Changes in Undesirable Impacts on Sustainable Road Transport of a set of European Countries

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Abstract

Road transport is vital to the economic development, trade and social integration. However, it is also responsible for the majority of negative impacts on environment and society. To achieve sustainable development, there is a growing need for a country to assess its undesirable costs so as to determine road transport policy. In this study, total energy consumption, greenhouse gas emissions, as well as the number of fatalities in the European road transport are selected representing the level of each EU country's sustainable development. With data from the period of 1995-2007, the extent to which the 27 EU countries have improved their 'productivity' on sustainable road transport is evaluated based on data envelopment analysis (DEA) and Malmquist productivity index approach, which measures the productivity change over time, and can be further decomposed into two components: the change in efficiency and the technical change. The results show a considerable progress towards the sustainable road transport in Europe during this period. The decomposition into the two components further revealed that the bulk of the improvement was attained through the adoption of productivity-enhancing new technologies throughout the road transport sector, rather than through the relatively inefficient countries catching up with those efficient ones. Furthermore, the growth in both two aspects slowed down in 2007, which implies the momentum of further improvement is in danger of being lost so that new impetus is needed.

1 INTRODUCTION

The economic and structural development of our present society is to a very large extent based on successive improvements in transport. By speeding up communications and the transport of goods and people, the transportation systems have become a crucial component of modernity, and have generated a revolution in contemporary economic and social relations. In Europe, the transport sector generates an annual turnover of around €363 billion (or 4.5% of EU GDP) and employs more than 8.2 million people (*1*). If one takes into account related services, including the manufacture of transport equipment, infrastructure construction and maintenance, trade, as well as tourism, the jobs and wealth stemming from transport are even greater. However, the transport growth has not come about without cost: energy consumption, greenhouse gas (GHG) emissions and safety issues are all directly linked to modern transport systems, which render the transport to be one of the key challenges of the EU sustainable development strategy (*2*).

Of all the transport modes, due to easy accessibility, flexibility of operations, and door-to-door service, road transport has emerged as the dominant segment in European transport sector, which represents roughly 84% of all passenger transport and 45% of freight transport (*3*). However, it is also responsible for the majority of negative impacts on sustainable transport. In 2007, road transport in the EU-27 accounted for about 82% of transport energy consumption, with an increasing rate of 1.4% per year on average between 2000 and 2007 (*2,4*). Moreover, since fossil fuels are still the primary energy source for road transport nowadays, their ever-growing consumption is strongly linked to the issues such as the security of supply, production of renewables, and, to an increasing extent, climate change due to rising emissions of GHG (e.g., CO_2, CH_4, and N_2O). Specifically, the EU-27 total GHG emissions from transport (excluding international aviation and maritime transport) increased by 26% between 1990 and 2007, and it is the only major source category currently producing considerably more GHG emissions than in 1990. Amongst others, road is the most important driver for this development with 94% of total transport GHG emissions in 2007 (*4*). Furthermore, road transport is increasingly associated with the rise in the negative effects on safety, which is important not only because of the lost travel time or cost of property damage, but also because of the loss of human life and serious injuries sustained. In 2007, more than 42,000 persons died as a consequence of road crashes in the EU-27, and many more suffer non-fatal injuries (*5*). Despite the fact that this figure keeps decreasing since 2001, the year in which the EU set itself a target of halving the yearly number of road fatalities within 10 years (*6*), it is, however, still far away from the 25,000 objectives for 2010. Moreover, the rising costs in health services and the added burden on public finances due to road traffic injuries and fatalities representing about 2% of the GDP of the EU (*7*) are becoming increasingly socially unacceptable and difficult to justify to citizens. As a result, in the mid-term review of the European Commission's 2001 Transport White Paper, the EU has renewed the definition of its future transport policy directions that "although mobility is essential to Europe's prosperity and to the freedom of movement of its citizens, the negative effects of mobility, i.e. energy consumption and impacts on health and the environment, must be reduced" (*8*).

In order to achieve the sustainable road transport, there is a growing need for a country to assess its changes in the undesirable impacts over time, to compare them with the ones of other countries, and to provide estimates of their future developments, thus helping policy makers in designing effective strategies, setting realistic targets, determining intervention priorities and monitoring programme effectiveness. In this study, data envelopment analysis (DEA) (*9*), which applies mathematical optimization technique to measure the relative efficiency of a set of decision making units (DMUs) on the basis of multiple inputs and multiple outputs, and the Malmquist productivity index (*10*), which evaluates productivity change of DMUs over time, are employed to undertake the assessment. Using passenger-kilometers travelled (pkm) and freight tonne-kilometers travelled (tkm) as the model's inputs, and the three undesirable impacts on the sustainable road transport, i.e., the total energy consumption, the GHG emissions, as well as the number of fatalities in road transport as outputs, this study measures the extent to which the 27 EU countries have improved their 'productivity' on sustainable road transport over the period of 1995-2007. In doing so, an adjusted DEA-based Malmquist productivity index is proposed, the results indicate that there was a significant progress towards the sustainable road transport in Europe during this period. However, the development in the different countries was unbalanced, and some of them were even deteriorating. Moreover, the decomposition of the index into technical changes and efficiency changes further revealed that the bulk of the improvement was attained through the adoption of productivity-enhancing new technologies throughout the road transport sector, rather than through the relatively inefficient countries catching up with those efficient ones.

The remaining of the paper is structured as follows. In Section 2, we briefly review the principle of data envelopment analysis and propose an adjusted DEA for modeling undesirable outputs. In Section 3, we elaborate the construction of Malmquist productivity index based on the proposed DEA model. In Section 4, we demonstrate the application of this DEA-based Malmquist productivity index for sustainable road transport evaluation, and the results are subsequently provided and discussed. The paper ends with conclusions in Section 5.

2 EFFICIENCY MEASUREMENT BASED ON DEA MODEL WITH UNDESIRABLE OUTPUTS

Data envelopment analysis, originally proposed by Charnes et al. (*9*), is a non-parametric linear programming methodology to measure the relative efficiency of a homogeneous set of DMUs. It provides a new way of obtaining empirical estimates of relations between the multiple inputs and multiple outputs related to DMUs by constructing an efficient production frontier based on the best practices without a priori information on tradeoffs among the inputs and outputs. Since its first introduction in 1978, DEA has been quickly recognized as a powerful analytical research tool for modeling operational processes in terms of performance evaluations and has been successfully applied to a host of different types of entities engaged in a wide variety of activities in many contexts (*11-13)*.

In this study, different from the definition of the best practices in classical DEA models which rely on the assumption that inputs have to be minimized and outputs have to be maximized (such as in economics field), here we want the outputs, i.e., the energy consumption, GHG emissions, and the number of road fatalities to be as low as possible based on a given set of inputs, i.e., the passenger and freight transport. Therefore, the DEA frontier DMUs (or countries in this study) are those with minimum output levels given input levels, and each DMU's efficiency is then measured relative to this frontier.

Graphically, consider two units P(x_0, y_0) and Q(x_1, y_1), each consuming one single input and producing one undesirable output. Based on the DEA principle that for a given amount of input, units providing lower amounts of the output will be the efficient ones, we can identify that unit Q is efficient. Thereby the efficiency frontier *F* is the ray extending from the origin through the Q, and the area above this frontier constituting the production possibilities sets, in which the unit P is located. Hence, P is inefficient, and its efficiency score can be computed as: AB/AP, which is also defined as the distance function of P, denoted as $D_o(x_o, y_o)$.

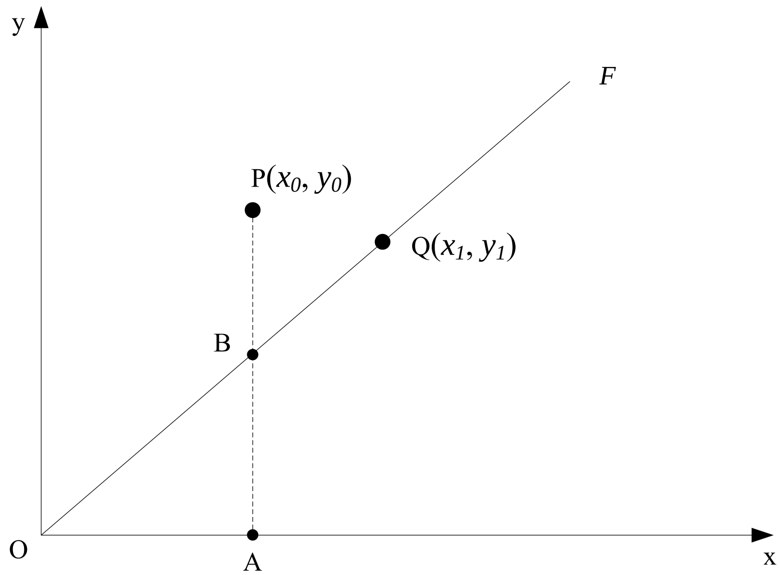

FIGURE 1 Graphic representation of efficiency frontier based on the DEA model with an undesirable output

Mathematically, consider a set of *n* DMUs, or the 27 EU countries in this study, in which each unit consumes *m* different inputs to produce *s* different outputs (in the study undertaken here, *m*=2, and *s*=3). The efficiency score of a particular DMU_o can be obtained by solving the following adjusted output-oriented DEA model[1]:

$$
\begin{aligned}
& D_o(x_o, y_o) = \min \ \theta_o \\
& s.t. \quad \sum_{j=1}^{n} x_{ij}\lambda_j \geq x_{io}, \quad i = 1, \cdots, m \\
& \qquad \sum_{j=1}^{n} y_{rj}\lambda_j \leq \theta_o y_{ro}, \quad r = 1, \cdots, s \\
& \qquad \lambda_j \geq 0, \quad j = 1, \cdots, n
\end{aligned}
\qquad (1)
$$

This linear program is computed separately for each DMU, and the subscript, *o*, refers to the DMU whose efficiency is to be evaluated. θ ($0 < \theta \leq 1$) is the uniform proportional reduction in the DMU_o's outputs. Its minimum amount is known as the DEA efficiency score for DMU_o, which also equals to its distance function, i.e., $D_o(x_o, y_o)$. Moreover, λ_j is an n×1 nonnegative vector of the weight given to the *j*th DMU's inputs and outputs in constructing for DMU_o a hypothetical composite unit (HCU) that outperforms it. In other words, solving this linear programming problem enables us to find the lowest possible value of θ, for which there exists a HCU that owns at least as much of each input as DMU_o, meanwhile leading to no more than θ times each of the outputs of that DMU. Hence, if the value of θ equals to one, then the DMU is efficient and its input-output combination lies on the efficiency frontier, such as the unit Q in Fig. 1. In the case that θ<1, the DMU is inefficient, and it lies inside the frontier, such as

[1] The model can be deduced from the basic input-oriented DEA model *(9)* by switching each of the inputs and outputs into the place of the other.

the unit P whose efficiency score equals to AB/AP<1, and the point B could be treated as its HCU.

3 DEA-BASED MALMQUIST INDEX FOR PRODUCTIVITY CHANGE ASSESSMENT

The concept of the Malmquist productivity index, introduced by Malmquist (*10*) as a quantity for analyzing the consumption of inputs, has been further developed by Caves et al. (*14*). Afterwards, Färe et al. (*15*) combined the ideas on the measurement of efficiency and the measurement of productivity to construct a Malmquist productivity index directly from input and output data using DEA. Specifically, by using panel data, the DEA-based Malmquist productivity index, hereafter referred to as DEA-MI, relies on firstly constructing efficiency frontiers over the whole sample realized by DEA (as illustrated in Section 2), and then computing the distance of individual observations from the frontiers. In practice, the DEA-MI has proven to be a good tool for measuring the productivity change of DMUs over time (*16-18*).

Moreover, in contrast to conventional production functions or other index approaches, the DEA-MI can be further decomposed into two components, one measuring the change in efficiency (*EFFCH*) and the other measuring the change in the frontier technology (*TECHCH*). From the output-oriented view of sustainable road transport assessed in this study, an improvement in efficiency occurs when there are decreases in the quantities of outputs (i.e., energy consumption, GHG emissions, and road fatalities) based on a given set of inputs, using a given technology. Operationally, it can be realized by enhancing traffic management, for instance, encouraging citizens to use public transport instead of private cars has been widely recognized as a useful way in lowering energy consumption, decreasing the negative environmental affects issues, and improving road safety situation as well, under the same road traffic volume. In contrast to a change in efficiency, technical change occurs through the adoption of new technologies or strategies that reduce the minimum quantities of outputs given a certain level of inputs. In this respect, adoption of renewable fuels, introduction of new types of vehicles, and improvement in road infrastructures are all related to productivity-enhancing technical changes.

Towards a sustainable road transport system, both efficiency enhancements and technical improvements are required. The DEA-MI calculated here will allow us to measure the combined effect of *EFFCH* and *TECHCH* of each DMU within the given period, and it will also capture the separate impact of each effect.

Mathematically, the DEA-MI is computed as the product of *EFFCH* and *TECHCH*. Therefore, to calculate the total productivity change of a DMU over time, we need to firstly derive its *EFFCH* and *TECHCH.* In doing so, consider the same situation as in Fig. 1, but with two time periods t and $t+1$, which is illustrated in Fig. 2.

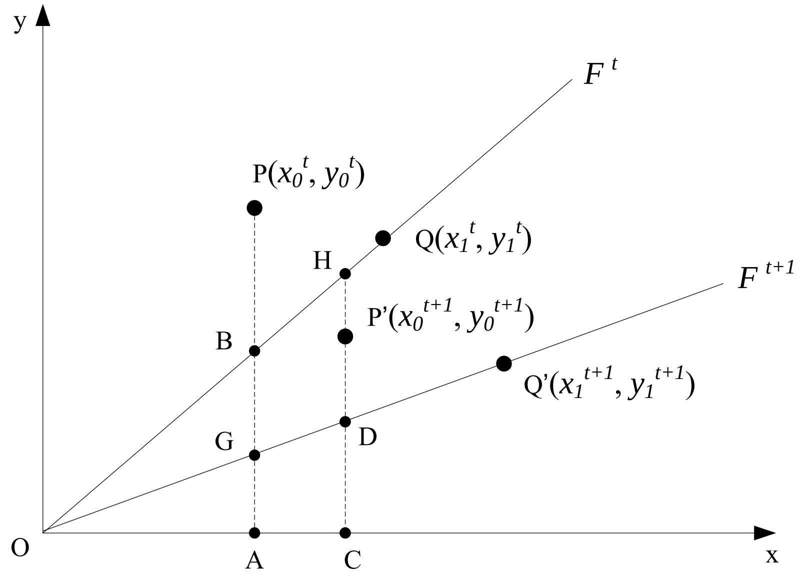

FIGURE 2 Graphic representation for EFFCH and TECHCH computation

By identifying the efficient unit in each time period, which is $\mathrm{Q}(x_1^t, y_1^t)$ and $\mathrm{Q'}(x_1^{t+1}, y_1^{t+1})$, respectively, we derive the efficiency frontiers F^t and F^{t+1} as in Fig. 2. Now, the magnitude of the efficiency change of unit P from the period t to t+1 can be measured as: $\frac{\mathrm{CD}}{\mathrm{CP'}} \Big/ \frac{\mathrm{AB}}{\mathrm{AP}}$, which can be further expressed in the corresponding distance function forms as follows:

$$EFFCH = \frac{D_o^{t+1}(x_o^{t+1}, y_o^{t+1})}{D_o^t(x_o^t, y_o^t)} \qquad (\mathbf{2})$$

where the two distance functions can be computed by means of DEA as in (**1**), and they are represented as bellow:

$$\begin{aligned}
& D_o^t(x_o^t, y_o^t) = \min\theta & & D_o^{t+1}(x_o^{t+1}, y_o^{t+1}) = \min\theta \\
& s.t. \quad \sum_{j=1}^{n} x_{ij}^t \lambda_j \ge x_{io}^t, \quad i = 1, \cdots, m & & s.t. \quad \sum_{j=1}^{n} x_{ij}^{t+1} \lambda_j \ge x_{io}^{t+1}, \quad i = 1, \cdots, m \\
& \qquad \sum_{j=1}^{n} y_{rj}^t \lambda_j \le \theta y_{ro}^t, \quad r = 1, \cdots, s & & \qquad \sum_{j=1}^{n} y_{rj}^{t+1} \lambda_j \le \theta y_{ro}^{t+1}, \quad r = 1, \cdots, s \qquad (\mathbf{3}) \\
& \qquad \lambda_j \ge 0, \quad j = 1, \cdots, n & & \qquad \lambda_j \ge 0, \quad j = 1, \cdots, n
\end{aligned}$$

For the effect of efficiency change, which also reflects the capability of a DMU in catching up with those efficient ones, *EFFCH*>1 indicates progress in the relative efficiency of the DMU_o from the period t to t+1, while *EFFCH*=1 and *EFFCH*<1 means respectively no change and regress in efficiency.

To fully evaluate the productivity change, we should also take into account the technical change, which measures the shift in the technology frontier between two time periods. In Fig. 2 case, we notice that the production possibilities set expands from the period t to t+1, as a great number of input-output combinations become feasible when the frontier moves from F^t to F^{t+1}, and the HCU of unit P also moves from B to G. Thus, the *TECHCH* at $\mathrm{P}(x_0^t, y_0^t)$ is evaluated by: AB/AG, which is equivalent to:

$$TECHCH_{\mathrm{P}} = \frac{\mathrm{AB/AP}}{\mathrm{AG/AP}} = \frac{D_o^t(x_o^t, y_o^t)}{D_o^{t+1}(x_o^t, y_o^t)} \quad (4)$$

where the denominator $D_o^{t+1}(x_o^t, y_o^t)$ denotes the relative efficiency of $\mathrm{P}(x_0^t, y_0^t)$ with respect to the frontier at time t+1.

Similarly, the *TECHCH* at $\mathrm{P'}(x_0^{t+1}, y_0^{t+1})$ is expressed by:

$$TECHCH_{\mathrm{P'}} = \frac{\mathrm{CH/CP'}}{\mathrm{CD/CP'}} = \frac{D_o^t(x_o^{t+1}, y_o^{t+1})}{D_o^{t+1}(x_o^{t+1}, y_o^{t+1})} \quad (5)$$

where the numerator $D_o^t(x_o^{t+1}, y_o^{t+1})$ represents the relative efficiency of $\mathrm{P'}(x_0^{t+1}, y_0^{t+1})$ relative to the frontier at time t.

The overall *TECHCH* is defined as the geometric mean of the above two *TECHCH*s, i.e.,

$$TECHCH = \left[\frac{D_o^t(x_o^t, y_o^t)}{D_o^{t+1}(x_o^t, y_o^t)} \frac{D_o^t(x_o^{t+1}, y_o^{t+1})}{D_o^{t+1}(x_o^{t+1}, y_o^{t+1})} \right]^{1/2} \quad (6)$$

where the two mixed-period measures, i.e., $D_o^{t+1}(x_o^t, y_o^t)$ and $D_o^t(x_o^{t+1}, y_o^{t+1})$, can be derived by the following modification of the DEA model as in (**1**):

$$\begin{aligned} & D_o^{t+1}(x_o^t, y_o^t) = \min \theta & & D_o^t(x_o^{t+1}, y_o^{t+1}) = \min \theta \\ s.t. \quad & \sum_{j=1}^{n} x_{ij}^{t+1} \lambda_j \geq x_{io}^t, \quad i = 1, \cdots, m & s.t. \quad & \sum_{j=1}^{n} x_{ij}^{t} \lambda_j \geq x_{io}^{t+1}, \quad i = 1, \cdots, m \\ & \sum_{j=1}^{n} y_{rj}^{t+1} \lambda_j \leq \theta y_{ro}^t, \quad r = 1, \cdots, s & & \sum_{j=1}^{n} y_{rj}^{t} \lambda_j \leq \theta y_{ro}^{t+1}, \quad r = 1, \cdots, s \\ & \lambda_j \geq 0, \quad j = 1, \cdots, n & & \lambda_j \geq 0, \quad j = 1, \cdots, n \end{aligned} \quad (7)$$

For the change in the frontier technology, values greater than one indicate an improvement in this aspect, while values equal to and less than one imply the status quo and deterioration, respectively.

By now, the DEA-MI, which measures the productivity change of a particular DMU_o from the period t to t+1, can be computed as the product of *EFFCH* and *TECHCH*:

$$\begin{aligned} MI_o &= \frac{D_o^{t+1}(x_o^{t+1}, y_o^{t+1})}{D_o^t(x_o^t, y_o^t)} \left[\frac{D_o^t(x_o^t, y_o^t)}{D_o^{t+1}(x_o^t, y_o^t)} \frac{D_o^t(x_o^{t+1}, y_o^{t+1})}{D_o^{t+1}(x_o^{t+1}, y_o^{t+1})} \right]^{1/2} \\ &= \left[\frac{D_o^t(x_o^{t+1}, y_o^{t+1})}{D_o^t(x_o^t, y_o^t)} \frac{D_o^{t+1}(x_o^{t+1}, y_o^{t+1})}{D_o^{t+1}(x_o^t, y_o^t)} \right]^{1/2} \end{aligned} \quad (8)$$

MI_o>1 indicates progress in the total factor productivity of the DMU_o from the period t to t+1, while MI_o=1 and MI_o<1 means respectively the status quo and decay in productivity.

In the following section, the DEA-MI is applied to assess the changes in the undesirable impacts on sustainable road transport in Europe from 1995 onwards. Meanwhile, the two effects on efficiency enhancements and technical change are captured separately.

4 APPLICATIONS FOR SUSTAINABLE ROAD TRANSPORT EVALUATION

Sustainable development is a fundamental and overarching objective of the European Union, in which sustainable road transport is one of the key challenges requiring particular concerns. In this respect, energy consumption, environmental pollution, and road crashes are three essential aspects against the objective and can not be viewed in isolation. In this study, changes in all these three undesirable impacts over time are evaluated simultaneously based on the DEA-MI approach. Specifically, using passenger transport (1,000 million pkm) and freight transport (1,000 million tkm) as the model's inputs, and the total energy consumption in road transport (Mtoe), the GHG emissions in road transport (million tonnes CO2 equivalent), as well as the number of road fatalities as outputs, with the data collected from 1995 to 2007 for the 27 EU countries being Austria (AT), Belgium (BE), Bulgaria (BG), Cyprus (CY), Czech Republic (CZ), Denmark (DK), Estonia (EE), Finland (FI), France (FR), Germany (DE), Greece (EL), Hungary (HU), Ireland (IE), Italy (IT), Latvia (LV), Lithuania (LT), Luxembourg (LU), Malta (MT), the Netherlands (NL), Romania (RO), Poland (PL), Portugal (PT), Slovakia (SK), Slovenia (SI), Spain (ES), Sweden (SE), and the United Kingdom (UK) (*3,19*), the DEA-MI is adopted to measure the extent to which the countries have improved their 'productivity' on sustainable road transport during the period under study. The results are shown in Fig. 3.

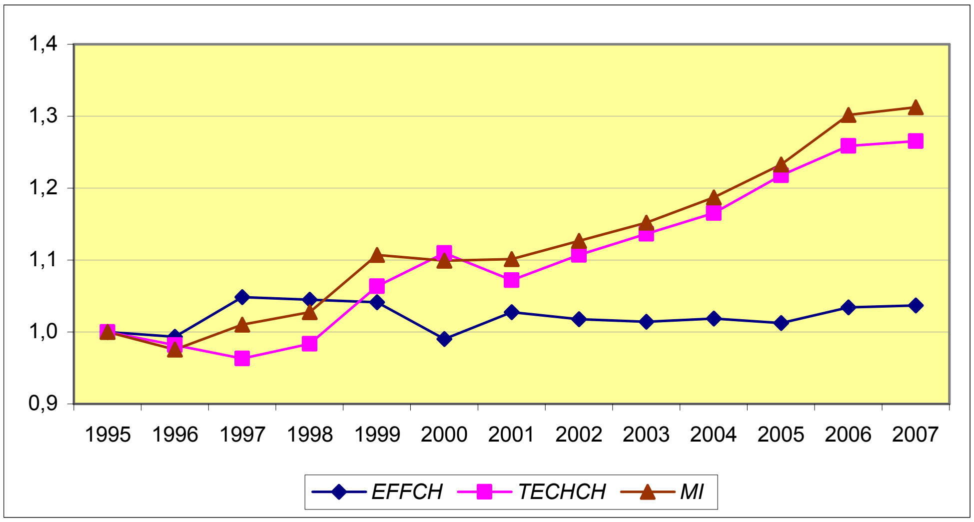

FIGURE 3 The evolution in *MI* and its decomposition into technical and efficiency changes in 1995-2007

Fig. 3 indicates the cumulative *MI* of the EU-27 and its decomposition (i.e., *EFFCH* and *TECHCH*) from 1995 to 2007 by sequential multiplication of the improvements in each year with 1995 as the index year (equal to one). From the trend of *MI*, we can see that the 27 EU countries as a whole exhibits considerable improvement towards the sustainable road transport (over 30%) during this period. Although slight decreases existed in 1996 and 2000, from 2001 onwards, the total 'productivity' went steadily up, and it was mostly dominated by its technical component. In other words, the main source of this growth came about more through the adoption of productivity-enhancing new technologies throughout the road transport sector than through the efficiency improvements among those relatively inefficient countries. However, it should be noticed that in 2007, the growth in both two aspects slowed down, which also led to the slow down of the final 'productivity'. This developing trend implies that the momentum of further improvement is in danger of being lost so that new impetus is needed.

To illustrate the progress of each of the 27 EU countries during the past 13 years, we firstly look at the changes in technical efficiency. Table 1 and 2 present the DEA efficiency scores and the corresponding efficiency changes of the EU-27 over the period of 1995-2007.

TABLE 1 Efficiency scores of the 27 EU countries over the period of 1995-2007

Country	Efficiency score												
	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
BE	0.90	0.86	0.89	0.83	0.82	0.81	0.84	0.83	0.80	0.78	0.77	0.78	0.77
BG	0.71	0.78	0.93	0.80	0.66	0.62	0.69	0.72	0.64	0.68	0.65	0.59	0.71
CZ	1.00	1.00	1.00	1.00	1.00	0.95	1.00	1.00	0.99	0.89	0.78	0.94	0.80
DK	0.91	0.88	0.90	0.86	0.88	0.84	0.85	0.83	0.82	0.81	0.82	0.82	0.72
DE	0.87	0.87	0.87	0.88	0.91	0.88	0.95	0.95	0.97	1.00	1.00	1.00	1.00
EE	0.58	0.62	0.67	0.76	0.79	0.79	0.85	0.74	0.77	0.84	0.90	0.75	0.79
IE	0.92	0.81	0.80	0.71	0.71	0.69	0.69	0.69	0.73	0.70	0.66	0.66	0.70
EL	0.51	0.56	0.61	0.62	0.62	0.60	0.67	0.68	0.67	0.71	0.68	0.66	0.68
ES	0.71	0.70	0.74	0.70	0.71	0.67	0.71	0.75	0.77	0.83	0.85	0.90	0.96
FR	0.91	0.90	0.90	0.91	0.93	0.87	0.91	0.93	0.97	0.99	1.00	0.98	0.94
IT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
CY	0.49	0.47	0.52	0.51	0.50	0.46	0.49	0.51	0.49	0.39	0.38	0.39	0.38
LV	0.64	0.69	0.86	1.00	0.92	0.81	0.82	0.80	0.80	0.80	0.76	0.85	0.89
LT	0.86	0.93	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
LU	1.00	0.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HU	1.00	1.00	1.00	0.98	0.84	0.78	0.78	0.69	0.66	0.66	0.63	0.66	0.71
MT	0.74	0.70	0.69	0.68	1.00	0.69	0.69	0.67	0.67	0.74	0.69	0.86	0.72
NL	0.97	0.97	1.00	1.00	1.00	0.92	1.00	1.00	0.93	1.00	1.00	1.00	1.00
AT	0.74	0.72	0.78	0.71	0.75	0.71	0.73	0.67	0.68	0.63	0.61	0.70	0.71
PL	0.70	0.81	0.88	0.95	0.74	0.88	0.95	0.98	0.85	0.90	0.82	0.84	0.95
PT	0.70	0.77	0.83	0.76	0.74	0.71	0.77	0.73	0.74	0.77	0.79	0.86	0.87
RO	0.88	0.70	0.83	0.82	0.88	0.70	0.66	0.69	0.79	0.78	1.00	1.00	1.00
SI	0.73	0.71	0.74	0.85	0.90	0.83	0.93	0.95	0.98	1.00	1.00	1.00	0.97
SK	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.00	1.00	1.00	1.00	1.00
FI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SE	1.00	1.00	1.00	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
UK	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 2 Efficiency changes of the 27 EU countries from 1995 to 2007

Country	*EFFCH*												
	96/95	97/96	98/97	99/98	00/99	01/00	02/01	03/02	04/03	05/04	06/05	07/06	07/95
AT	0.97	1.08	0.92	1.06	0.94	1.04	0.91	1.01	0.94	0.96	1.16	1.01	0.96
BE	0.96	1.04	0.94	0.98	0.98	1.04	0.99	0.96	0.98	0.99	1.01	0.99	0.86
BG	1.10	1.19	0.86	0.82	0.95	1.11	1.04	0.89	1.06	0.97	0.90	1.20	0.99
CY	0.96	1.11	0.98	0.97	0.92	1.08	1.04	0.95	0.79	0.99	1.03	0.96	0.77
CZ	1.00	1.00	1.00	1.00	0.96	1.05	1.00	0.99	0.90	0.88	1.20	0.85	0.80
DE	1.00	1.00	1.01	1.04	0.96	1.08	1.00	1.02	1.03	1.00	1.00	1.00	1.16
DK	0.98	1.02	0.96	1.02	0.96	1.01	0.98	0.98	0.99	1.02	1.00	0.87	0.79
EE	1.08	1.08	1.13	1.04	1.01	1.07	0.87	1.04	1.09	1.08	0.83	1.06	1.38
EL	1.10	1.08	1.01	1.00	0.97	1.11	1.02	0.98	1.06	0.96	0.97	1.04	1.33
ES	0.99	1.05	0.95	1.00	0.95	1.06	1.05	1.03	1.08	1.03	1.05	1.07	1.35
FI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
FR	0.99	1.00	1.01	1.02	0.94	1.04	1.02	1.05	1.02	1.01	0.99	0.96	1.04
HU	1.00	1.00	0.98	0.86	0.92	1.00	0.89	0.95	1.01	0.95	1.06	1.07	0.71
IE	0.88	0.99	0.88	1.01	0.96	1.00	1.01	1.05	0.96	0.94	1.01	1.06	0.76
IT	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
LT	1.09	1.04	1.04	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.17

LU	0.80	1.26	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
LV	1.08	1.24	1.17	0.92	0.89	1.01	0.98	0.99	1.00	0.95	1.11	1.05	1.39
MT	0.94	0.99	0.99	1.47	0.69	1.01	0.97	1.00	1.12	0.93	1.23	0.85	0.98
NL	1.00	1.04	1.00	1.00	0.92	1.09	1.00	0.93	1.08	1.00	1.00	1.00	1.04
PL	1.16	1.08	1.08	0.78	1.19	1.08	1.03	0.86	1.06	0.91	1.03	1.13	1.36
PT	1.10	1.07	0.93	0.97	0.96	1.09	0.94	1.02	1.03	1.03	1.09	1.01	1.24
RO	0.79	1.19	1.00	1.07	0.79	0.95	1.05	1.14	0.98	1.29	1.00	1.00	1.14
SE	1.00	1.00	1.00	0.99	1.00	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SI	0.97	1.03	1.15	1.06	0.93	1.12	1.02	1.03	1.02	1.00	1.00	0.97	1.33
SK	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.06	1.00	1.00	1.00	1.00	1.00
UK	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

It can be seen from Table 1 that Finland, Italy, and the United Kingdom are the three most efficient countries since they obtain the technical efficiency score of one in each time period. Moreover, Luxembourg, Sweden, and Slovakia are also efficient when the overall efficiency change is taken into account (see the last column of Table 2). For these six countries, although *EFFCH*=1 indicates no improvement in technical efficiency between two time periods, they determine the efficiency levels of other countries since they are the ones that shift the frontier in most periods. For the remaining 21 countries, both improvement and decline exist during these 13 years, and there are still nine countries (Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Hungary, Ireland, and Malta) whose overall efficiency changes less than one, which implies their weak capability in catching up with those efficient ones.

With respect to the change in the frontier technology, the results are shown in Table 3. Although fluctuations occur in every country within these 13 years, the overall technical changes of the 27 EU countries are all greater than one, which indicates the improvement in this aspect for every country. Among others, Luxembourg is the technological innovators, which has already doubled its technology performance compared with that in 1995.

TABLE 3 Technical changes of the 27 EU countries from 1995 to 2007

Country	*TECHCH*												
	96/95	97/96	98/97	99/98	00/99	01/00	02/01	03/02	04/03	05/04	06/05	07/06	07/95
AT	1.01	0.98	1.04	1.01	1.05	0.96	1.05	0.97	1.04	1.01	0.95	0.96	1.01
BE	1.01	0.98	1.03	1.00	1.07	0.96	1.02	1.01	1.00	1.03	1.02	1.02	1.17
BG	0.95	0.96	0.96	1.21	1.18	0.92	0.98	1.07	1.00	1.06	1.09	0.93	1.29
CY	1.00	0.99	0.99	1.03	1.10	0.96	1.00	1.02	1.00	1.01	1.04	1.05	1.19
CZ	0.88	0.97	1.04	1.03	1.05	0.94	1.05	0.98	1.07	1.04	0.99	1.03	1.05
DE	1.02	1.00	1.02	0.98	1.04	0.99	1.02	1.00	1.02	1.03	1.04	1.04	1.21
DK	1.02	0.99	1.03	1.00	1.06	0.98	1.01	1.01	1.01	1.01	1.01	1.00	1.12
EE	0.96	0.98	1.00	1.10	1.03	0.92	1.06	1.01	1.04	1.05	1.03	1.02	1.22
EL	0.94	0.96	0.99	1.06	1.09	0.94	1.03	1.04	1.00	1.06	1.07	0.99	1.16
ES	1.00	0.98	1.03	1.02	1.08	0.95	1.04	0.97	1.05	1.02	0.99	1.00	1.12
FI	1.06	0.97	1.10	1.00	1.09	0.94	1.04	1.01	1.02	0.99	0.99	0.95	1.16
FR	1.02	1.00	1.00	1.00	1.08	0.97	0.99	1.00	1.02	1.00	1.04	1.05	1.18
HU	1.02	0.96	0.94	1.13	1.12	0.94	1.04	1.06	0.99	1.08	1.05	1.04	1.40
IE	1.02	1.00	1.01	0.98	1.03	1.00	1.03	1.01	1.01	1.02	1.02	1.00	1.13
IT	1.02	1.00	1.00	0.98	1.08	0.97	0.99	1.00	1.02	0.99	1.06	1.06	1.17
LT	0.95	0.97	1.01	1.28	1.17	0.93	1.06	1.08	0.98	1.13	1.08	0.92	1.63
LU	0.83	1.15	1.18	1.20	0.95	1.18	1.12	1.12	1.00	0.97	1.21	0.96	2.15
LV	1.01	0.95	0.97	1.18	1.10	0.91	1.12	1.05	1.01	1.17	1.07	1.05	1.72

MT	0.99	1.01	1.02	1.58	0.64	1.02	1.03	0.99	1.05	1.00	1.00	1.02	1.14
NL	1.05	0.98	1.12	1.03	1.06	0.97	1.01	1.07	1.12	0.99	1.00	0.98	1.42
PL	0.85	0.97	1.00	1.18	1.02	0.96	1.03	1.10	1.02	1.15	1.08	1.02	1.37
PT	0.91	0.95	1.03	1.04	1.03	0.97	1.03	1.02	1.01	1.04	1.00	1.01	1.01
RO	0.95	0.95	0.96	1.25	1.18	0.92	1.08	1.05	1.02	1.23	1.08	1.00	1.80
SE	1.07	1.02	1.01	0.98	1.03	0.99	1.04	1.04	1.06	1.06	1.00	0.99	1.31
SI	0.99	0.99	0.99	1.04	1.11	0.97	1.01	1.00	1.01	1.04	1.01	1.00	1.15
SK	1.04	0.87	1.09	1.10	0.91	0.93	1.02	1.08	1.09	1.12	1.00	1.07	1.31
UK	1.00	1.01	1.03	1.00	1.00	1.02	1.03	0.99	1.05	0.99	1.01	1.03	1.16

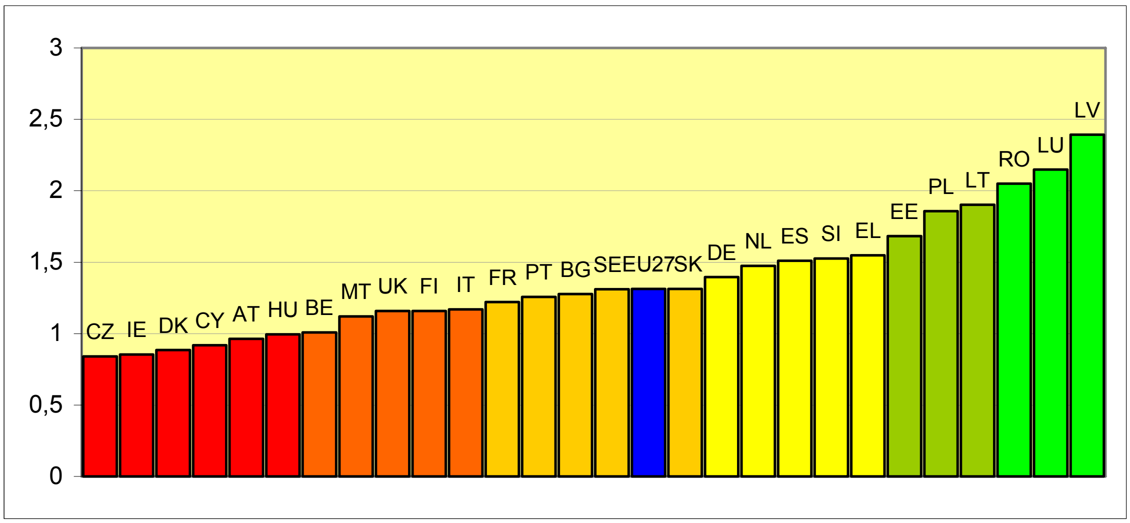

FIGURE 4 Overall progress on sustainable road transport in the 27 EU countries from 1995 to 2007

By now, the Malmquist productivity index can be computed, and the overall progress on sustainable road transport of each of the 27 EU countries during the past 13 years is illustrated in Fig. 4, together with their average progress. It can be seen that most of the EU countries have reduced their undesirable impacts on sustainable road transport during the time period, in which Latvia, Luxembourg and Romania are three best performers, which have already doubled their performance due to their great efficiency enhancements and technical improvements during the past 13 years. However, there are still six countries being Czech Republic, Ireland, Denmark, Cyprus, Austria, and Hungary, whose overall *MI* value less than one. It means that their sustainable development on road transport is deteriorating, thereby great efforts are still needed, and more attentions should be paid to efficiency improvement by reducing unnecessary costs.

5 CONCLUSIONS

Road transport is vital to the economic development, trade and social integration. However, it is also responsible for the majority of negative impacts on environment and society. Nowadays, since more and more countries are taking steps to achieve sustainable development, there is a growing need for a country to assess the changes in the undesirable costs over time so as to determine road transport policy. In this study, based on the information on the passenger and freight transport on the one hand, and the total energy consumption, the greenhouse gas emissions, as well as the number of fatalities in road transport on the other hand, the data envelopment analysis and the Malmquist productivity index approach were adopted to measure the extent to which the 27 EU countries have improved their 'productivity' on sustainable road transport over the period of 1995-2007. The analysis found that there was a significant progress towards the sustainable road transport in Europe during this period. However, the development in the different countries was unbalanced. Some of them were even deteriorating in terms of the sustainable road transport. Moreover, the decomposition of the DEA-MI into technical changes and efficiency changes further revealed that the bulk of the improvement was attained through the adoption of productivity-enhancing new technologies throughout the road transport sector, rather than through the relatively inefficient countries catching up with those efficient ones. Furthermore, the growth in both two aspects slowed down in 2007, which implies the momentum of further improvement is in danger of being lost so that new impetus is needed.

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