Environmental Sustainability of Road Transport in OECD Countries

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Abstract: Road transport is a primary source of various forms of air pollution and climate-impacting emissions, and contains huge potential for improving the environment and combating climate change. This paper studies the environmental sustainability of road transport for a set of OECD countries over the period 2000–2014. We capture the sustainability performance of road transport in two data envelopment analysis (DEA) models, corresponding to the concepts of natural disposability and managerial disposability, respectively. Air pollution and carbon emissions are treated as undesirable outputs. The models produce two unified measures of environmental sustainability performance, accounting for transport activities and environmental impacts simultaneously. We find that the studied countries have improved their overall managerial disposability performance from 2000 to 2014, driven by technological progress and tightening regulations on fuel economy and vehicle emissions. The analysis enables us to identify best-practice and laggard countries in transport sustainability.

Keywords: sustainability; road transport; DEA; OECD; transport efficiency

1. Introduction

Since it provides mobility to people, goods, and services, transport is fundamental to human welfare and constitutes indispensable infrastructure for modern life. However, it is also a quite challenging sector from the perspective of sustainable development. The Organization for Economic Co-operation and Development (OECD) has noted five unsustainable trends in the transport sector: (1) transport represents a growing source of climate-impacting emissions and its share of climate-impacting emissions continues to grow relative to other sectors; (2) transport impacts on regional air quality, as its share of responsibility for causing acidification, eutrophication, and dangerous levels of tropospheric ozone continues to grow; (3) transport affects local air quality, as the growing vehicle fleet and increasing distance traveled by road freight diesel vehicles continues to contribute to the exceedance of ambient air quality standards for particulate matter (PM); (4) transport noise, particularly from road vehicles, is the major source of external acoustic nuisance in urban areas; and (5) land use for transport generates more transport activity and contributes to environmental stress [1]. According to the Intergovernmental Panel on Climate Change (IPCC), the transport sector was responsible for 14% of global greenhouse gas (GHG) emissions in 2010 [2]. Accordingly, the United Nations Environment Programme (UNEP) viewed the transport sector as one of the major sectors containing the potential for reducing global GHG emissions and combating climate change [3].

As part of overall efforts to achieve sustainable development, the OECD encouraged its member countries to move away from the conventional policy approach in the light of “business-as-usual” circumstances, and to employ a new backcasting approach to address the environmental and health risks associated with transport. The OECD defines environmentally sustainable transport (EST) as a system where transportation does not endanger public health or ecosystems and meets needs for...
access consistent with (a) use of renewable resources below their rates of regeneration, and (b) use of non-renewable resources below the rates of development of renewable substitutes [1]. Using the methods of scenario construction and backcasting, the OECD developed Guidelines towards Environmentally Sustainable Transport in 2002 to guide member countries towards proactive sustainable transport policy making [1]. Since then, OECD countries have used different strategies towards the realization of EST, including non-policy measures such as the adjustment of inputs into the transport sector, as well as policy instruments such as emissions regulation and pricing policies [4].

This paper aims to analyze how certain OECD countries have performed in the past two decades towards reversing the unsustainable trends in transport and realizing their EST goals. We focus here on road transport, which according to the UNEP contains the most significant GHG reduction potential among the different modes of transport [3]. As data is lacking in relation to countries’ efforts in noise control and local land use, this paper focuses on GHG emissions and emissions of major air pollutants in the road transport sector of certain OECD countries. To integrate all sustainability-related factors and develop a unified measure of performance, we use the data envelopment analysis (DEA) approach. Under the DEA framework, the transport sectors of OECD countries are viewed as production units with multiple inputs and multiple outputs. The inputs include the physical infrastructure of the road system and the capital invested into the transport sector. The outputs include the people and freight transported in the road system, and GHG emissions and air pollution generated by the vehicles. Clearly, the negative environmental impacts of transport in the form of GHG emissions and air pollution are undesirable and should be reduced, whereas the people and freight transported are generally desirable and should be increased. The presence of both desirable and undesirable outputs can be addressed under the DEA framework through the application of the concepts of natural disposability and managerial disposability. The concepts have been proposed and discussed in detail in reference [5], but their application to transport is rare to our knowledge. Here, natural disposability refers to the scenario where a country can reduce undesirable outputs of transport by cutting back the inputs into the road system, which will inevitably affect the desirable outputs. Managerial disposability refers to the scenario where a country can raise the inputs to the road system to increase the desirable outputs, and simultaneously reduce the undesirable outputs through managerial efforts and better management practices. Based on these two concepts, we can derive two DEA models and their corresponding efficiency values.

We apply the two models to assess the performance of 25 OECD countries in the transport sector for a 15-year period covering 2000–2014. We find that under managerial disposability, the overall efficiency performance of the sample has improved during the period under study, and most countries covered were able to achieve perfect efficiency at the end of the time horizon. The improvement reflects technology progress as well as tightening regulations on fuel economy and vehicle emissions. The results under natural disposability exhibit less conspicuous patterns. Based on managerial disposability and natural disposability, we can identify best practice countries as well as countries that are lagging behind. We also examine and discuss the drivers behind the intertemporal change of performance.

The remainder of the paper proceeds as follows. Section 2 reviews the background and literature related to this research. Section 3 describes the methodology. Section 4 summarizes the sample and variables. Section 5 presents the results and Section 6 concludes.

2. Background and Literature Review

Transport is vital for fulfilling sustainable development. Of the 17 Sustainable Development Goals (SDGs) established by the United Nations (UN) to be accomplished by 2030, transport is related to eight of them [6]. These SDGs cannot be achieved without advances in sustainable transport. A considerable amount of attention has been paid to sustainable transport in OECD countries. Due to their prominent position in the global economy, what the OECD countries do may have profound implications for other countries. The OECD is a pioneer in sustainable transport. It launched the environmentally sustainable transport project as early as 1994, to provide guidelines to member countries on policy design in order
to achieve EST [7]. Despite the continued efforts, the OECD countries still bear substantial financial burdens related to environmental problems in transport. By the estimate of OECD itself, the health impact of air pollution in OECD countries costed an astronomical US$1.7 trillion, and road transport was responsible for half of this figure [8]. Assessing the performance of OECD countries can help us better understand the situation and the associated challenge.

The environmental sustainability of transport is part of the concept of sustainable transport, which was put forward and popularized in the 1990s [9,10]. The literature in the past three decades has approached the environmental sustainability of transport from various social, economic, environmental, cultural and technical, and other perspectives, and also covered a broad range of issues, including its definition, analytical framework, planning, policy, regulation, and implementation [10,11]. For example, Bakker et al. [12] analyze the sustainable transport of Southeast Asian countries from a policy perspective. Beltrán-Esteve and Picazo-Tadeo [13] study the environmental performance of the transport sector in 38 countries and the driving forces behind its changes. Saidi and Hammami [14] investigate the relationship between transport, economic growth, and environmental degradation for a set of 75 countries. The aforementioned studies are just a small sample of research on transport sustainability. Goyal and Howlett [15] study the governance of sustainability transitions in the field of urban transport. Zhu and Gao [16] investigate the factors influencing carbon emissions of the transport sector for 57 countries based on panel data. Hansson and Nerhagen [17] study the policy coordination and impact assessment problems in promoting cleaner transport. None of the above research explores the concepts of natural disposability and managerial disposability.

Methodology-wise, DEA is an important and useful benchmarking approach for assessing environmental sustainability. We refer the readers to [18] for a comprehensive review of research in this aspect. In the domain of transport, measuring transport efficiency can provide assistance and insights on a variety of tasks, including urban planning, policy formulation, regulation, resource allocation, and fleet configuration, among others [19,20]. The assessment can be conducted for various entities, including countries, regions, cities, companies, facilities and routes, and various transportation modes, including roads, railways, air, and maritime [19,21]. By being capable of modeling multiple inputs and multiple outputs, DEA provides an overall perspective on performance.

The classical DEA model assumes all outputs are desirable and hence that more is better [22]. Since undesirable outputs may arise in many real-life situations, ensuing research develops new DEA methodologies to model undesirable outputs along with desirable ones [23]. The typical approaches addressing undesirable outputs under a DEA framework include: (i) convert undesirable outputs into desirable ones through data transformation so the standard DEA model can still be used [24]; (ii) treat undesirable outputs as inputs, since for them less is better than more [25]; (iii) use the input/output slacks to derive efficiency with undesirable factors, a method based on the slacks-based measure [26]; (iv) use the radial method based on the concepts of natural/managerial disposability [27]; (v) use the range-adjusted measure where the efficiency involves the product of data ranges and input/output slacks [28]. These methodologies have seen wide applications in many disciplines, especially in the field of energy and environment where various types of pollutants are generated as undesirable outputs [29].

3. Methods

DEA is a widely-applied benchmarking method that can measure the efficiency of a decision making unit (DMU) in a relative sense by comparing its performance against other DMUs [22]. Compared to parametric methods such as stochastic frontier analysis, DEA’s main attractions are its capability of dealing with DMUs of multiple inputs and multiple outputs, and the nonparametric treatment of data without assuming any functional form for the relationship between inputs and outputs. DEA model in its conventional form can only handle desirable outputs such as production quantity and profit. Due to the prevalence of undesirable outputs in reality, ensuing research has proposed DEA models to handle undesirable outputs. These models can be classified into two groups:
radial models and non-radial models [30]. The radial models assume proportionate contraction of inputs and proportionate expansion of outputs in seeking better production efficiency, whereas the non-radial models discard this assumption. Based on orientation, there are output-oriented and input-oriented models. In terms of returns-to-scale, there are variable returns-to-scale (VRS) and constant returns-to-scale (CRS) models. In this paper, we employ the radial models under the assumptions of VRS and output-orientation.

In order to formulate the models, we first introduce the following notations. Suppose there are \( n \) DMUs to be evaluated, denoted by \( i = 1, \ldots, n \). Let \( t = 1, \ldots, T \) represent the annual periods. Each DMU uses \( m \) inputs (labeled as \( j = 1, \ldots, m \)) to produce \( s \) desirable outputs (labeled as \( r = 1, \ldots, s \)) and \( h \) undesirable outputs (labeled as \( f = 1, \ldots, h \)). For the \( i \)-th DMU, let \( x_{ij} \in R_+ \), \( g_{ir} \in R_+ \) and \( b_{if} \in R_+ \) denote the \( j \)-th input, the \( r \)-th desirable output and the \( f \)-th undesirable output, respectively. Let \( \lambda_i \) be the weight assigned to the \( i \)-th DMU. Let \( d_j^r, d_j^h \) and \( s_i^r, s_i^h \) denote the unknown slack variables for the \( j \)-th input, the \( r \)-th desirable output, and the \( f \)-th undesirable output, respectively. Let \( \epsilon \) be an infinitesimal number. The following three sets of numbers represent the data ranges related to inputs, desirable outputs, and undesirable outputs, respectively:

\[
R_j^r = (m + s + h)^{-1} \left( \max \{ x_{ij} \mid i = 1, \ldots, n \} - \min \{ x_{ij} \mid i = 1, \ldots, n \} \right)^{-1} \quad \text{for } j = 1, \ldots, m; \tag{1}
\]

\[
R_j^s = (m + s + h)^{-1} \left( \max \{ g_{ir} \mid i = 1, \ldots, n \} - \min \{ g_{ir} \mid i = 1, \ldots, n \} \right)^{-1} \quad \text{for } r = 1, \ldots, s; \tag{2}
\]

\[
R_j^h = (m + s + h)^{-1} \left( \max \{ b_{if} \mid i = 1, \ldots, n \} - \min \{ b_{if} \mid i = 1, \ldots, n \} \right)^{-1} \quad \text{for } f = 1, \ldots, h. \tag{3}
\]

Note that these three data ranges are fixed and readily available before running the DEA models, since they are constructed based on the sample.

3.1. Unified Efficiency under Natural Disposability

The concept of natural disposability as proposed in prior studies [5,30] means that to increase the unified efficiency, the DMUs can reduce the inputs in order to decrease the undesirable outputs [31–33]. The model to evaluate the \( k \)-th DMU is formulated as follows,

\[
\max_{\lambda, \theta} \quad \theta + \epsilon \left( \sum_{j=1}^{m} R_j^x d_j^x + \sum_{r=1}^{s} R_j^s d_j^s + \sum_{f=1}^{h} R_j^h d_j^h \right)
\]

subject to:

\[
\sum_{i=1}^{n} x_{ij} \lambda_i + d_j^x = x_{kj} \quad (j = 1, \ldots, m)
\]

\[
\sum_{i=1}^{n} g_{ir} \lambda_i - d_j^s \theta g_{kr} = g_{kr} \quad (r = 1, \ldots, s)
\]

\[
\sum_{i=1}^{n} b_{if} \lambda_i + d_j^h + \theta b_{kf} = b_{kf} \quad (f = 1, \ldots, h)
\]

\[
\sum_{i=1}^{n} \lambda_i = 1
\]

\[
\lambda_i \geq 0 \quad (i = 1, \ldots, n), \quad d_j^x \geq 0 \quad (j = 1, \ldots, m),
\]

\[
d_j^s \geq 0 \quad (r = 1, \ldots, s), \quad d_j^h \geq 0 \quad (f = 1, \ldots, h).
\]
Under natural disposability, the efficiency of the \( k \)-th DMU is determined by the following formula,

\[
\text{UEN}_k = 1 - \left[ \theta^* + \epsilon \left( \sum_{j=1}^{m} R_j^x d_j^x + \sum_{r=1}^{s} R_r^x d_r^x + \sum_{f=1}^{h} R_f^x d_f^x \right) \right].
\] (5)

where the variables \( \theta^* \), \( d_j^x \), \( d_r^x \), and \( d_f^x \) are obtained from the optimality in the solution of (4). Note that the unified efficiency under natural disposability is obtained by maintaining in (4) positive slacks (\( +d_j^x \)) for inputs, positive slacks (\( +d_r^x \)) for undesirable outputs, and negative slacks (\( -d_f^x \)) for desirable outputs.

3.2. Unified Efficiency under Managerial Disposability

The concept of managerial disposability assumes that a DMU can simultaneously increase the desirable outputs and reduce the undesirable outputs through managerial efforts. The concept of managerial disposability was first proposed in reference [5] and has been applied to assess the eco-efficiency of transportation systems [34,35]. The DEA model under managerial disposability is formulated as follows:

\[
\max_{\lambda, \theta} \quad \theta + \epsilon \left( \sum_{j=1}^{m} R_j^x d_j^x + \sum_{r=1}^{s} R_r^x d_r^x + \sum_{f=1}^{h} R_f^x d_f^x \right)
\]

subject to:

\[
\sum_{i=1}^{n} x_{ij} \lambda_i - d_j^x = x_{kj} \quad (j = 1, \ldots, m)
\]

\[
\sum_{i=1}^{n} g_{ir} \lambda_i - d_r^x - \theta g_{kr} = g_{kr} \quad (r = 1, \ldots, s)
\]

\[
\sum_{i=1}^{n} b_{if} \lambda_i + d_f^x + \theta b_{kf} = b_{kf} \quad (f = 1, \ldots, h)
\]

\[
\sum_{i=1}^{n} \lambda_i = 1
\]

\[
\lambda_i \geq 0 \quad (i = 1, \ldots, n), \quad d_j^x \geq 0 \quad (j = 1, \ldots, m)
\]

\[
d_r^x \geq 0 \quad (r = 1, \ldots, s), \quad d_f^x \geq 0 \quad (f = 1, \ldots, h).
\]

The following equation determines the level of efficiency of the \( k \)-th DMU,

\[
\text{UEM}_k = 1 - \left[ \theta^* + \epsilon \left( \sum_{j=1}^{m} R_j^x d_j^x + \sum_{r=1}^{s} R_r^x d_r^x + \sum_{f=1}^{h} R_f^x d_f^x \right) \right]
\] (7)

where the variables \( \theta^* \), \( d_j^x \), \( d_r^x \) and \( d_f^x \) are obtained from the optimality in the solution of (6). The key difference between (4) and (6) is that the positive slack \( (+d_j^x) \) in (4) has now become \( (-d_j^x) \). The sign before the slack variable results in the interpretations of natural disposability and managerial disposability.

As our sample has a panel structure, we need to adapt the aforementioned DEA models to panel data. Literature documents four methods to deal with panel data under the DEA framework, DEA window analysis [34], contemporaneous analysis, sequential analysis, and intertemporal analysis [35]. These methods are characterized by different mechanisms in selecting the reference set of observations to construct the frontier. Another popular approach to deal with panel data is to combine DEA with the Malmquist index measurement [36,37]. In this paper, we use the intertemporal analysis method, which generates a frontier using the pooled set of all observations. It benchmarks all DMUs in any given year against the same frontier and allows us to compare efficiency values across different years.
in a fair way. A potential concern in DEA application is the existence of outliers in assessment [38], but our computational results do not seem to imply this is a problem with the data available. We note that the formulations (4) and (6) are linear programs, which can be solved by any linear programming solvers. In this paper, we solve them in Matlab with the values of the variables given in Section 4.

4. Data and Variables

We obtain the sample used in this study from the OECD database (Link for the database: https://stats.oecd.org/). We employ two input variables. Road corresponds to the total length of roads in each country, and serves as a proxy for the capacity or size of the road system from an infrastructure perspective. Investment represents the financial input into the road system and is defined as the sum of infrastructure investment and maintenance cost. We employ the following two desirable outputs. Passenger is defined as the number of passengers transported by the road system multiplied by the transportation distance. Freight is the multiplication of freight quantity and transportation distance. We also utilize the five undesirable outputs. \( \text{SO}_2 \) is the amount of Sulfur dioxide \( \text{SO}_2 \) emitted in road transport. \( \text{NO}_x \) is the amount of nitrogen oxides \( \text{NO}_x \) emitted in road transport. \( \text{PM}_{10} \) and \( \text{PM}_{2.5} \) are the emissions of particulate matter less than 10 and 2.5 micrometers in diameter. These particulate matters are the most concerning health-damaging pollutants and were associated with 2.9 million premature deaths globally in 2017 [39]. \( \text{CO}_2 \) is the amount of carbon dioxide emissions in road transport. We note that the inputs and desirable outputs in our paper have been widely employed in other transportation efficiency studies [21].

As indicated in Section 3, we treat each country-year observation as a standalone DMU. The coverage of countries and time horizon for each variable differ in the OECD database. We remove all country-year observations with missing values in any of the abovementioned variables. This yields an unbalanced panel of 25 OECD countries for the 15-year period 2000–2014, with a total of 304 country-year observations. The 25 OECD countries covered in the sample are: Belgium, Canada, the Czech Republic, Denmark, Estonia, Finland, France, Hungary, Iceland, Italy, Korea, Latvia, Lithuania, Mexico, the Netherlands, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

Note that the OECD has been growing since its foundation in 1961. There were 34 member countries as of 2014, the last year of the horizon under study. Five countries (the Czech Republic, Hungary, Korea, Mexico, and Poland) received membership in the 1990s. One country (the Slovak Republic) was admitted in the 2000s. Four countries (Chile, Estonia, Israel, and Slovenia) obtained membership in the year 2010. Our sample covers more than two thirds of the OECD countries. Table 1 reports the summary statistics of the sample.
Table 1. Summary statistics.

<table>
<thead>
<tr>
<th>Year</th>
<th>N</th>
<th>Road (thousand km)</th>
<th>Investment (million EURO)</th>
<th>Passenger (billion passenger-km)</th>
<th>Freight (billion ton-km)</th>
<th>SO$_2$ (thousand tons)</th>
<th>NO$_x$ (thousand tons)</th>
<th>PM10 (thousand tons)</th>
<th>PM2.5 (thousand tons)</th>
<th>CO$_2$ (million tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>19</td>
<td>542.8</td>
<td>7421.5</td>
<td>24.9</td>
<td>110.7</td>
<td>(1486.1)</td>
<td>(769.1)</td>
<td>(54.9)</td>
<td>(1721.6)</td>
<td>(342.7)</td>
</tr>
<tr>
<td>2001</td>
<td>20</td>
<td>589.2</td>
<td>7746.5</td>
<td>15.9</td>
<td>16.5</td>
<td>(1471.0)</td>
<td>(761.0)</td>
<td>(51.1)</td>
<td>(1555.1)</td>
<td>(33.1)</td>
</tr>
<tr>
<td>2002</td>
<td>21</td>
<td>565.0</td>
<td>7195.8</td>
<td>16.5</td>
<td>21.1</td>
<td>(1444.1)</td>
<td>(780.0)</td>
<td>(49.9)</td>
<td>(2020.0)</td>
<td>(43.8)</td>
</tr>
<tr>
<td>2003</td>
<td>21</td>
<td>567.2</td>
<td>6853.6</td>
<td>14.3</td>
<td>31.1</td>
<td>(1416.5)</td>
<td>(745.8)</td>
<td>(41.3)</td>
<td>(1892.0)</td>
<td>(78.4)</td>
</tr>
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<td>2004</td>
<td>22</td>
<td>550.9</td>
<td>6501.3</td>
<td>11.8</td>
<td>30.3</td>
<td>(1421.4)</td>
<td>(753.6)</td>
<td>(33.8)</td>
<td>(1590.3)</td>
<td>(77.2)</td>
</tr>
<tr>
<td>2005</td>
<td>22</td>
<td>552.6</td>
<td>7298.3</td>
<td>8.3</td>
<td>28.9</td>
<td>(1428.7)</td>
<td>(738.0)</td>
<td>(21.0)</td>
<td>(1524.4)</td>
<td>(72.9)</td>
</tr>
<tr>
<td>2006</td>
<td>22</td>
<td>555.4</td>
<td>8216.1</td>
<td>5.3</td>
<td>28.3</td>
<td>(1434.1)</td>
<td>(689.1)</td>
<td>(8.3)</td>
<td>(1456.1)</td>
<td>(71.9)</td>
</tr>
<tr>
<td>2007</td>
<td>22</td>
<td>558.0</td>
<td>8000.0</td>
<td>2.4</td>
<td>27.9</td>
<td>(1458.0)</td>
<td>(491.1)</td>
<td>(21.0)</td>
<td>(1353.5)</td>
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<tr>
<td>2008</td>
<td>21</td>
<td>512.7</td>
<td>7847.1</td>
<td>2.3</td>
<td>27.4</td>
<td>(1532.8)</td>
<td>(440.8)</td>
<td>(21.0)</td>
<td>(1271.5)</td>
<td>(64.6)</td>
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<tr>
<td>2009</td>
<td>19</td>
<td>559.2</td>
<td>8146.6</td>
<td>2.0</td>
<td>24.8</td>
<td>(1539.0)</td>
<td>426.9</td>
<td>(7.9)</td>
<td>(1168.0)</td>
<td>(62.2)</td>
</tr>
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<td>2010</td>
<td>19</td>
<td>568.6</td>
<td>8694.5</td>
<td>2.1</td>
<td>23.3</td>
<td>(1541.6)</td>
<td>398.3</td>
<td>(7.6)</td>
<td>(1200.2)</td>
<td>(57.0)</td>
</tr>
<tr>
<td>2011</td>
<td>19</td>
<td>576.0</td>
<td>9100.9</td>
<td>1.7</td>
<td>27.9</td>
<td>(1546.5)</td>
<td>416.9</td>
<td>(6.3)</td>
<td>(1132.4)</td>
<td>(50.0)</td>
</tr>
<tr>
<td>2012</td>
<td>19</td>
<td>567.4</td>
<td>9426.1</td>
<td>1.7</td>
<td>26.2</td>
<td>(1514.9)</td>
<td>396.3</td>
<td>(6.2)</td>
<td>(1050.6)</td>
<td>(41.0)</td>
</tr>
<tr>
<td>2013</td>
<td>20</td>
<td>466.1</td>
<td>9157.9</td>
<td>3.5</td>
<td>26.1</td>
<td>(1621.2)</td>
<td>414.6</td>
<td>(6.2)</td>
<td>(1022.6)</td>
<td>(31.0)</td>
</tr>
<tr>
<td>2014</td>
<td>18</td>
<td>466.2</td>
<td>9730.2</td>
<td>1.7</td>
<td>24.4</td>
<td>(22560.7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The numbers in parentheses are the standard deviations. The units for the variables are: Road: thousand km; Investment: million EURO; Passenger: billion passenger-km; Freight: billion ton-km; SO$_2$: thousand tons; NO$_x$: thousand tons; PM10: thousand tons; PM2.5: thousand tons; CO$_2$: million tons.
5. Results

We solve the unified efficiency under natural disposability (UEN) and the unified efficiency under managerial disposability (UEM) in models (4)–(7) and analyze the results in this section. Table 2 reports the UEN and UEM values for all countries in the first and the last years of each country’s time horizon. Figures 1 and 2 depict the evolution of UEN and UEM for all countries in the sample. It is worth noting that data is only available for a limited numbers of years for some countries covered in the sample, resulting in the difficulty of fully capturing the changes to the unified efficiencies for those countries in the whole 2000–2014 time period. For example, data for Mexico is only available for the year 2013, making it impossible to do a year-to-year comparison for this country.

Table 2. UEN and UEM for all countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Horizon</th>
<th>UEN</th>
<th>UEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First</td>
<td>Last</td>
<td>Change</td>
</tr>
<tr>
<td>Belgium</td>
<td>2000–2014</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Canada</td>
<td>2001–2007</td>
<td>1</td>
<td>0.739</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>2000–2014</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Denmark</td>
<td>2000–2014</td>
<td>0.926</td>
<td>0.943</td>
</tr>
<tr>
<td>Estonia</td>
<td>2000–2014</td>
<td>1</td>
<td>0.727</td>
</tr>
<tr>
<td>Finland</td>
<td>2000–2014</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
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<td>2000–2014</td>
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<td>0.906</td>
</tr>
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<td>1</td>
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<tr>
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<td>0.998</td>
<td>0.966</td>
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<td>1</td>
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<td>0.945</td>
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<td>1</td>
</tr>
<tr>
<td>Mexico</td>
<td>2013</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
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<td>0.829</td>
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<tr>
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<tr>
<td>United Kingdom</td>
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<tr>
<td>United States</td>
<td>2000–2014</td>
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Note: “First” (“Last”) denotes the first (last) year of the time horizon for the countries during which data are available to compute the UEN and UEM. “Change” indicates the percentage change of the efficiency values between the first year and the last year of the horizon.
Table 2 shows that twelve countries were able to achieve the perfect UEN of 1.000 in both the first and the last years of their respective time horizons: Belgium, the Czech Republic, Finland, Italy, Korea, Lithuania, Poland, Portugal, Sweden, Turkey, the United Kingdom, and the United States. A perfect UEN implies that these countries have achieved the best possible outcome in meeting their needs for access to transport while protecting the environment and human health by reducing the inputs to decrease the undesirable output of carbon emissions and emissions of various pollutants. According to Figure 1, the UEN of these countries has been largely stable over the years, with some fluctuations occurring in several countries in certain years. The United States has seen a sharp decrease in the values of the UEN to 0.937 in 2005 and to 0.858 in 2006, with the values of the UEN in preceding and succeeding years at or near 1.000. It is noteworthy that the government of the United States has stated that sharp increases between 2004 and 2006 in the costs of construction materials, such as steel, asphalt, and cement in the United States, had eroded the purchasing power of its investment in highway and bridge infrastructure, causing highway capital spending to fall in constant dollar terms over this period [40].
Finally, we would like to emphasize that UEN and UEM provide rankings of the countries based on relative performance. Knowing the rankings of the countries would help policymakers to identify the countries that can serve as role models, and the countries that should be targeted for improvement. Knowing UEN and UEM would also help policymakers monitor the performance change over time relative to other countries. Even if a country reduces emissions in its transport sector, its UEN and UEM may still deteriorate because UEN and UEM are measured relative to other countries.

6. Conclusions

This study assesses the environmental sustainability of the road transport systems of 25 OECD countries by applying the DEA methodology under natural disposability and managerial disposability, respectively. The assessment takes the road transport activity, climate-impacting emissions, and environment-impacting emissions into account. We find that, on average, the efficiency under managerial disposability has improved over the 15-year period covering 2000–2014 and most countries covered were able to achieve perfect efficiency in managerial disposability at the end of the time horizon. The overall improvement of efficiency under managerial disposability indicates a combined effect of technology progress, and tightening fuel economy and vehicle emission regulations. The results under natural disposability display a less conspicuous pattern. Through the analysis, we are also able to identify best-practice countries as well as laggards.

The study has the following limitations. First, due to a lack of data, the current study is unable to cover all OECD countries or all years in the 15-year period of each of the covered countries. It therefore may not display all the EST trends in the period for all the OECD countries. Second, data...
UEM of 1.000 at the end of their respective time horizons, namely, Belgium, the Czech Republic, the Netherlands, Portugal, and the Slovak Republic. These results imply that all countries have improved their managerial efforts during the period under study and were able to deliver the best managerial efforts to control climate and environment-impacting emissions at the end of the period. According to Table 2, eight countries are the best performers among all studied countries, with their UEM landing on a perfect 1.000 score for both the first and the last years in their respective time horizons. These eight countries can be further classified into two groups: Poland, Turkey, and the United States, which are able to attain perfect efficiency scores in both UEN and UEM; and Canada, Estonia, Hungary, Iceland, and Slovenia, who have relatively low UEN scores. For the countries in the latter group, a possible explanation is that their strategies in achieving environmentally sustainable transport were tilted towards managerial efforts instead of input reduction. According to Figure 2, Denmark, Norway, Sweden, Slovenia, and Turkey displayed an abrupt increase in their UEM values in 2009 or 2010. It is noteworthy that the European Union (EU) Fuel Quality Directive requiring reduction of GHG intensity of transport fuels and of air pollutant emissions was enacted in 2009, and that all these countries, except for Turkey, are either EU member states or are bound to comply with EU environmental regulations (in the case of Norway).

Other than the factors discussed above, UEN and UEM can be affected by other forces. The fuel composition of the fleet clearly affects the emissions. The stable performance of the United States can be attributable at least partially to the biofuel policy of the country. Biofuel is mainly produced by corn and is argued to generate fewer emissions than fossil fuel. The US is the biggest producer of biofuel including biodiesel and ethanol and has one of the most aggressive biofuel policies in the world. The primary policy to promote biofuel is the Renewable Fuel Standards (RFS) enacted in 2005 and revised in 2007. RFS sets a sequence of escalating the minimum level of annual biofuel consumption to be blended into transportation fuel until 2022. Consuming a large amount of biofuel may contribute the good environmental performance of the US transport sector. The proportion of biofuel in transport fuel is lower in European countries because of the more limited supply of corn [42]. Therefore, European countries’ UEMs are generally not as good as that of the US for most of the studied time horizon. However, European countries are catching up with the US and some are able to achieve perfect efficiency by the end of the time horizon.

The environmental performance of road transport is also affected by technology progress as well as fuel economy and vehicle emission regulations. For instance, the primary regulation of fuel economy in the US is the Corporate Average Fuel Economy (CAFE) standards enacted as early as 1975. CAFE and similar regulations in other countries drive technology progress, as well as pressure the automakers to shift the fleet mix to smaller and more fuel efficient vehicles [43]. According to the International Energy Agency (IEA), key European countries including Italy, France, the United Kingdom, and Germany have better fuel economies than the US and Canada for light-duty vehicles [44].

Finally, we would like to emphasize that UEN and UEM provide rankings of the countries based on relative performance. Knowing the rankings of the countries would help policymakers to identify the countries that can serve as role models, and the countries that should be targeted for improvement. Knowing UEN and UEM would also help policymakers monitor the performance change over time relative to other countries. Even if a country reduces emissions in its transport sector, its UEN and UEM may still deteriorate because UEN and UEM are measured relative to other countries.

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The overall improvement of efficiency under managerial disposability indicates a combined effect of technology progress, and tightening fuel economy and vehicle emission regulations. The results under natural disposability display a less conspicuous pattern. Through the analysis, we are also able to identify best-practice countries as well as laggards.

The study has the following limitations. First, due to a lack of data, the current study is unable to cover all OECD countries or all years in the 15-year period of each of the covered countries. It therefore may not display all the EST trends in the period for all the OECD countries. Second, data are lacking with respect to countries’ efforts in noise control and local land use. As the OECD has pointed out, noise and land-use targets were not necessarily met when the CO2 target was met and separate focuses were needed on these concerns [1]. Without relevant data, this study has to bypass these two rather important aspects of EST.

This study suggests two avenues for future research. First, as the OECD views technological development as a major factor contributing to EST, it would be useful to further investigate and separate the effects of technological development from policy instruments and other factors, in order to determine the real driving forces behind the EST movement. Second, sustainable transport is a multifaceted concept. EST can be viewed as an integral part of the larger concept of sustainable transport, which contains other aspects such as safety and economic and social impacts [45]. It would be interesting to analyze the studied countries’ performances in achieving environmentally friendly as well as safety-related and economically sustainable transport, to determine whether synergies or contradictions exist among the different sustainable transport goals.

**Author Contributions:** Conceptualization, F.M.; methodology, D.W.; software, D.W.; validation, F.M.; formal analysis, D.W.; investigation, F.M.; resources, D.W.; data curation, D.W.; writing—original draft preparation, D.W. and F.M.; writing—review and editing, F.M.; visualization, D.W.; supervision, D.W.; project administration, D.W.; funding acquisition, D.W.

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**Conflicts of Interest:** The authors declare no conflict of interest.

**References**


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