052*	1.055*	1.114*	0.854*	1.020*	1.156
Italy	Gas	1.119*	0.874*	1.137*	0.998*	1.063*	0.871*	1.018*	1.172*	0.998*	0.997*	0.995*	1.216
Belgium	Gas	1.082*	0.910*	1.198*	1.054*	0.852*	1.004*	0.953*	1.022*	1.036*	0.981*	1.031*	1.085
Greece	Coal	1.155*	1.022*	1.094*	1.139*	0.997*	0.809*	0.907*	1.074*	1.034*	0.812	1.155*	1.119
Austria	Other	0.922*	0.979*	1.060*	1.034*	1.052*	0.939*	1.101*	1.043*	1.082*	0.950*	0.952*	1.100
United Kingdom	Coal	1.123*	0.888*	1.269*	1.074*	0.898*	0.853*	1.036*	0.987*	1.051*	0.927*	1.023*	1.062
Germany	Coal	1.099*	0.927*	1.104*	1.065*	0.953*	0.797	1.035*	1.044*	1.178*	0.806	1.085*	1.012
Estonia	Coal	1.102*	0.866*	1.138*	1.050*	1.103*	0.900*	1.008*	1.005*	1.161*	0.810*	1.001*	1.080
Slovenia	Coal	1.198*	1.042*	1.103*	0.982*	0.854*	0.909*	1.008*	1.032*	1.109*	0.873*	0.994*	1.049
Sweden	Other	1.000	1.000*	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000*	1.000
Hungary	Gas	1.082*	1.037*	1.180*	0.983*	0.929*	0.869*	1.092*	1.020*	1.014*	1.014*	1.022*	1.229
Ireland	Gas	1.180*	0.907*	1.249*	1.070*	0.951*	0.709	1.012*	1.028*	0.989*	0.963*	0.986*	0.942
Czech Republic	Coal	1.112*	0.940*	1.100*	1.087*	0.976*	0.852*	0.976*	1.058*	1.081*	0.799*	1.102*	1.021
Lithuania	Gas	0.985*	0.909*	1.017*	0.993*	0.978*	1.047*	1.066*	0.953*	0.992*	1.084*	1.021*	1.032
France	Other	0.930*	1.112*	0.970*	0.936*	0.898*	1.039*	0.932*	0.966*	1.218*	0.733	0.940*	0.662
Poland	Coal	1.067*	0.969*	1.099*	0.993*	0.962*	0.896*	0.961*	1.097*	1.092*	0.847*	1.028*	0.974
Bulgaria	Coal	0.888*	0.916*	1.085*	1.019*	0.823*	0.842*	1.152*	1.022*	1.044*	0.979*	1.284*	0.963
Romania	Coal	1.036*	0.952*	0.977*	1.011*	0.978*	0.935*	1.040*	0.988*	1.009*	0.995*	0.959*	0.882
Denmark	Coal	1.000	0.851*	1.089*	1.079*	1.000	1.000	0.931*	0.860*	0.955*	1.073*	0.957*	0.786
Latvia	Gas	1.000	1.000	1.000	1.000	1.000	1.000	1.000*	1.000	1.000	1.000*	1.000	1.000
Mean		1.064	0.968	1.114	1.035	0.963	0.914	0.999	1.025	1.062	0.924	1.023	1.045
Mean new MS		1.037	0.972	1.078	1.022	0.978	0.917	1.033	1.020	1.054	0.929	1.046	1.052
Mean old MS		1.083	0.964	1.140	1.044	0.952	0.912	0.974	1.029	1.068	0.920	1.006	1.041
Mean coal-based		1.075	0.969	1.128	1.048	0.960	0.903	0.981	1.025	1.074	0.900	1.042	1.048
Mean gas-based		1.090	0.939	1.131	1.027	0.960	0.904	1.028	1.036	1.021	0.985	1.011	1.094
Mean coal/net long		1.027	0.967	1.110	1.035	0.985	0.914	0.997	1.022	1.081	0.897	1.042	1.026
Mean coal/net short		1.196	0.973	1.174	1.080	0.896	0.876	0.943	1.032	1.058	0.907	1.041	1.102
Mean gas/net long		1.062	0.971	1.084	1.017	0.963	0.935	1.053	1.007	1.030	0.988	1.016	1.104
Mean gas/net short		1.127	0.897	1.195	1.041	0.955	0.862	0.995	1.074	1.008	0.980	1.004	1.081

Note: * denotes significant differences from unity at 0.01. “Base fuel” shows what fuel was dominant (the share larger than 50%) in fuel mix in 2007.

Table 14: Technological change component for ECON TFP

Country	Base fuel	97-96	98-97	99-98	00-99	01-00	02-01	03-02	04-03	05-04	06-05	07-06	Cumulative 1996-2007
Finland	Coal	0.915*	0.942*	1.082*	1.001*	1.154*	1.073*	1.178*	0.970*	0.887*	1.205*	1.018*	1.435
Slovakia	Coal	1.017*	1.036*	0.883*	0.949*	1.093*	1.074*	1.010*	0.952*	0.954*	1.064*	0.995*	1.005
Portugal	Coal	0.976*	1.082*	0.876*	0.973*	1.076*	1.136*	0.999*	0.969*	0.928*	1.102*	0.999*	1.089
Spain	Coal	0.886*	1.106*	0.927*	0.926*	1.119*	1.212*	0.991*	0.984*	1.007*	0.962*	1.005*	1.083
Netherlands	Gas	0.888*	1.151*	0.870*	0.929*	1.116*	1.215*	0.968*	0.980*	0.923*	1.096*	0.997*	1.071
Italy	Gas	0.896*	1.146*	0.871*	0.942*	1.104*	1.204*	0.937*	0.979*	0.981*	1.003*	1.002*	1.012
Belgium	Gas	0.905*	1.108*	0.938*	0.952*	1.134*	1.109*	1.003*	0.982*	0.953*	1.046*	1.000*	1.105
Greece	Coal	0.878*	1.067*	0.875*	0.993*	1.049*	1.165*	1.080*	0.931*	0.887*	1.229*	0.946*	1.033
Austria	Other	1.045*	1.062*	0.955*	0.943*	1.085*	1.034*	0.940*	0.967*	0.983*	1.030*	0.999*	1.032
United Kingdom	Coal	0.883*	1.160*	0.869*	0.933*	1.113*	1.208*	0.965*	0.980*	0.945*	1.064*	0.999*	1.058
Germany	Coal	0.881*	1.123*	0.871*	0.943*	1.104*	1.206*	1.035*	0.971*	0.878*	1.220*	0.951*	1.107
Estonia	Coal	0.901*	1.061*	0.877*	0.962*	1.063*	1.157*	1.070*	0.930*	0.895*	1.211*	0.950*	1.017
Slovenia	Coal	0.898*	1.070*	0.874*	0.977*	1.066*	1.163*	1.025*	0.969*	0.907*	1.158*	0.985*	1.044
Sweden	Other	0.998*	1.096*	0.935*	0.970*	1.097*	1.080*	0.956*	1.020*	0.990*	0.954*	0.998*	1.081
Hungary	Gas	0.937*	1.002*	0.885*	0.940*	1.111*	1.089*	0.968*	0.956*	1.009*	0.975*	0.997*	0.859
Ireland	Gas	0.880*	1.116*	0.871*	0.945*	1.098*	1.205*	0.984*	0.978*	0.950*	1.074*	0.999*	1.049
Czech Republic	Coal	0.884*	1.036*	0.878*	1.007*	1.029*	1.123*	1.078*	0.927*	0.896*	1.222*	0.943*	0.966
Lithuania	Gas	1.034*	1.052*	0.951*	0.987*	1.022*	0.975*	0.949*	1.017*	0.991*	0.957*	1.005*	0.936
France	Other	0.995*	0.916*	1.068*	1.014*	1.097*	1.001*	1.075*	1.039*	0.914*	1.235*	1.047*	1.433
Poland	Coal	0.896*	1.011*	0.881*	0.979*	1.065*	1.082*	1.076*	0.919*	0.910*	1.204*	0.946*	0.922
Bulgaria	Coal	0.881*	1.057*	0.877*	0.956*	1.090*	1.163*	0.947*	0.967*	0.970*	1.059*	0.970*	0.903
Romania	Coal	1.026*	1.047*	0.952*	0.989*	1.022*	1.025*	0.954*	0.994*	1.005*	0.972*	1.002*	0.983
Denmark	Coal	0.885*	0.961*	0.958*	1.007*	1.067*	1.012*	1.162*	1.005*	0.986*	1.021*	0.999*	1.041
Latvia	Gas	0.986*	0.936*	0.888*	0.951*	1.080*	0.943*	1.036*	0.916*	1.012*	1.034*	0.986*	0.778
Mean		0.932	1.056	0.913	0.965	1.085	1.111	1.016	0.971	0.948	1.087	0.989	1.043
Mean new MS		0.946	1.031	0.895	0.970	1.064	1.079	1.011	0.955	0.955	1.085	0.978	0.941
Mean old MS		0.922	1.074	0.926	0.962	1.101	1.133	1.020	0.983	0.944	1.089	0.997	1.116
Mean coal-based		0.915	1.054	0.906	0.971	1.079	1.128	1.041	0.962	0.932	1.121	0.979	1.049
Mean gas-based		0.932	1.073	0.896	0.949	1.095	1.106	0.978	0.973	0.974	1.026	0.998	0.973
Mean coal/net long		0.926	1.036	0.914	0.977	1.076	1.105	1.051	0.960	0.931	1.128	0.977	1.047
Mean coal/net short		0.886	1.101	0.886	0.957	1.087	1.187	1.015	0.966	0.936	1.103	0.984	1.054
Mean gas/net long		0.961	1.035	0.898	0.952	1.082	1.056	0.980	0.967	0.984	1.015	0.996	0.911
Mean gas/net short		0.894	1.123	0.893	0.946	1.112	1.173	0.975	0.980	0.961	1.041	1.000	1.056

Note: * denotes significant differences from unity at 0.01. “Base fuel” shows what fuel was dominant (the share larger than 50%) in fuel mix in 2007.

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