Transport and CO_2: Productivity Growth and Carbon Dioxide Emissions in the European Commercial Transport Industry

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Transport and CO_2: Productivity Growth and Carbon Dioxide Emissions in the European Commercial Transport Industry

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In the last decades transport activities persistently increased in the EU27 and were strongly coupled to growth in GDP. Like most production processes, they are inevitably linked with the generation of environmentally hazardous by-products, such as CO_2 emissions. This leads to the question of how to promote a sustainable transport sector that meets both environmental protection targets and economic requirements. In this context, the objective of this paper is to compare the CO_2-sensitve productivity development of the European commercial transport industry for the period between 1995 and 2006. We calculate a Malmquist-Luenberger productivity index to investigate the effects of country-specific regulations on productivity and to identify innovative countries. Our results show a high variation in the CO_2-sensitive productivity development and a slight productivity decrease on average. Efficiency losses indicate that the majority of the countries were not able to follow the technological improvements induced by some innovative countries.

Keywords: European transport industry, Carbon dioxide emissions, Productivity growth, Malmquist-Luenberger index

JEL classification: L92, Q47, Q53, Q56

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1 Introduction

The transport industry plays an important role in modern economies by enabling economic growth and creating jobs. In the EU27 the transport industry accounted for about 4.6% of Gross Value Added (GVA)[1] and employed around 9.1 million people, some 4.5% of total employment, in 2008 (European Commission, 2011*a*). Historically, the trend in

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[1] GVA measures the contribution of an industry to Gross Domestic Product (GDP).

transport activities, especially in freight transportation, follows economic developments and is strongly coupled to the growth in GDP. Growth in transportation of goods is associated with productive or economic activity and is particularly important to spatially linking markets. While in the EU27 the average annual growth rate of GDP (measured at constant 1995 prices) was 2.4% from 1995 to 2006, freight transport activities (measured in tonne-kilometers) grew by an average annual rate of 2.8% and passenger transport activities (measured in passenger-kilometers) by a rate of 1.7%, respectively (Eurostat, 2009*b*).

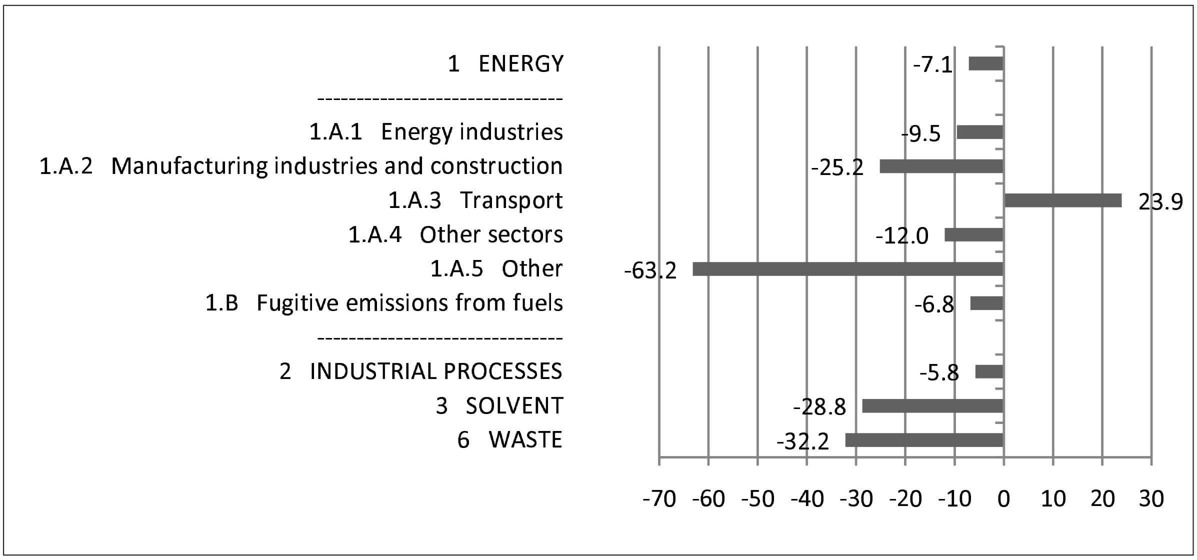
In the age of international climate protection and greenhouse gas (GHG) emissions reduction efforts, the challenge is not only to create a competitive and efficient, but simultaneously a sustainable transport system.[2] Generally the generation of GHG emissions is a by-product or bad output of the production process of marketable or good outputs.[3] The fact that good and bad outputs are jointly produced implies that the future development of the transport sector's productivity and of the inputs used, especially the fuel type, are directly influencing the development of CO_2 emissions. In this regard the transport sector is a large and steadily growing source of GHG and especially of CO_2 emissions. In 2008 it accounted for almost one-quarter of total CO_2 emissions in the EU27. Furthermore, as illustrated in Figure 1, the transport sector was the only sector that had not reduced its CO_2 emissions from 1990 to 2008; transport-related CO_2 emissions increased by almost 24% compared to an at least 5.8% decrease for all other sectors (UNFCCC, 2011). This development is mainly due to a consistent high growth rate in all modes of transportation.

Both passenger and freight transport activities have increased by more than 40% (measured in passenger- and tonne-kilometers) in the period from 1990 to 2010 (see Figure 2). Additionally, by 2030 the European Commission expects these figures to further rise by more than 40 percentage points compared to the 2010 level (European Commission, Directorate-General for Energy and Transport, 2008).

More so, the EU transport is still dominated by oil and oil products that account for 96% of its energy needs, although the energy efficiency improved through technological progress (European Commission, 2011*b*). The European Commission projects that the transport sector's dependency on oil will remain, despite a share of oil and oil products of the fuel mix that will decrease to 91% by 2030. The Commission assumes that the small loss in market share is due to the intensified use of biofuels (European Commission, Directorate-General for Energy and Transport, 2008). A tendency towards new energy carriers and technologies, like the electric mobility, cannot be observed at the current market.

[2] Greenhouse gases covered by the Kyoto protocol include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorcarbons (PFCs) and sulphur hexafluoride (SF_6).

[3] Throughout this paper, ´desirable‘ or ´good‘ output refers to the marketed good produced by the transport industry. ´Undesirable‘ or ´bad‘ output refers to CO_2 emissions, the environmentally hazardous by-product.



Note: Calculations based on the UNFCCC Greenhouse Gas Inventory Data (UNFCCC, 2011). Sectors according to Annex A of the Kyoto Protocol (sector 4 'agriculture': no CO_2 emissions; exclusive sector 5 'LULUCF').

Figure 1: Change in CO_2 emissions in the EU27 from 1990 to 2008, in %

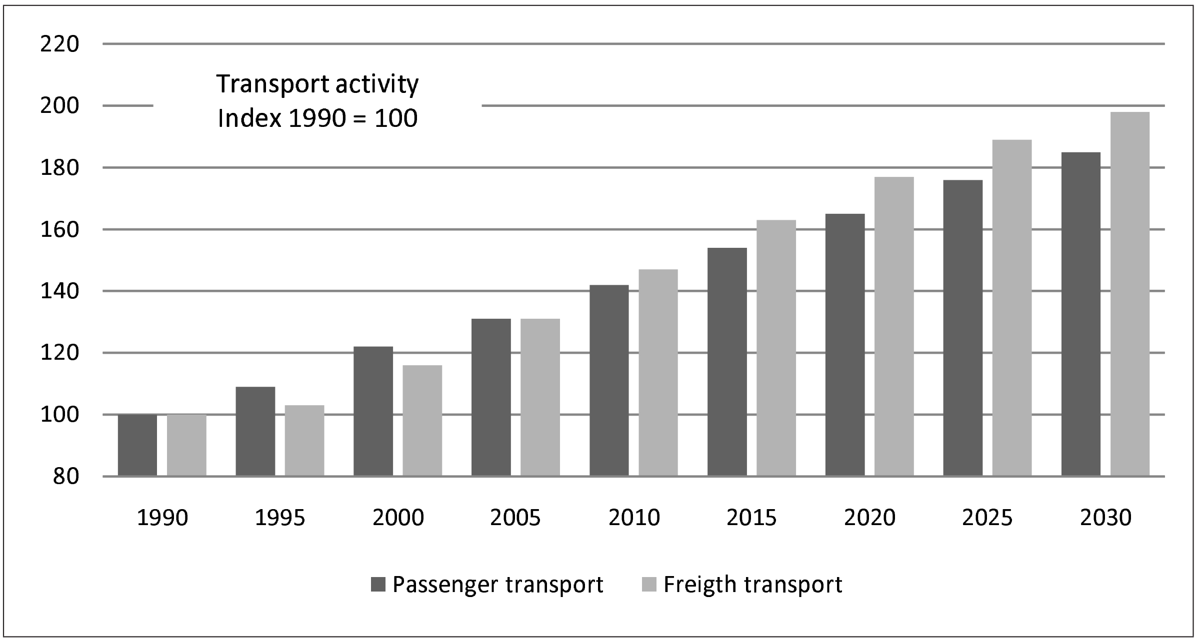
Regarding the climate protection efforts of the European Union, these figures emphasize the importance of transport-related CO_2 emissions and their reduction.[4] The challenge is to promote a sustainable transport sector that meets environmental protection targets as well as economic requirements. Or in the words of the European Commission's White Paper 2011: "Growing Transport and supporting mobility while reaching the 60% emission reduction target."[5]

The described problem causes a great deal of attention to the effects of environmental regulations on economic or productivity growth among policy-makers and academia alike. In the last decades the EU member states implemented a variety of different economic instruments and regulations in order to reduce transport-related CO_2 emissions. Generally, environmental regulations result in a reallocation of input resources, shifting from the production of the marketable output to the use for emission abatement activities (Färe et al., 2001). All European countries are therefore confronted with a trade-off between economic growth and climate protection.

The objective of this paper is to compare the CO_2-sensitve productivity development of the commercial transport industry in 17 European countries for the period between 1995 and 2006. In this context, the commercial transport industry of each country is

[4] In 2007 the EU reached a unilateral agreement with the target of emission reductions in the amount of 20% below 1990 levels by 2020. The EU offered to increase this reduction to 30% if other developed countries commit themselves to comparable reduction targets and more advanced developing countries to adequate targets in line with their abilities (European Communities, 2009).

[5] Commission analysis shows that a reduction of at least 60% of GHG emissions by 2050 compared to the 1990 level is required from the transport sector in order to reach the overall reduction target of 80-95% to limit the climate change below 2ºC.



Note: Calculations based on data from the European Commission, Directorate-General for Energy and Transport (2008).

Figure 2: Transport Activity Growth in the EU27, 1990–2030

compared to a best-practice frontier based on the data from all countries in the study. Because CO_2 reducing regulations are different on country level and in transport mode, it is necessary to investigate the effects of country-specific regulations on productivity growth. For this analysis, we employ the Malmquist-Luenberger (ML) productivity index developed by Chung et al. (1997), which accounts for both marketed output and the output of emission abatement activities.[6]

By decomposing the ML index into its components, we analyse different sources of productivity growth, namely efficiency changes and technological changes, and compare the differences in growth patterns across the European countries. Improvements in the efficiency-change component of the Malmquist index indicate a catch-up to the best-practice frontier while improvements in the technological-change component indicate an outward shift of the frontier. By determining which countries cause that frontier shift we can identify innovative countries, so called "innovators".

This paper presents three models: Two models measure CO_2 sensitive productivity indices that reflect the situation of strong and weak environmental regulation respectively; one model measures a conventional productivity index that ignores CO_2 emissions. The first CO_2-sensitive model assumes strong regulation with the objective to increase the good output and to simultaneously decrease the bad output. This model works with equiproportional changes of the outputs because increasing mobility and reducing CO_2

[6] A variety of studies have used the ML productivity index to evaluate environmentally sensitive productivity growth on the industry and country level (see e.g. Färe et al., 2001; Domazlicky and Weber, 2004; Yörük and Zaim, 2005; Kumar, 2006; Wu and Wang, 2007; Oh and Heshmati, 2010).

emissions are equally important targets to the White Papers´ initiatives. The second CO_2-sensitive model reflects weak regulation which seeks to maximize the good output at constant levels of the bad output. By weighing the good output of the transport industry relatively stronger, it describes the lower bound of environmental regulation intensity. Furthermore, we compare the results to a conventional productivity index that completely ignores CO_2 emissions. Given the existing environmental regulations, this model reflects the bias generated by conventional productivity measures that neglect CO_2 emissions.[7]

For the analysis a unique data set is used that links CO_2 emissions with economic figures on an industry level. Data on CO_2 emissions are drawn from Eurostat's Air Emissions Accounts (AEA), which report air emissions by economic activities (Eurostat, 2011). Compared to the countries' geographic definition in national emissions inventories, such as the UNFCCC Greenhouse Gas Inventories, the AEA´s definition of a country is more economically orientated and thus allows merging data on CO_2 emissions from the AEA with economic data.

The remainder of this paper is organized as follows. Section 2 introduces the methodology. Section 3 describes the data and gives an overview about statistical trends. Estimation results are illustrated in Section 4. Section 5 summarizes and presents conclusions.

2 Methodology

To describe the model, assume that $x = (x_1, \ldots, x_N) \in \Re^N_+$ denotes a vector of inputs, $y = (y_1, \ldots, y_M) \in \Re^M_+$ denotes a vector of desired or good outputs, and $b = (b_1, \ldots, b_I) \in \Re^I_+$ denotes a vector of undesired or bad outputs. The production technology can then be modelled as:

$$P(x) = \{(y, b) : x \text{ can produce } (y, b)\}, x \in \Re^N_+, \quad (1)$$

where the output set $P(x)$ represents all the combinations of good and bad outputs (y, b) that can be produced using the input vector x. $P(x)$ is a convex and compact set and satisfies the standard properties of no free lunch, possibility of inaction, and strong or free disposability of inputs (see e.g. Färe and Primont, 1995).

In order to account for the joint production of good and bad outputs, we define three additional assumptions: First, we assume null-jointness of the output set[8]:

$$\text{if } (y, b) \in P(x) \text{ and } b = 0 \text{ then } y = 0. \quad (2)$$

[7] Note: Since our estimations are based on real data characterized by the current country-specific regulations the estimated conventional productivity index does not reflect the situation without any CO_2 regulation.

[8] The null-jointness assumption was introduced by Shephard and Färe (1974).

That is, no good output can be produced without producing any bad outputs. Second, the good and the bad outputs are considered as being together weakly disposable[9]

$$(y, b) \in P(x) \text{ and } 0 \leq \theta \leq 1 \text{ imply } (\theta y, \theta b) \in P(x). \tag{3}$$

This assumption states that a reduction of the bad outputs is not costless and negatively influences the production level of the good outputs. In other words, abatement activities require resources which otherwise could have been used to expand the amount of the good outputs.

Finally, the good outputs are assumed to be strongly or freely disposable:

$$(y, b) \in P(x) \text{ and } y' \leq y \text{ imply } (y', b) \in P(x). \tag{4}$$

This assumption implies that a reduction of the good outputs is feasible without a simultaneous reduction of the bad outputs. Further, with Equation 3 it emphasizes the asymmetry between the good and the bad outputs insofar as good outputs are costlessly disposable but bad outputs are not (Färe et al., 2001).

A production technology that satisfies these assumptions can be represented by a directional output distance function. Introduced by Chambers et al. (1996, 1998), it can be formally defined on $P(x)$ as:

$$\vec{D}_0(x, y, b; g_y, g_b) = \sup \{\beta : (y, b) + (\beta g_y, \beta g_b) \in P(x)\}, \tag{5}$$

where $g = (g_y, g_b)$ and β, respectively, represent the direction and proportion in which the output vector (y, b) is scaled to reach the boundary or frontier of the output set $P(x)$. The directional output distance function value β is bounded below by zero. A value of zero identifies the observed output vector as located on frontier and, hence, as being technically efficient. Values greater than zero belong to output vectors within the frontier, indicating technical inefficiency.

We estimate three models of the directional output distance function with different output sets $P(x)$ and directional vectors $g = (g_y, g_b)$. In Model I, $\vec{D}_o(x, y, 0; y, 0)$, the bad outputs are excluded from the output set $P(x)$ and the directional vector is $g = (y, 0)$. This model completely ignores the harmfully characteristics of the bad outputs and solely seeks to increase the good outputs. In contrast, in Model II and III the bad outputs are a part of the output set $P(x)$. Choosing the same directional vector as in Model I, Model II, $\vec{D}_o(x, y, b; y, 0)$, seeks to increase the good outputs while the bad outputs are kept on their current level. Finally, in Model III, $\vec{D}_o(x, y, b; y, -b)$, the directional vector is $g = (y, -b)$. This model seeks to increase the good outputs and to decrease the bad outputs at the same time by the same proportion.

The three directional output distance function models are illustrated in Figure 3[10]. The vertical axis shows the good output y, while the horizontal axis shows the bad output b. $P(x)$ is the area of all feasible combinations of the good and the bad output

[9] The concept of weak disposability was introduced by Shephard (1970).

[10] Figure 3 follows Domazlicky and Weber (2004).

that can be produced by the input vector x. Points A, B and D represent efficient production points located on the frontier of the output set $P(x)$ while point C within the frontier indicates an inefficient production point.

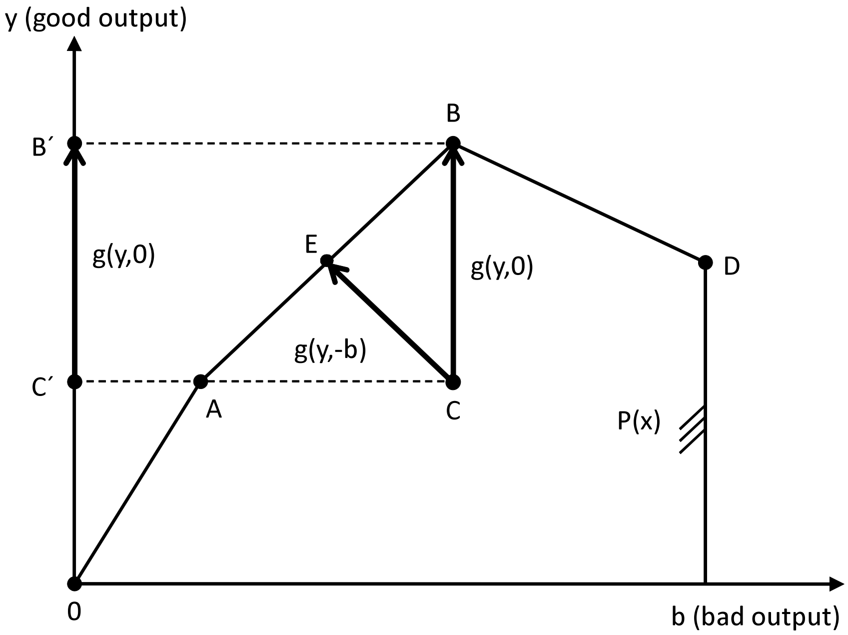


Figure 3: Directional output distance function

First, consider Model I ignoring any bad output. In this case, the feasible output set $P(x)$ reduces to the line segment $0B'$ on the vertical axis. B' represents the efficient good output level of production point B, and C' represents the inefficient good output level of production point C. Hence, Model I expands the original output vector $(y, 0)$ at point C' along the direction $g = (y, 0)$ to the efficient output vector $(y + \beta y, 0)$ at point B'. In contrast, Models II and III both include the bad output. While Model II uses the direction $g = (y, 0)$ to expand the original output vector (y, b) at point C to the efficient output vector $(y + \beta y, b)$ at point B, Model III uses the direction $g = (y, -b)$ to reach the efficient output vector $(y + \beta y, b - \beta b)$ at point E.

In order to measure the model-specific productivity change we use the sequential Malmquist-Luenberger (SML) productivity index as introduced by Oh and Heshmati (2010). Compared to the conventional contemporaneous Malmquist-Luenberger productivity index (Chung et al., 1997), that constructs the output set $P^t(x^t)$ in period t from the observations in that period only, the SML index incorporates past information and includes all observations from period 1 up to period t. More formally, the sequential output set in period t is defined as:

$$\bar{P}^t\left(x^t\right) = P^1\left(x^1\right) \cup P^2\left(x^2\right) \cup \ldots \cup P^t\left(x^t\right), \tag{6}$$

where $1 \leq t \leq T$. Hence, the SML index assumes that in each period of time all preceding technologies are also feasible and thus, in contrast to the conventional ML index, eliminates the possibility of any technological regress by definition. As noted by Shestalova (2003), technological regress can be reasonably explained for sectors like mining, whereas in most other industrial sectors technology progresses or at least remains unchanged. In the European transport sector, technological progress can be assumed. For example, the final energy consumption intensity of the EU27 transport sector decreased by more than 7% between 1990 and 2007 (European Environment Agency, 2010).[11] Given this development, the conventional ML index does not accurately depict the nature of technology and therefore may yield biased estimation results (Oh and Heshmati, 2010).[12]

To calculate the SML productivity index we need to specify four directional distance functions for each of our three models: two functions where the observations under consideration and the sequential output set are from the same period, $\vec{D}_o^t\left(x^t, y^t, b^t; g_y^t, g_b^t\right)$ and $\vec{D}_o^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}; g_y^{t+1}, g_b^{t+1}\right)$, and two functions where the observations under consideration and the sequential output set are from different periods, $\vec{D}_o^t\left(x^{t+1}, y^{t+1}, b^{t+1}; g_y^{t+1}, g_b^{t+1} \right)$ and $\vec{D}_o^{t+1}\left(x^t, y^t, b^t; g_y^t, g_b^t\right)$. Abbreviating the functions with $\vec{D}_o^t(t)$, $\vec{D}_o^{t+1}(t+1)$, $\vec{D}_o^t(t+1)$ and $\vec{D}_o^{t+1}(t)$, respectively, the SML index of productivity change between period t and $t+1$ can be defined as:

$$SML_t^{t+1} = \left[\frac{[1+\vec{D}_o^t(t)]}{[1+\vec{D}_o^t(t+1)]} \times \frac{[1+\vec{D}_o^{t+1}(t)]}{[1+\vec{D}_o^{t+1}(t+1)]} \right]^{\frac{1}{2}}. \tag{7}$$

A value equal to unity indicates no productivity change. A value less than unity indicates a productivity decrease and a value greater than unity indicates a productivity increase.

Further, the SML index can be decomposed into an efficiency change component $SMLEFF_t^{t+1}$ and a technological change component $SMLTECH_t^{t+1}$. That is,

$$SML_t^{t+1} = SMLEFF_t^{t+1} \times SMLTECH_t^{t+1}, \tag{8}$$

where

$$SMLEFF_t^{t+1} = \frac{[1+D_o^t(t)]}{[1+\vec{D}_o^{t+1}(t+1)]}, \tag{9}$$

and

$$SMLTECH_t^{t+1} = \left[\frac{[1+\vec{D}_o^{t+1}(t)]}{[1+\vec{D}_o^t(t)]} \times \frac{[1+\vec{D}_o^{t+1}(t+1)]}{[1+\vec{D}_o^t(t+1)]} \right]^{\frac{1}{2}}. \tag{10}$$

[11] The transport sector's final energy consumption intensity is measured as the ratio of the sector's final energy consumption to gross domestic product.

[12] For a more detailed discussion on sequential and contemporaneous productivity indices, see for example Tulkens and Vanden Eeckaut (1995); Shestalova (2003); Thirtle et al. (2003).

$SMLEFF_t^{t+1}$ captures the change in the distance of an observation to its respective best-practice frontier in period t and $t+1$. A value equal to unity indicates no change. A value less than unity indicates an increase in the distance and hence an efficiency decrease. Finally, a value greater than unity indicates a decrease in the distance and hence an increase in efficiency. A shift of the frontier between period t and $t+1$ is captured by $SMLTECH_t^{t+1}$. A value greater than unity indicates an outward shift of the best-practice frontier and hence technological progress. A value equal to unity indicates no shift and hence no technological change.

The sequential directional output distance functions can be determined by linear programming techniques. Starting with Model III and given $\tau = 1, \ldots, T$ time periods and $k = 1, \ldots, K$ observations of inputs and outputs $(x^{k,\tau}, y^{k,\tau}, b^{k,\tau})$, the sequential directional output distance function $\vec{D}_o^t(t)$ for each observation k' in each period t is obtained by solving the following linear program:

$$\begin{aligned}
&\vec{D}_o^t\left(x^{t,k'}, y^{t,k'}, b^{t,k'}; y^{t,k'}, -b^{t,k'}\right) = max\,\beta \\
&\quad s.t. \sum_{\tau=1}^{t}\sum_{k=1}^{K} z_k^\tau y_{km}^\tau \geq (1+\beta) y_{k'm}^t, \quad m = 1, \ldots, M, \quad (i) \\
&\quad \sum_{\tau=1}^{t}\sum_{k=1}^{K} z_k^\tau b_{ki}^\tau = (1-\beta) b_{k'i}^t, \quad i = 1, \ldots, I, \quad (ii) \\
&\quad \sum_{\tau=1}^{t}\sum_{k=1}^{K} z_k^\tau x_{kn}^\tau \leq x_{k'n}^t, \quad n = 1, \ldots, N, \quad (iii) \\
&\quad z_k^\tau \geq 0, \quad k = 1, \ldots, K, \quad (iv)
\end{aligned} \tag{11}$$

where z_k^τ are intensity variables assigning a weight to each observation k when constructing the best-practice frontier. The inequality constraints in (i) and (iii) state that observation k' does not produce more good outputs or uses fewer inputs than its efficient benchmark on the frontier. In other words, good outputs and inputs are freely disposable. Further, together with the inequality constraints in (i), the strict equality constraints in (ii) impose weak disposability of the good and the bad outputs. Finally, the non-negativity constraints on the intensity variables in (iv) indicate that the production technology exhibits constant returns to scale (Chung et al., 1997). The solution to this program, the maximum value of β for Model III, shows at given inputs, how much the good and the bad outputs can be proportionally expanded and contracted relative to the efficient benchmark on the frontier.

In order to ensure that the program also satisfies the null-jointness assumption, the following restrictions on the bad outputs have to be added:

$$\sum_{k=1}^{K} b_{ki}^\tau > 0, \quad i = 1, \ldots, I \text{ and } \tau = 1, \ldots, T, \tag{12}$$

$$\sum_{i=1}^{I} b_{ki}^{\tau} > 0, \quad k = 1, \ldots, K \text{ and } \tau = 1, \ldots, T. \tag{13}$$

The inequality constraints in (12) imply that in each time period τ each bad output i is produced by at least one observation k, and the inequality constraints in (13) state that in each time period τ each observation k produces at least one bad output i. If for observation k' all bad outputs are equal to zero ($b_{k'i}^{t} = 0, i = 1, \ldots, I$), these restrictions imply that all intensity variables in (11) are zero ($z_k^{\tau} = 0, k = 1, \ldots, K$), which in turn implies that all good outputs must be zero ($y_{k'm}^{t} = 0, m = 1, \ldots, M$). Hence, null-jointness is guaranteed (Färe et al., 2001). Finally, the linear programs for the other three directional distance functions, $\vec{D}_o^t(t+1)$, $\vec{D}_o^{t+1}(t)$ and $\vec{D}_o^{t+1}(t+1)$ are obtained by substituting t with $t+1$ only on the right hand side, only on the left hand side, and on both sides of the constraints in (i)-(iv), respectively.[13]

Taken together, the four versions of the linear program in (11) and the restrictions in (12) and (13) represent Model III of which Models I and II are special cases. For Model I, the objective function changes to $\vec{D}_o^t\left(x^{t,k'}, y^{t,k'}, 0; y^{t,k'}, 0\right) = max\beta$ and the equality constraints in (ii) and the restrictions (12) and (13) are dropped. For Model II the objective function changes to $\vec{D}_o^t\left(x^{t,k'}, y^{t,k'}, b^{t,k'}; y^{t,k'}, 0\right) = max\beta$ and the equality constraints in (ii) are replaced with the equality constraints $\sum_{\tau=1}^{t}\sum_{k=1}^{K} z_k^{\tau} b_{ki}^{\tau} = b_{k'i}^{t}$, $i = 1, \ldots, I$. Hence, the maximum value of β for Models I and II shows at given inputs, how much the good outputs can be expanded relative to the efficient benchmark on the frontier while the former completely ignores any bad outputs and the latter holds the bad outputs constant.

3 Data

Our analysis is based on industry level panel data of 17 countries, 16 member states of the European Union and Norway for the period 1995-2006.[14] The commercial transport sectors´ annual time-series of the input quantities, as well as the quantities of the good and the bad outputs are classified according to the International Standard Industrial Classification (ISIC). For our analysis we use aggregated quantities of the industry categories I60 to I63 as listed in Table 1.[15] Our input variables are *intermediate inputs* (energy, materials and services), *capital stock* and *number of employees*. *Gross output*

[13] Note: If observation k' in period $t+1$ is not a member of the output set $P^t(x^{t+1,k'})$ the linear program for the mixed period directional distance function $\vec{D}_o^t(t+1)$ yields an infeasible solution. See Appendix B in Färe et al. (2001) for an illustration of this problem.

[14] Norway participates in the European Union's single market via the European Economic Area (EEA) agreement. This makes Norway a highly integrated member of the EU internal market. Switzerland and the eleven other member states of the European Union could not be included in the analysis because of missing data.

[15] Unfortunately, disaggregated data for each industry category shows a huge number of gaps and therefore precludes a separate analysis of each category.

is considered as the desirable or good output and CO_2 *emissions* as the undesirable or bad output.[16]

Table 1: ISIC of the transport sector

I 60 – Land transport; transport via pipelines
I 61 – Water transport
I 62 – Air transport
I 63 – Supporting and auxiliary transport activities; activities of travel agencies

The raw data series, which are mainly drawn from the OECD Structural Analysis (STAN) Database for industrial analysis (OECD, 2011*a*), are all measured in local currency units at current prices, except employees which are measured in numbers. A small number of STAN data series that report missing values are replaced by those of the EU KLEMS Growth and Productivity Accounts (EU KLEMS, 2008). GDP deflators from the OECD (OECD, 2011*b*) are used to transform these series into constant prices based on the year 2000.[17] For cross-country comparisons, the local currency measures are converted to an international common unit using purchasing power parities (PPPs) also collected from the OECD (OECD, 2011*b*).

Data on gross fixed capital formation in the transport sector and the standard perpetual inventory method (PIM) are used to estimate the capital stock. That is

$$K_{i,t} = (1-\delta)K_{i,t-1} + I_{i,t}, \tag{14}$$

where $K_{i,t}$ and $I_{i,t}$ are the capital stock and the gross fixed capital formation of country i in period t, respectively, and δ is a uniform depreciation rate assumed to be 5% per year.[18] The initial capital stock K_0 for each country is calculated as $I_0/(g_I+\delta)$, where I_0 is the country's value of gross fixed capital formation in 1995, g_I is the average geometric growth rate of the gross fixed capital formation series from 1995 to 2006, and δ again represents depreciation of 5%.

Data on CO_2 emissions (measured in thousands of tons) are drawn from Eurostat's Air Emissions Accounts (AEA), which report air emissions by economic activities Eurostat (2011). Compared to the geographic definition of a country in national emission inventories, such as the UNFCCC Greenhouse Gas Inventories, the AEA definition of a country is more economically oriented. The AEA assign air emissions to those economic entities that actually are carrying out the activity from which the emissions are originated. Accordingly, the AEA are based on the residence principle, including all

[16] This variable choice follows the gross output concept of productivity measurement appropriate when analysing firm or industry level data. For a detailed comparison of gross output based and value added based productivity measures, see the 'OECD Manual on Measuring Productivity' (OECD, 2001).

[17] GDP deflators are used due to incomplete industry-specific deflators in the OECD STAN Database.

[18] The 5% depreciation rate is a country average derived from diverse sources such as Abadir and Talmain (2001) and Görzig (2007). Testing the robustness of our estimations we also applied a 3% and 10% depreciation rate. The results reveal no significant differences.

emissions from resident units' economic activities both on the national territory and in the rest of the world. In contrast, national emissions inventories include all emissions from activities by resident and non-resident units operating on the national territory. This means that in the AEA, emissions of non-resident units producing on the national territory are excluded, while emissions from resident units producing abroad are included under the industry earning the value added from these activities.[19]

The AEA classify economic activities according to the Statistical Classification of Economic Activities in the European Community (NACE), which is compatible with the ISIC used in the OECD STAN Database.[20] This and the applied residence principle allow to merge data on CO_2 emissions from the AEA with economic data from the OECD STAN Database and hence to perform an integrated environmental-economic analysis on an industry level.

The descriptive statistics of all variables used in this study are presented in Table 2. As shown, the European commercial transport sector is characterised by a high heterogeneity among the countries. Indicating for almost all variables the highest values, Germany has by far the largest transport industry in the sample. Only the maximum value of CO_2 emissions belongs to the United Kingdom. In contrast, Estonia and Slovenia have the smallest transport industries. In terms of output production, Germany's transport industry produces approximately 87 times more gross output than Estonia's transport industry.

Table 2: Descriptive statistics of the sample

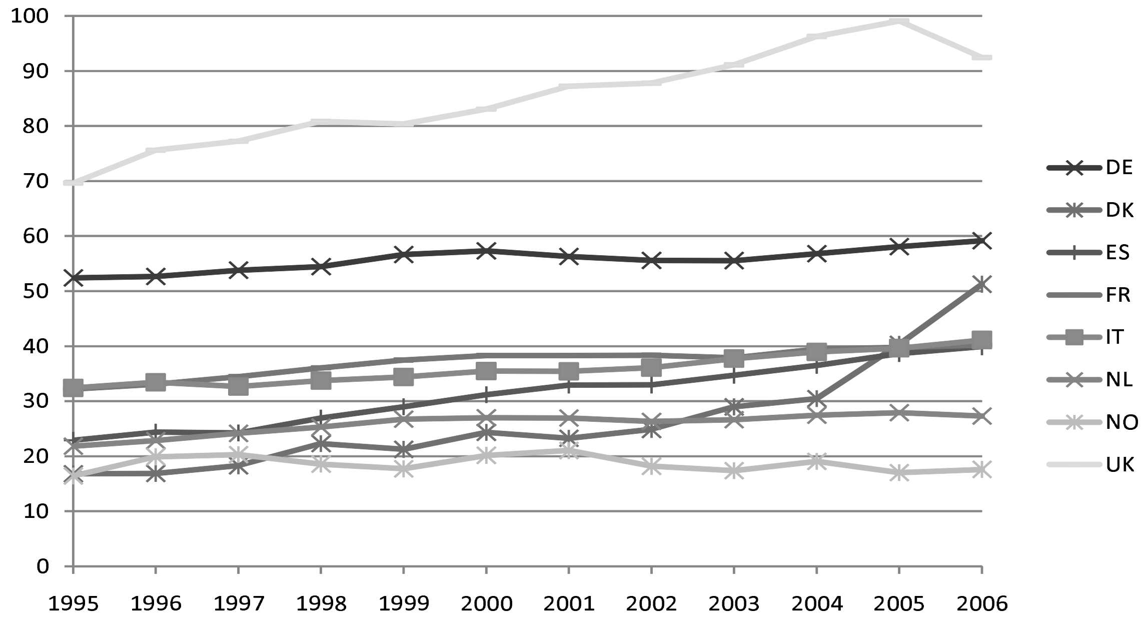
Variable	Unit	Mean	SD	Min	Max
Capital stock	million int. US$	92964	90706	2550	381301
Employees	number in thousands	388	402	33	1498
Intermediate Inputs	million int. US$	32155	33730	1692	138971
Gross Output	million int. US$	55734	58045	2613	228603
CO_2 Emissions	tons in thousands	21320	22436	567	99081

Figure 4 displays the level and development of transport-related CO_2 emission from 1995 to 2006. The upper part of the figure shows the CO_2 development for the so called 'high emitters' with emission values over 15 million tons per year, while the lower part shows the same for all other countries with lower emission values. The 'high emitters' are the five countries with the largest transport industries in the EU (Germany, Italy, the United Kingdom, France, and Spain) and the Netherlands with a remarkably high share of air transport, as well as Denmark and Norway both with an exceptionally large shipping sector.

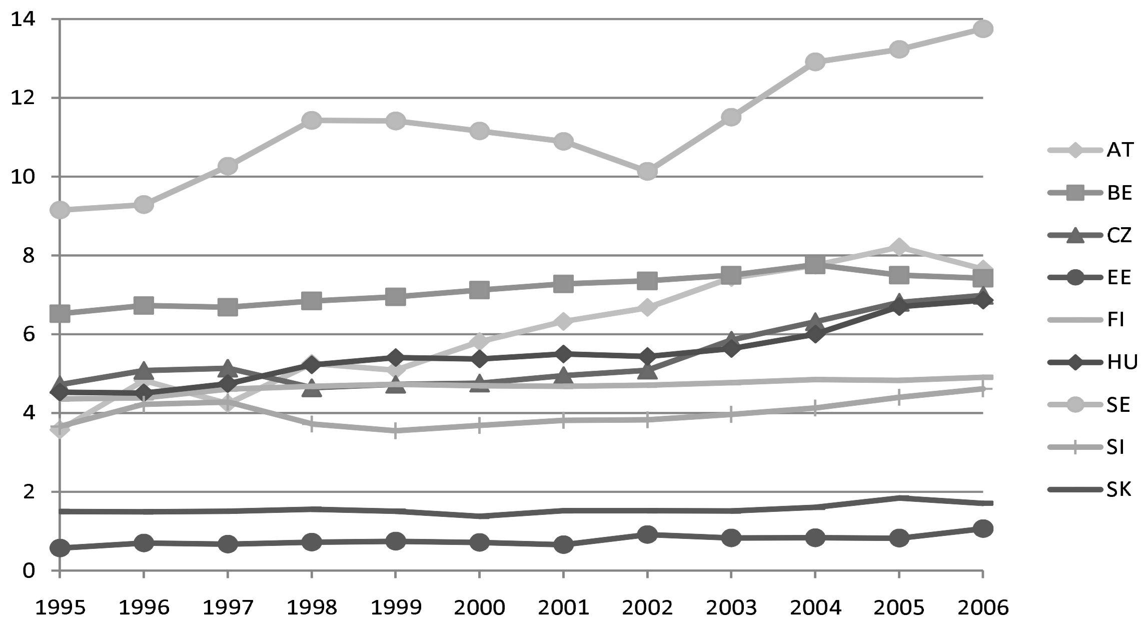
As shown, all countries increased their CO_2 emissions over time. The highest value of CO_2 emissions is observed for the United Kingdom in 2005 (99 million tons), while the

[19] For detailed information see the 'Manual for Air Emission Accounts' from (Eurostat, 2009*a*).

[20] NACE stands for 'Nomenclature statistique des activités économiques dans la Communauté européenne'.



(a) High emitters



(b) All other countries

Note: The country codes represent Austria (AT), Belgium (BE), Czech Republic (CZ), Germany (DE), Denmark (DK), Estonia (EE), Spain (ES), Finland (FI), France (FR), Hungary (HU), Italy (IT), Netherlands (NL), Norway (NO), Sweden (SE), Slovenia (SI), Slovakia (SK), and United Kingdom (UK).

Figure 4: Trend in CO_2 emissions (in million tons), 1995–2006

minimum value belongs to Estonia in 1995 (0.6 million tons). The rather steep increase in CO_2 emissions for Denmark from 2004 to 2006 and Sweden from 2002 to 2006 is due to an exceptionally high growth rate of the two countries' transport industries within the specific periods.

Table 3 shows the average annual growth rates of desirable and undesirable outputs, inputs and CO_2 intensity over the period 1995 to 2006. CO_2 intensity is measured as the ratio of CO_2 emissions to economic output, here gross output. On average, growth rates of the desirable output (i.e. gross output), and the undesirable output (i.e. CO_2 emissions), were 3.05% and 3.32% per year, respectively. Denmark, Austria and Germany had the highest average annual growth in gross output (5.91%, 5.50% and 5.32%, respectively), while gross output in Hungary decreased over the observed period (-2.67%). CO_2 emissions have increased for all 17 countries with average annual growth rates ranging from 0.64% to 10.67%. Belgium, Germany, Finland, Norway and Slovakia had the lowest average annual growth in emissions, all less than 1.20%. On average, growth rates of capital stock, employees and intermediate inputs were 4.87%, 0.98% and 4.08% per year; most countries have increased these inputs. CO_2 intensity shows an annual growth rate of 0.29% on average. During the observed period, almost half of the countries have decreased their CO_2 intensity. With -4%, Germany shows the largest average annual decrease, while Hungary's CO_2 intensity rapidly increased with an average rate of more than 6% per year.

Table 3: Average annual growth rates of outputs, inputs and CO_2 intensity, in %

Country	Gross Output	CO_2 emissions	Capital stock	Employees	Intermed. inputs	CO_2 intensity
AT	5.50	7.18	6.91	0.91	8.77	1.59
BE	3.52	1.18	3.21	1.00	4.32	−2.26
CZ	1.37	3.63	7.10	−0.04	2.25	2.23
DE	5.32	1.11	5.42	0.46	5.78	−4.00
DK	5.91	10.67	2.21	0.59	7.84	4.50
EE	4.11	5.85	4.95	−0.09	4.88	1.68
ES	4.00	5.17	10.42	4.53	4.98	1.13
FI	4.11	1.09	4.43	1.47	4.50	−2.90
FR	4.71	2.04	3.70	1.47	5.45	−2.56
HU	−2.67	3.86	−2.09	−0.03	−2.06	6.71
IT	1.91	2.18	3.30	2.70	2.77	0.27
NL	3.34	2.05	0.31	1.34	4.26	−1.25
NO	1.72	0.64	−0.29	1.11	2.30	−1.06
SE	3.94	3.77	5.28	0.55	4.41	−0.16
SI	1.41	2.14	10.43	0.27	1.98	0.72
SK	0.33	1.19	9.57	−1.19	2.57	0.85
UK	3.23	2.61	7.95	1.63	4.29	−0.61
Mean	3.05	3.32	4.87	0.98	4.08	0.29

Note: The country codes are the same as in Figure 4.

4 Results

Measuring the effects of environmental regulations on productivity growth, we estimate three different ML indices. Model I completely ignores the bad output and only maximizes the increase of the good output. Model II and III both maximize the increase of the good output while CO_2 emissions are either kept on the current level or are decreased by the same proportion as the increase of the good output. Decomposing the indices into their components, we analyse different sources of productivity growth, namely catch-up effects and technological improvements, and identify innovative countries.

The results of our CO_2 sensitive productivity analysis are presented in Table 4 and 5.[21] We report the cumulative indices for Models I, II, and III over the period 1995 to 2006. Table 4 shows the cumulative productivity growth while Table 5 reports the cumulative efficiency change and the cumulative technological change, respectively.[22]

[21] All estimates are obtained using the General Algebraic Modeling System (GAMS). We thank Carl Pasurka for providing us with the basic GAMS code for the linear programs.

[22] The cumulative indices for Denmark in Model II and III are not applicable due to infeasible solutions of the linear programs in the majority of years (see Section 2).

For all indices, values greater than one indicate an improvement; values less than one imply deterioration.

Table 4: Cumulative productivity growth (1995 = 1)

Country	Model I	Rank	Model II	Rank	Model III	Rank
AT	0.8455	14	0.8668	14	0.8959	14
BE	1.0684	5	1.2226	1	1.1386	1
CZ	0.8836	13	0.9284	13	0.9399	10
DE	1.0760	4	1.0895	4	1.1055	2
DK	1.2167	1	n/a	–	n/a	-
EE	0.9623	9	0.9759	9	0.9292	11
ES	0.8328	15	0.8346	16	0.8393	15
FI	1.0805	3	1.0952	3	1.0893	4
FR	1.0292	7	1.0441	5	1.0410	6
HU	0.9348	11	0.9379	12	0.9077	13
IT	0.9221	12	0.9670	10	0.9763	9
NL	1.0311	6	1.0044	7	1.0305	7
NO	0.9726	8	0.9534[a]	11	0.9246[b]	12
SE	1.1376	2	1.1149	2	1.0916	3
SI	0.8075	16	0.8621[a]	15	0.8237[b]	16
SK	0.7579	17	1.0338	6	1.0210	8
UK	0.9494	10	1.0011	8	1.0415	5
Mean	0.9711		0.9957		0.9872	

Notes: n/a = not available; [a]Norway for 1996/1997 to 2005/2006 and Slovenia for 1997/1998 to 2005/2006; [b]Norway and Slovenia for 1997/1998 to 2005/2006.

First referring to productivity growth, all three models suggest that on average, productivity decreased over time. In Model I which completely ignores CO_2 emissions and thus all abatement activities, productivity decreased on average by about 3% from 1995 to 2006. In contrast, average productivity in Models II and III which credit constant or decreasing CO_2 emissions, respectively, remains nearly unchanged or declines only by about 1%. This finding and the lower cumulative productivity values observed for the majority of the countries in Model I suggest that most of the countries undertook CO_2 abatement activities. In contrast to Model I, Models II and III reward these countries for their efforts and hence show a lower productivity decrease or a higher productivity increase than in Model I.

On the country level, all models show a high variation in the productivity development. The lowest cumulative value is observed for Slovakia in Model I indicating a productivity decrease of about 24% when CO_2 emissions are ignored. The highest value is shown for Belgium in Model II suggesting an increase of productivity of about 22% when CO_2 emissions are held constant. Independent of the model, we find a positive development of productivity for nearly half of the countries. Only Slovakia and the United Kingdom, show a productivity decrease in Model I but an increase in Models II and III.

In all models, Belgium, Germany, Finland, and Sweden are among the top performers with relative high growth rates between 7 and 22%. In contrast, Austria, Spain, and Slovenia are among the low performers. For these countries we observe a productivity decrease between 10 and 19%. Finally, while for the most countries the ranking across the models is quite stable, the ranks for Belgium, Norway, Slovakia, and the United Kingdom differ significantly from one model to the other. The ranking of Norway, one of the three countries that show lower growth rates in the CO_2 sensitive Models II and III than in the pure economic Model I (Norway, the Netherlands, and Sweden), falls from rank 8 to rank 11 in Model II and to rank 12 in Model III. On the other hand, Belgium, Slovakia, and the United Kingdom show higher ranks in the CO_2 sensitive models. The highest rank improvement is observed for Slovakia that ranks 11 (9) places better in Model II (Model III) than in Model I. This result, together with the positive productivity development in Models II and III and the negative productivity development in Model I, indicates that Slovakia's achievements in transport-related CO_2 abatement are much higher in relation to its achievements in transport-related economic output.

Table 5 depicts the cumulative efficiency change and cumulative technological change for the three models. As shown, all models suggest that on average efficiency decreased over time. In Model I, average efficiency decreased by around 5%, in Model II by around 6%, and in Model III by around 7%. Further, for 11 of the 17 countries a negative efficiency development is observed.

Referring to the cumulative technological change, all models indicate a positive rate of technological change over time, on average and for all countries. In the CO_2 sensitive Models II and III, the average rate of cumulative technological change (about 6%) is twice as high as in Model I (about 3%). While these results suggest technological improvements for all input mixes and levels, they do not indicate whether all countries implemented these improvements. Referring to Model III, a country's positive rate of cumulative technological change simply indicates an outward shift of the country's relevant portion of the best-practice frontier towards more gross output and fewer CO_2 emissions, but not whether the country actually operates on that frontier or causes its outward shift (Färe et al., 1994). For example, in Model III Slovakia shows the highest rate of cumulative technological change, about 16%. However, in the same model we also observe a cumulative efficiency decrease for Slovakia, about 12%. This means, that for Slovakia's production technology, CO_2 abating innovations occurred over time, but Slovakia was not able to follow these innovations in all years. Graphically spoken, over the observed period Slovakia was not able to catch up to the outward shifted best-practice frontier. Nevertheless, Slovakia's positive cumulative productivity change value in Model III still indicates productivity improvements of about 2%.

An opposing picture is shown, for example, for Finland in Model III. The cumulative efficiency change value of 1 and the equal cumulative technological change and productivity change value of 1.0893 suggest that Finland in all years operated on the best-practice frontier and pushed it outwards by technological innovations. On the whole, Finland

Table 5: Cumulative efficiency change and technological change (1995 = 1)

	Model I		Model II		Model II	
Country	CumEFF	CumTECH	CumEFF	CumTECH	CumEFF	CumTECH
AT	0.8241	1.0261	0.8153	1.0633	0.8620	1.0394
BE	1.0614	1.0066	1.0316	1.1854	1.0179	1.1186
CZ	0.8705	1.0151	0.9186	1.0108	0.9369	1.0031
DE	1.0572	1.0178	1.0717	1.0167	1.0814	1.0221
DK	1.1961	1.0172	n/a	n/a	n/a	n/a
EE	0.9555	1.0071	0.9262	1.0536	0.8917	1.0420
ES	0.8229	1.0121	0.8233	1.0138	0.8291	1.0122
FI	1.0000	1.0806	1.0000	1.0952	1.0000	1.0893
FR	1.0119	1.0172	1.0295	1.0141	1.0209	1.0198
HU	0.9264	1.0092	0.9311	1.0072	0.9022	1.0060
IT	0.9183	1.0043	0.9318	1.0378	0.9491	1.0286
NL	0.9513	1.0841	0.9119	1.1013	0.9168	1.1243
NO	0.9483	1.0258	0.8709[a]	1.0949[a]	0.8599[b]	1.0753[b]
SE	1.1277	1.0088	1.1131	1.0017	1.0878	1.0035
SI	0.7753	1.0415	0.8453[a]	1.0200[a]	0.8027[b]	1.0258[b]
SK	0.7120	1.0644	0.8361	1.2364	0.8790	1.1616
UK	0.9189	1.0332	0.9269	1.0802	0.9210	1.1308
Mean	0.9458	1.0277	0.9365	1.0645	0.9349	1.0564

Notes: n/a = not applicable; [a]Norway for 1996/1997 to 2005/2006 and Slovenia for 1997/1998 to 2005/2006; [b]Norway and Slovenia for 1997/1998 to 2005/2006.

realized a cumulative productivity improvement of about 9% as a result of technological innovations.

Altogether, our results on cumulative efficiency change and cumulative technological change suggest that some innovative countries shifted the best-practice frontier outwards by implementing technological innovations. However, the decline in cumulative efficiency change for 11 of the 17 countries shows that these innovations did not diffuse and that the majority of the countries were not able to catch-up to the new best-practice frontier.

While our cumulative results for Models II and III clearly identify Finland as an innovative country shifting the frontier they do not reveal much about any innovative behaviour of the other countries. In order to determine which countries in which periods are 'innovators' the following set of conditions defined by Färe et al. (2001) is used:

$$SMLTECH_t^{t+1} > 1 \tag{15}$$

$$\vec{D}_o^t(t+1) < 0 \tag{16}$$

$$\vec{D}_o^{t+1}(t+1) = 0 \tag{17}$$

The first condition indicates an outward shift of the best-practice frontier from period t to period $t+1$. That is in Model I a shift towards more gross output, in Model II a shift towards more gross output with constant CO_2 emissions, and in Model III a shift towards more gross output and fewer CO_2 emissions. The second condition states that the country's production in period $t+1$ is located above the best-practice frontier of period t. This means, that not only has the country's relevant portion of the best-practice frontier shifted outward, but that the country itself made technological progress. Finally, the third condition implies that the country's production in period $t+1$ is located on the best-practice frontier in $t+1$. Table 6 list the frontier shifting innovative countries for each consecutive two-year period in our three models.

Out of the 17 European countries, seven countries are innovators. Some countries are innovators only for a short period (e.g. the United Kingdom or Italy), whereas other countries, namely Finland and Belgium are innovators for a longer period. Finland is identified as an innovator in all consecutive two-year periods in the two CO_2 sensitive models. Further, with the exception of one period, Finland is also an innovator for all consecutive two-year periods in Model I. In contrast, Belgium is only an innovator in the CO_2 sensitive models.[23]

Table 6: Countries shifting the frontier

Years	Model I	Model II	Model III
1995-1996	FI, SK, UK	DK, FI, SK, UK	FI, SK, UK
1996-1997	FI, UK	BE, FI, NO, SK, UK	BE, FI, SK, UK
1997-1998	UK	BE, FI, UK	BE, FI, UK
1998-1999	FI	BE, DK, FI	BE, DK, FI
1999-2000	FI	BE, FI, IT, SK	BE, FI, IT, SK
2000-2001	FI	BE, FI, IT, SK	BE, FI, IT, SK
2001-2002	FI	FI	FI
2002-2003	FI	FI	FI
2003-2004	FI	FI	FI
2004-2005	FI	BE, FI	BE, FI
2005-2006	FI	BE, FI	BE, FI

Note: The country codes are the same as in Figure 4.

Finally, in order to analyse productivity changes over time, Figure 5 presents the development of average cumulative productivity growth and its components for the period

[23] In order to investigate which factors define innovators and/or drive productivity improvements, we regressed the countries' cumulative productivity growth on several country-specific factors. Among them were socio-economic variables like GDP per capita and population density, environmental-economic variables like energy intensity and energy taxes as well as transport-specific variables like network density and modal split. However, none of these factors was statistically significant.

1995 to 2006. In Model I, average cumulative productivity was less than unity over the whole observed period. This development was driven by a continuous efficiency decrease and could not be counteracted by the steady but rather low increase in average cumulative technological change. In contrast, in Model II and to a lesser extent in Model III, average cumulative productivity growth exceeded unity for a few selective years. Nevertheless, after a peak in 2001, both models show a by efficiency losses induced decrease of average cumulative productivity growth as well. Similar to Model I, the continuous increase in average cumulative technological change was not able to fully compensate this development. However, at the end, the higher increase of average cumulative technological change and hence the better development of average cumulative productivity growth in Models II and III indicate that productivity enhancing CO_2 abating technological improvements took place during the observed period.

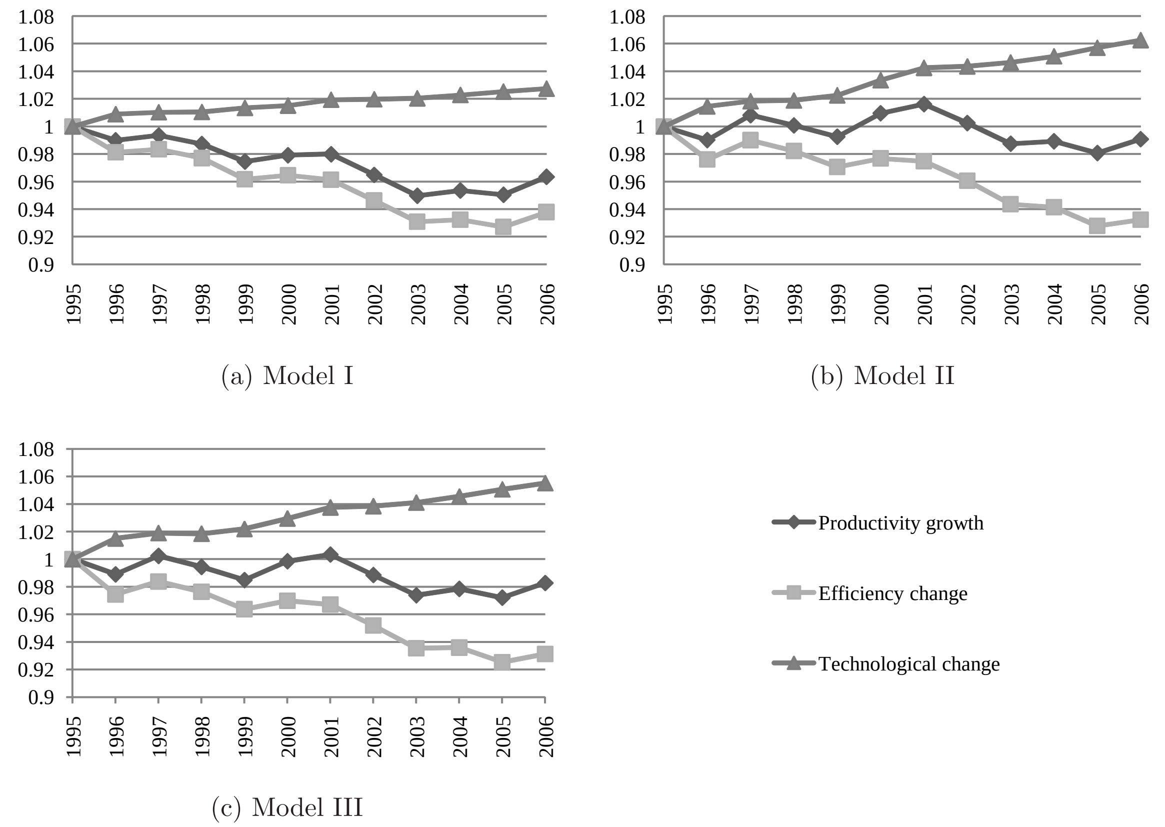


Figure 5: Development of average cumulative productivity growth and its components

5 Conclusions

In this paper we analysed the CO_2 sensitive productivity growth of the commercial transport industry in 16 member states of the European Union and in Norway for the period

1995-2006. Because the transport sector is a large and steadily growing source of GHG and especially of CO_2 emissions, it is important to meet both environmental protection targets as well as economic requirements. The objective is to compare CO_2-sensitve productivity and efficiency growth of the European commercial transport industry which is subject to regulations for reducing CO_2 emissions. Because regulations are country-specific and related to individual rather than to standardised measures, it is necessary to investigate the effects of those regulations on productivity growth.

Using a directional distance function approach, we calculated three versions of the sequential Malmquist-Luenberger productivity index that allows accounting for the joint production of good and bad outputs. While our first model completely ignores the bad output (i.e. CO_2 emissions), and solely seeks to increase the good output (i.e. gross output), the second and the third models give credit to observations that increase gross output at a constant or at a reduced level of CO_2 emissions. Our results provide first insights in the CO_2 sensitive productivity development in the European commercial transport industry. By using a unique data set that combines economic figures with environmental information we provide a first benchmark and identify best-practice countries.

Independent of the model we find a positive productivity development for nearly half of the countries in the observed period. Furthermore, for the majority of the countries, higher productivity growth values are found in the two CO_2 sensitive models than in the pure economic model. This result indicates that the majority of countries undertook CO_2 abatement activities. The pure economic model does not account for these activities and hence underestimates the 'real' productivity growth.

Nevertheless, all models indicate a productivity decrease on average. Decomposing productivity growth into its elements revealed that this development is driven by efficiency losses which on the average level could not be counteracted by technological improvements. Altogether, 11 of the 17 countries show efficiency losses, indicating that the majority of the countries were not able to fully follow the technological improvements induced by some innovative countries. As the main innovators, Finland and Belgium were identified as shifting the best-practice frontier in almost all years. Unfortunately we were not able to identify which factors define these innovative countries or foster CO_2 sensitive productivity growth. Standard economic, environmental-economic, and transport-specific variables revealed no significant influence. In all likelihood this is due to the aggregation level of our data and the huge heterogeneity of the country-specific transport industries and the country-specific environmental protection efforts.

While in the last decades a mixture of economic instruments differing between transport mode and EU member state were implemented, our benchmark reflects the resulting inefficiencies and hence corroborates the findings of the European Commission's White Paper (European Commission, 2011*b*). The White Paper enhances a competitive and sustainable transport system under provision of a coherent European policy framework. Overall the development and impact on productivity of the implementation of coordinated and more uniform environmental regulations should be considered rather than individual country-specific policies in the European transport sector.

Further research should extend the analysis by gathering more detailed, disaggregated information on the industries' sub sectors (i.e. road transport, rail, aviation, and shipping), and the country-specific environmental protection efforts (i.e. technological regulations, taxes, and so forth). Moreover it would be of particular interest to analyse the impact of upcoming EU legislation, such as the extension of the EU Emissions Trading System to the aviation sector, the limitation of CO_2 emissions per km for new vehicles, or the implementation of alternative fuels and of the White Paper's initiatives.

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ABOUT EWI

EWI is a so called An-Institute annexed to the University of Cologne. The character of such an institute is determined by a complete freedom of research and teaching and it is solely bound to scientific principles. The EWI is supported by the University of Cologne as well as by a benefactors society whose members are of more than forty organizations, federations and companies. The EWI receives financial means and material support on the part of various sides, among others from the German Federal State North Rhine-Westphalia, from the University of Cologne as well as – with less than half of the budget – from the energy companies E.ON and RWE. These funds are granted to the institute EWI for the period from 2009 to 2013 without any further stipulations. Additional funds are generated through research projects and expert reports. The support by E.ON, RWE and the state of North Rhine-Westphalia, which for a start has been fixed for the period of five years, amounts to twelve Million Euros and was arranged on 11th September, 2008 in a framework agreement with the University of Cologne and the benefactors society. In this agreement, the secured independence and the scientific autonomy of the institute plays a crucial part. The agreement guarantees the primacy of the public authorities and in particular of the scientists active at the EWI, regarding the disposition of funds. This special promotion serves the purpose of increasing scientific quality as well as enhancing internationalization of the institute. The funding by the state of North Rhine-Westphalia, E.ON and RWE is being conducted in an entirely transparent manner.