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How Does the Change of Carbon Dioxide Emissions Affect Transportation Productivity? A Case Study of the US Transportation Sector from 2002 to 2011

Jaesung Choi[1*], David C. Roberts[2]

[1]Transportation and Logistics Program, North Dakota State University, Fargo, ND, USA
[2]Department of Agribusiness & Applied Economics, North Dakota State University, Fargo, ND, USA
Email: [*]jaesung.choi@ndsu.edu, david.c.roberts@ndsu.edu

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Abstract

A variety of research fields has analyzed actual productivity change from environmental pollution through the Malmquist environmental productivity index, but to our best knowledge, no research has thus far been conducted in the transportation sector to evaluate the effects of a CO_2 emissions change on actual productivity. For this reason, this study reviews how actual productivity in the US transportation sector has been affected by the CO_2 emissions change for 2002-2012 and then reveals the driving forces behind it. We find that the CO_2 emissions increase from 2002 to 2007 has a negative effect on actual productivity in the US transportation sector, but the CO_2 emissions reduction for 2008-2011 increases actual productivity. A state mainly showing a sustainable growing pattern (decrease in CO_2 emissions and increase in actual productivity) experiences a higher technological innovation increase than an efficiency decrease. This finding suggests that using fuel-efficient and carbon reduction technologies as well as alternative transportation energy sources may be essential factors to both grow transportation and prevent global warming.

Keywords

Actual Productivity, CO_2, Malmquist Environmental Productivity Index, Sustainable Growth, Transportation Sector

[*]Corresponding author.

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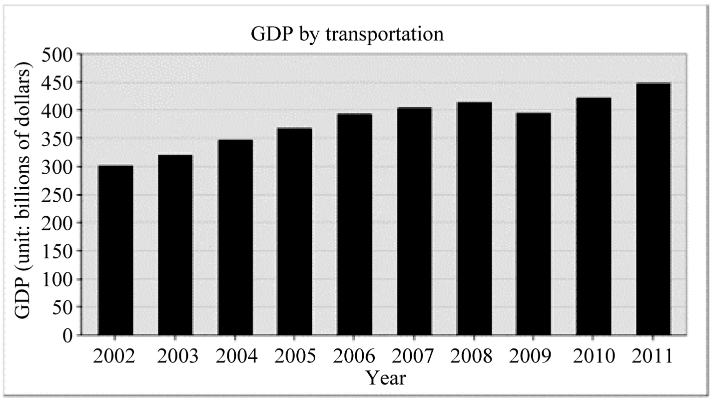
1. Introduction

The concentrations of greenhouse gases (GHGs) in the atmosphere made by human activities have increased since the Industrial Revolution and they have led to significant global warming compared with the past two centuries [1]. Rising temperature globally is contributing to a rise in sea level caused by melting ice in the North and South Poles, more frequent occurrences of natural disasters (floods, droughts, etc.), and a change of ecosystems on Earth, thereby threatening its survival and prosperity [2]-[4].

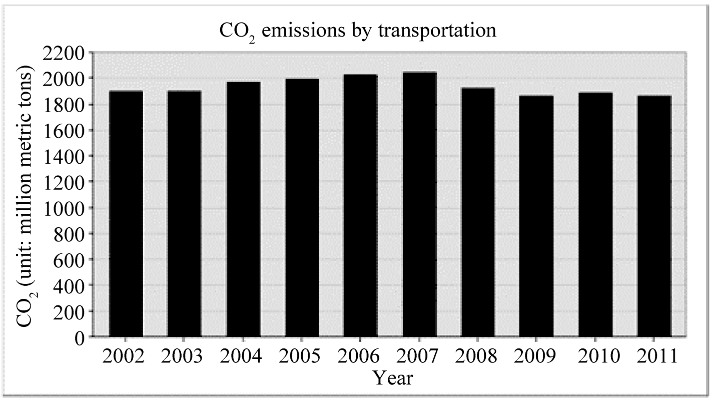
At the global scale, carbon dioxide (CO_2), which was the largest GHG emissions source in 2004, consists of 60% of total GHG emissions, while transportation-sector CO_2 emissions represented 15% of total GHG emissions in 2010. Furthermore, global CO_2 emissions from transport increased by 45% in 1990-2007, and these are projected to increase by approximately 40% from 2007 to 2030 [5] [6]. Hence, the transportation sector is a large and steadily growing source of GHG emissions [7].

In the US, CO_2 emissions account for 82% of total US GHG emissions, which is higher than the global average. Furthermore, the US transportation sector emitted over one-third of total US CO_2 emissions in 2012. US CO_2 emissions, which are the second largest in the world, represented 1481 million metric tons (MMT) in 2010, which accounted for 19% of CO_2 emissions in the world, while China emitted 2259 MMT (23%) [8] [9]. On the other hand, CO_2 emissions have reduced in the US transportation sector since 2008, as a result of not only political support for more fuel-efficient vehicle standards and the development of cost-effective alternative energy, but also changes in consumer and producer preferences toward eco-friendly vehicles [2] [10] [11].

Figure 1 shows the changes in gross domestic product (GDP) and CO_2 emissions from 2002 to 2011 for the US transportation sector [12] [13]. The increasing trend in US CO_2 emissions remained until 2007, but thereafter they fell compared with the period of 2002-2007. Although the US experienced a global financial crisis at the



(a)



(b)

Figure 1. Changes in GDP and CO_2 emissions in the US transportation sector from 2002 to 2011.

end of the 2000 s, the US transportation sector grew consistently after a slight decrease in 2009, so that CO_2 emissions reduction entered a new phase.

A transport mode that operates only on electricity or hydrogen does not emit CO_2 emissions [14]. However, most transport modes (airlines, light- and heavy-duty vehicles, rail, and sea vessels) are today driven by the combustion of fossil fuels. However, CO_2 will be emitted less and less with newer carbon reduction technologies and by using carbon-neutral alternative fuels [15]-[21].

For the past couple of decades, a variety of studies have used the Data Envelopment Analysis Malmquist productivity index to measure productivity changes [22]-[26]. However, but as a couple of authors have pointed out [27] [28], this approach is limited to analyzing the relationship between output change(s) and non-environmental factors.

However, Ball *et al*. [27] developed the Malmquist environmental productivity index to measure the effects of environmental pollution on actual productivity change and this has been applied in various fields including transportation by several researchers [27]-[32]. In 2004, Ball *et al*. [27] used the Malmquist environmental productivity index to measure US agriculture productivity for 1960-1996 with four environmental impact variables, and Lansink and Silva [29] utilized it to calculate the environmental productivity of pesticides based on the shadow price[1] of pesticides generated from a non-parametric method.

On the other hand, Managi *et al*. [30] and Watjanapukka [31] applied the Malmquist environmental productivity index to explain the interactions between environmental regulations, technological innovation, and productivity growth in the oil and gas industry in the Gulf of Mexico and productivity changes in US electricity generation from environmental externalities (SO_2, NO_x, and CO_2), respectively. Similarly, Heng *et al*. [28] used it to reveal the actual productivity change from an air pollution reduction in the US trucking industry and Shortalla and Barnesb [32] applied it to examine environmental efficiency, including the change in GHG emissions from milk ranches in Scotland.

In the literature, however, even though a variety of research fields has analyzed actual productivity change from environmental pollution through the Malmquist environmental productivity index, to our best knowledge, no research has thus far been conducted in the transportation sector to evaluate the effects of a CO_2 emissions change (GHG emissions change) on actual productivity. To address this limitation, this study reviews how actual productivity in the US transportation sector has been affected by the CO_2 emissions change for 2002-2012 and then reveals the driving forces behind it. From this study, state-level findings will be used to evaluate whether each state's CO_2 emissions reduction efforts have appropriately functioned at its boundary.

The second section of this study presents the study area and factors of CO_2 emissions changes and the third section explains the methodology. After the data and empirical results are presented, the conclusions discuss the relationship between actual productivity and the CO_2 emissions change in the US transportation sector.

2. Study Area and Factors of the CO_2 Emissions Change

The transportation sector plays an important role in the growth in the US economy, which showed spending of $1.33 trillion in 2012, accounting for 8.5% of US total GDP. While it is a major and large-scale sector to increase national wealth, the transportation sector is also a significant source of emitting CO_2 in the US Indeed, it is the fastest-growing source of CO_2 emissions among other sectors (industry, commercial, residential, and agriculture), showing an approximately 17% net increase in total US transportation CO_2 emissions between 1990 and 2011 [12] [33].

To consider the significant CO_2 emissions in the US transportation sector and to detect its micro-level change by state, the study area for this study was defined as all 49 states in the US and Hawaii and Alaska. There exist many possible factors behind the CO_2 emissions change, but among them, this study largely demonstrates three main factors. First, there is a state policy change. For example, many states show their own strategies to simultaneously achieve a CO_2 emissions reduction and economic development goals in the transportation sector. States are doing exemplary actions to address CO_2 emissions activities within their states by making either 1) case studies lead by example activities[2]; 2) a GHG inventory[3]; or 3) climate change action plans[4] [34].

Second, a total fuel consumption decline has been observed in the US transportation sector since 2008 and

[1]The shadow price means a value which is hard to calculate in the real world, and is not known with the actual price [29].
[2]A state is leading by example to reduce CO_2 emissions and encourage using clean energy in government facilities and operations [34].
[3]An accounting method of GHG emitted to or removed from the atmosphere in a particular period [34].
[4]Strategies such as particular policy recommendations that a state utilizes to reduce its GHG emissions [34].

this is projected to fall from 26.7 quadrillion Btu in 2012 to 25.5 quadrillion Btu in 2040. Because at least 99% of the carbon in a fuel is emitted as CO_2 through combustion, the recent CO_2 emissions reduction during the same period was directly led by the total fuel consumption decline. Such a decreasing trend in total fuel consumption was attributed to a variety of causes such as increases in vehicle fuel efficiency with improving CO_2 reduction technologies, oil price, biofuel production, and a decrease in vehicle mileage travel from Light Duty Vehicles[5] exceeding growth in other transport modes [14] [35].

Third, federal regulations in air pollution including GHG emissions have been stricter over time. For instance, under the Clean Air Act (1970) and Clean Air Act Amendments (1990), Energy Policy Act (2005) and Energy Independence and Security Act (2007), and Obama announcements of national policies to reduce GHG emissions in 2009-2011 and 2014, the US Environmental Protection Agency has set stricter limits of how much CO_2 can be emitted in the transportation sector [36] [37].

Figure 2 shows CO_2 emissions changes in the transportation sector by state for 2002-2011 [13]. During the period 2002-2011, 32 states among 51 emitted CO_2 in 2011 less than in 2002, but 19 states increased CO_2 emissions in 2011 compared with in 2002. The top five largest CO_2 emissions reductions between 2002 and 2011 arose in California, Michigan, Pennsylvania, Louisiana, and Ohio, but the top five largest CO_2 emissions increases occurred with Illinois, Florida, Georgia, South Carolina, and Iowa. However, as noted, since 2008, all states excluding Nebraska, North Dakota, and South Dakota have decreased CO_2 emissions.

3. Methodology

Let us define:

x^t = Input vector from time period, $t = 1, \cdots, T$.

b^t = Environmental pollution vector from time period, $t = 1, \cdots, T$.

y^t = Output vector from time period, $t = 1, \cdots, T$.

S^t = Production technology that x^t can produce y^t.

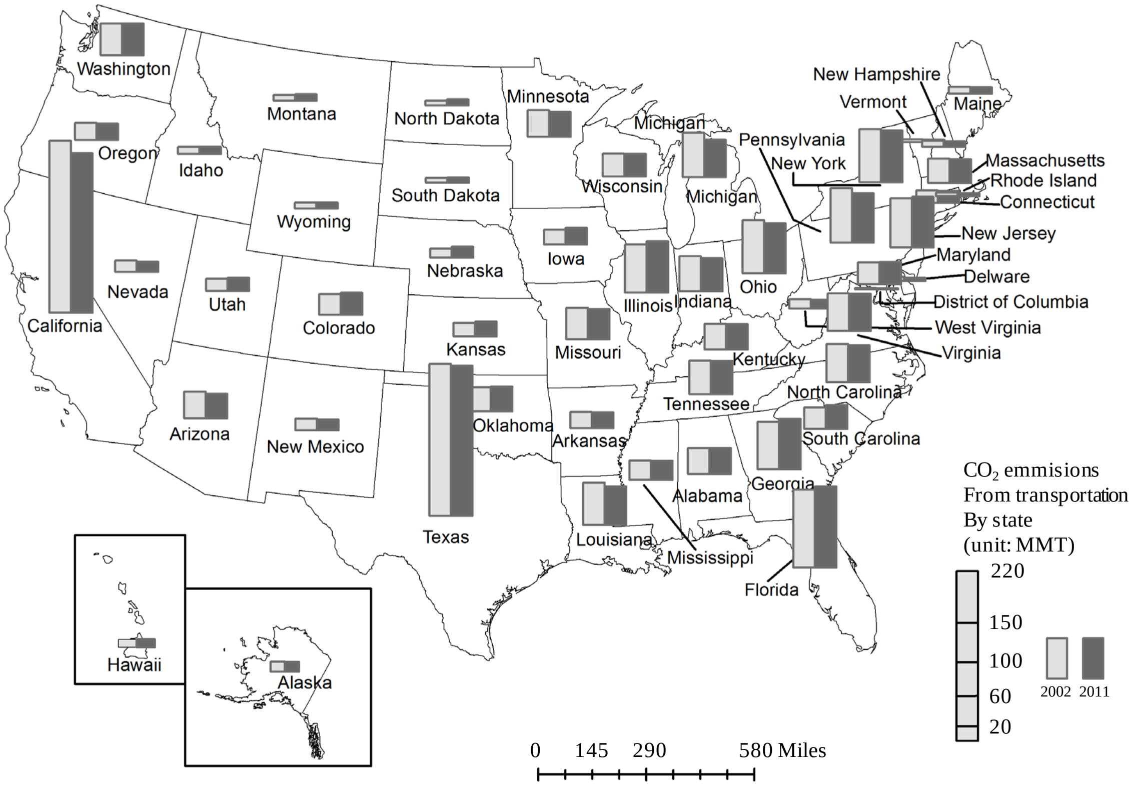


Figure 2. Changes in CO_2 emissions from the US transportation sector by state between 2002 and 2011.

[5]Light Duty Vehicles mean that their maximum gross vehicle weight rating is less than 8500 pounds [35].

Conventional Malmquist productivity is calculated from four output distance functions, and these functions are defined as follows [22]-[25]:

$$D_0^t\left(x^t, y^t\right) = \inf\left\{\theta : \left(x^t, y^t/\theta\right) \in S^t\right\}. \tag{1}$$

$$D_0^t\left(x^{t+1}, y^{t+1}\right) = \inf\left\{\theta : \left(x^{t+1}, y^{t+1}/\theta\right) \in S^t\right\}. \tag{2}$$

$$D_0^{t+1}\left(x^t, y^t\right) = \inf\left\{\theta : \left(x^t, y^t/\theta\right) \in S^{t+1}\right\}. \tag{3}$$

$$D_0^{t+1}\left(x^{t+1}, y^{t+1}\right) = \inf\left\{\theta : \left(x^{t+1}, y^{t+1}/\theta\right) \in S^{t+1}\right\}. \tag{4}$$

The first distance function in Equation (1) explains the maximum change in outputs from the input vector with the technology at *t*, and it is noted that it is less than or equal to 1 if and only if $\left(x^t, y^t\right) \in S^t$. If $D_0^t\left(x^t, y^t\right) = 1$; then, $\left(x^t, y^t\right)$ is on the technology frontier. The mixed-period distance function in Equation (2) means the maximum change in outputs from $t+1$ inputs compared with the t technology. In Equation (3), the maximum change in outputs from t inputs with the technology at $t+1$ is evaluated, and Equation (4) explains the maximum change in outputs by using a set of $t+1$ inputs compared with the $t+1$ technology.

Following Färe *et al*. [22] [24] [38], Färe and Grosskopf [23], and Choi *et al*. [39], the output-based conventional Malmquist productivity is as follows:

$$M_H\left(x^{t+1}, y^{t+1}, x^t, y^t\right) = \frac{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_0^t\left(x^t, y^t\right)}\left[\frac{D_0^t\left(x^{t+1}, y^{t+1}\right)}{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)} \frac{D_0^t\left(x^t, y^t\right)}{D_0^{t+1}\left(x^t, y^t\right)}\right]^{1/2}. \tag{5}$$

According to Ball *et al*. [27], output-based environmentally sensitive Malmquist productivity is defined as

$$M_{EH}\left(x^{t+1}, y^{t+1}, b^{t+1}, x^t, y^t, b^t\right) = \frac{D_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}\right)}{D_0^t\left(x^t, y^t, b^t\right)}\left[\frac{D_0^t\left(x^{t+1}, y^{t+1}, b^{t+1}\right)}{D_0^{t+1}\left(x^{t+1}, y^{t+1}, b^{t+1}\right)} \frac{D_0^t\left(x^t, y^t, b^t\right)}{D_0^{t+1}\left(x^t, y^t, b^t\right)}\right]^{1/2}. \tag{6}$$

In Equation (6), with the presence of environmental pollution, the environmental efficiency change is shown with out of the square brackets between t and $t+1$ periods and is called a catching up, namely how much closer a state can approach the ideal frontier. On the other hand, environmental technical progress is the geometric mean of the second term in the square brackets in periods of t and $t+1$, and this means a technological innovation, namely how much the ideal frontier shifts from the existing technology. If $M\left(EH\right) = 1$, then there is no environmental productivity growth between *t* and $t+1$ periods, whereas if $M\left(EH\right) > 1$ $\left(M\left(EH\right) < 1\right)$, there is positive (negative) environmental productivity growth between these two periods [24].

Following Ball *et al*. [27], the Malmquist environmental productivity index is the ratio of environmentally sensitive and conventional Malmquist productivities as follows:

$$E_H\left(x^{t+1}, y^{t+1}, b^{t+1}, x^t, y^t, b^t\right) = \frac{M_{EH}\left(x^{t+1}, y^{t+1}, b^{t+1}, x^t, y^t, b^t\right)}{M_H\left(x^{t+1}, y^{t+1}, x^t, y^t\right)}. \tag{7}$$

$E\left(H\right)$, the Malmquist environmental productivity index, has three signs: if $E\left(H\right) = 1$, then it means that environmentally sensitive Malmquist productivity and conventional Malmquist productivity are the same, that is, environmental pollution does not have any impact on actual productivity change; if $E\left(H\right) > 1$, then it implies that environmentally sensitive Malmquist productivity is greater than conventional Malmquist productivity (actual productivity growth is affected by the change in environmental pollution), and; if $E\left(H\right) < 1$, then environmentally sensitive Malmquist productivity is less than conventional Malmquist productivity. Hence, the change in environmental pollution has an impact on the actual productivity decline [28].

4. Data

The output distance function only needs data for inputs, output, and pollutions [28], meaning that in our analysis state-level panel data of 51 states for the period of 2002-2011 were used. These consist of one proxy for output, three proxies for inputs, and one proxy for GHG effects in the US transportation sector. The one output is GDP from the transportation sector in a state, which was measured in millions of dollars and derived from the US Bureau of Economic Analysis [12]. For inputs, the number of workers, number of establishments, and all petroleum consumption by the transportation sector in a state were utilized: the first and second inputs are measured in ones and obtained from the US Census Bureau [40] and the third input, thousand barrels of oils, was derived from the US Energy Information Administration [41]. To be representative of the GHG effect, state CO_2 emissions by fuel combustion in the transportation sector were chosen and derived from the US Environmental Protection Agency [13] and measured in MMT.

Table 1 shows the summary statistics for the data used in this study. The coefficient of variation in each variable that is calculated from the ratio of the standard deviation to the mean shows much less than 10[6], suggesting the dispersion of the variables is small [42]; therefore, no input and output used in the data shows a high heterogeneity among the 51 states. California has the largest transportation industry in the data, while District of Columbia is the smallest transportation industry. In addition, in terms of output production and CO_2 emissions, California's transportation industry produces approximately 125 times more gross output and 168 times more CO_2 emissions than District of Columbia's transportation industry. During the study period, CO_2 emissions from the US transportation sector in 2011 decreased by 2% compared with 2002, but GDP from it in 2011 increased by 48% during the same period.

5. Empirical Results

To measure the effects of the CO_2 emissions change on US transportation productivity for 2002-2011, the Malmquist environmental productivity index was calculated from a Data Envelopment Analysis (program 2.1)[7] and decomposed into conventional and environmentally sensitive Malmquist productivities and their efficiency and technological components in the Malmquist summary of state means in **Table 3**. In **Table 4**, the index from the Malmquist summary of annual means was used to reveal the relationship between CO_2 emissions changes and actual productivity.

Before further discussions of the Malmquist environmental productivity index, the two non-parametric statistical tests in **Table 2** were performed to assess the validity of conventional and environmentally sensitive Malmquist productivities. Even though the Sign test rejected the null hypothesis that the difference between them is equally positive or negative at the 10% significance level, there was insufficient evidence to show the difference

Table 1. Summary statistics for output and input variables from 2002 to 2011.

Variable	Mean	SD	Min	Max	CV
GDP (million dollars)	7489	8369	302	47,457	1.12
Labor (ones)	81,185	86,323	3110	468,916	1.06
Establishment (ones)	4123	4018	175	21,711	0.97
Petroleum (thousands of barrels)	97,643	107,158	2853	615,649	1.10
CO_2 (MMT)	38.02	41.64	1.07	238.14	1.10

Table 2. Non-parametric statistical tests between conventional and environmentally sensitive Malmquist productivities.

Statistical test	Statistic and p-value
Sign test	−7 (0.064)*
Signed Rank test	−231.5 (0.023)**

Notes: the null hypothesis of the Sign test is that the difference between conventional and environmentally sensitive Malmquist productivities is equally positive or negative; the null hypothesis of the Signed Rank test is that the mean difference between conventional and environmentally sensitive Malmquist productivities is zero; * and ** indicate significance at 10% and 5%, respectively.

[6]The coefficient of variation above 10 suggests the dispersion of a variable is large [42].

[7]A Data Envelopment Analysis program 2.1 is the software to calculate the Malmquist environmental productivity index.

Table 3. Conventional and environmentally sensitive Malmquist productivities ($M(H)$, $M(EH)$), their efficiency and technological changes (Effch and Techch), and the Malmquist environmental productivity index $E(H)$ in the US transportation sector by state means for 2002-2011.

State	Effch	Techch	$M(H)$	Effch	Techch	$M(EH)$	$E(H)$
Alabama	1.079	0.955	1.030	1.097	0.951	1.043	1.013
Alaska	1.099	0.933	1.025	1.097	0.937	1.028	1.003
Arizona	1.095	0.951	1.041	1.092	0.955	1.043	1.002
Arkansas	1.092	0.948	1.035	1.089	0.949	1.033	0.998
California	1.093	0.946	1.034	1.090	0.948	1.034	1.000
Colorado	1.101	0.961	1.058	1.099	0.964	1.059	1.001
Connecticut	1.090	0.964	1.051	1.087	0.965	1.049	0.998
Delaware	1.108	0.959	1.063	1.103	0.960	1.059	0.996
District of Columbia	1.107	0.970	1.074	1.102	0.969	1.068	0.994
Florida	1.108	0.973	1.077	1.103	0.975	1.075	0.998
Georgia	1.040	0.959	0.997	1.040	0.962	1.001	1.004
Hawaii	1.009	0.959	0.968	1.009	0.963	0.972	1.004
Idaho	1.002	0.932	0.934	1.002	0.937	0.939	1.005
Illinois	1.020	0.934	0.952	1.020	0.940	0.959	1.007
Indiana	1.012	0.930	0.941	1.012	0.937	0.948	1.007
Iowa	1.009	0.931	0.940	1.009	0.936	0.945	1.005
Kansas	0.989	0.923	0.913	0.989	0.929	0.919	1.007
Kentucky	0.997	0.921	0.918	0.996	0.928	0.924	1.007
Louisiana	0.988	0.913	0.902	0.988	0.919	0.907	1.006
Maine	0.982	0.895	0.879	0.982	0.899	0.883	1.005
Maryland	1.120	0.923	1.034	1.117	0.929	1.038	1.004
Massachusetts	1.023	0.948	0.970	1.020	0.954	0.973	1.003
Michigan	1.016	0.951	0.966	1.015	0.957	0.971	1.005
Minnesota	1.020	0.945	0.964	1.014	0.954	0.968	1.004
Mississippi	1.022	0.951	0.972	1.017	0.958	0.975	1.003
Missouri	1.025	0.960	0.984	1.020	0.967	0.987	1.003
Montana	1.019	0.964	0.983	1.013	0.972	0.985	1.002
Nebraska	1.028	0.979	1.007	1.023	0.987	1.009	1.002
Nevada	1.022	0.966	0.988	1.014	0.974	0.987	0.999
New Hampshire	1.021	0.980	1.000	1.012	0.984	0.995	0.995
New Jersey	1.059	0.982	1.040	1.056	0.981	1.037	0.997
New Mexico	1.029	0.966	0.994	1.049	0.956	1.002	1.008
New York	1.032	0.973	1.004	1.051	0.963	1.013	1.009
North Carolina	1.025	0.974	0.998	1.044	0.965	1.008	1.010
North Dakota	1.026	0.971	0.996	1.047	0.964	1.01	1.014
Ohio	1.033	0.965	0.998	1.054	0.959	1.011	1.013
Oklahoma	1.030	0.958	0.987	1.049	0.949	0.996	1.009
Oregon	1.042	0.961	1.001	1.062	0.953	1.011	1.010
Pennsylvania	1.033	0.970	1.002	1.052	0.959	1.008	1.006
Rhode Island	1.024	0.944	0.966	1.042	0.936	0.976	1.010
South Carolina	1.087	0.929	1.009	1.106	0.922	1.02	1.011
South Dakota	1.086	0.946	1.027	1.079	0.949	1.024	0.997
Tennessee	1.070	0.967	1.034	1.063	0.966	1.027	0.993
Texas	1.070	0.974	1.042	1.062	0.971	1.032	0.990
Utah	1.071	0.981	1.051	1.065	0.976	1.039	0.989
Vermont	1.078	0.986	1.063	1.072	0.986	1.057	0.994
Virginia	1.086	0.997	1.083	1.079	1.001	1.08	0.997
Washington	1.090	0.992	1.081	1.083	0.993	1.075	0.994
West Virginia	1.072	0.990	1.061	1.064	0.990	1.054	0.993
Wisconsin	1.079	0.990	1.068	1.071	0.993	1.063	0.995
Wyoming	1.102	0.998	1.099	1.096	0.999	1.094	0.995

Table 4. Conventional and environmentally sensitive Malmquist productivities ($M(H)$, $M(EH)$) and the Malmquist environmental productivity index $E(H)$ in the US transportation sector by annual means for 2002-2011.

Year	State mean CO_2 emissions (unit: MMT)	$M(H)$	$M(EH)$	$E(H)$
2003	36.883	0.884	0.899	1.017
2004	37.554	1.116	1.115	0.999
2005	37.831	0.916	0.911	0.995
2006	38.136	0.945	0.951	1.006
2007	38.304	1.297	1.297	1.000
2008	37.168	0.850	0.851	1.001
2009	36.561	0.901	0.903	1.002
2010	36.793	1.148	1.146	0.998
2011	36.508	1.071	1.073	1.002

Notes: CO_2 emissions in 2002 is 36.877 MMT; 2002 does not have a base year to calculate $M(H)$, $M(EH)$, and $E(H)$.

in the two productivities was nonzero. Therefore, the Signed Rank test was additionally performed to compare the differences between conventional and environmentally sensitive Malmquist productivities with zeroes, and then the null hypothesis of indifference between them was rejected at 5%, showing that they were statistically different from each other [43].

In **Table 3**, the effects of these CO_2 emissions changes were interpreted with the three distinct findings from the Malmquist environmental productivity index. First, among the 51 states, 17 states showed an actual productivity decline ($E(H) < 1$) with a decrease in CO_2 emissions, which suggests that a CO_2 emissions reduction in one-third of US states from the transportation sector negatively affected actual productivity. Second, California, which had emitted the largest CO_2 but decreased CO_2 emissions from the transportation sector the most, demonstrated that conventional and environmentally sensitive Malmquist productivities were the same ($E(H) = 1$), which means a CO_2 emissions reduction had not changed actual productivity. Third, as the ideal case, 30 states, much more than half of the 51 states sampled, revealed actual productivity growth ($E(H) > 1$) with a decrease in CO_2 emissions.

Many states (22 in 30) with $E(H) > 1$ showed higher (lower) technological (efficiency) change scores in environmentally sensitive Malmquist productivity than in conventional Malmquist productivity, implying that the driving force of actual productivity growth from a CO_2 emissions reduction was attributed to a technological innovation increase exceeding an efficiency decrease. On the other hand, all states with $E(H) < 1$ experienced lower efficiency change scores when considering a CO_2 emissions reduction compared with conventional Malmquist productivity. These lowered inefficiency scores eventually resulted in an actual productivity decline since they were not offset by increased technological scores, and were aggravated in some states by decreased technological scores in environmentally sensitive Malmquist productivity.

Most states have emitted less and less CO_2 from the transportation sector since 2008, but as noted Nebraska and North Dakota have increased CO_2 emissions, leading to actual productivity growth. The reverse trend of these two states is not desirable to compare to a sustainable growing pattern found by the third finding above. A solution might be achieved by actively considering existing and upcoming transportation policies to reduce CO_2 emissions. However, these could cause an actual productivity decline once they negatively function as a heavy burden to reducing CO_2 emissions, as in the second case. **Figure 3** geographically describes the summary of the Malmquist environmental productivity index with a CO_2 emissions change in the transportation sector by state means for 2002-2011.

Unlike **Table 3** (state means over the 10-year period), **Table 4** shows the findings by annual means. During the period 2002-2011, there was a probability of approximately 67% (because of 2003, 2006, and 2007) that if average CO_2 emissions by state in year t increased (decreased) compared with $t - 1$, then environmentally sensitive Malmquist productivity in year t was smaller (larger) than conventional Malmquist productivity in the same year. Thus, the average CO_2 emissions reduction since 2008 excluding 2010 by state in the transportation sector positively contributed to actual productivity growth. This finding was confirmed by the Malmquist environmental productivity indices showing more than or equal to one ($E(H) \geq 1$) during the same period.

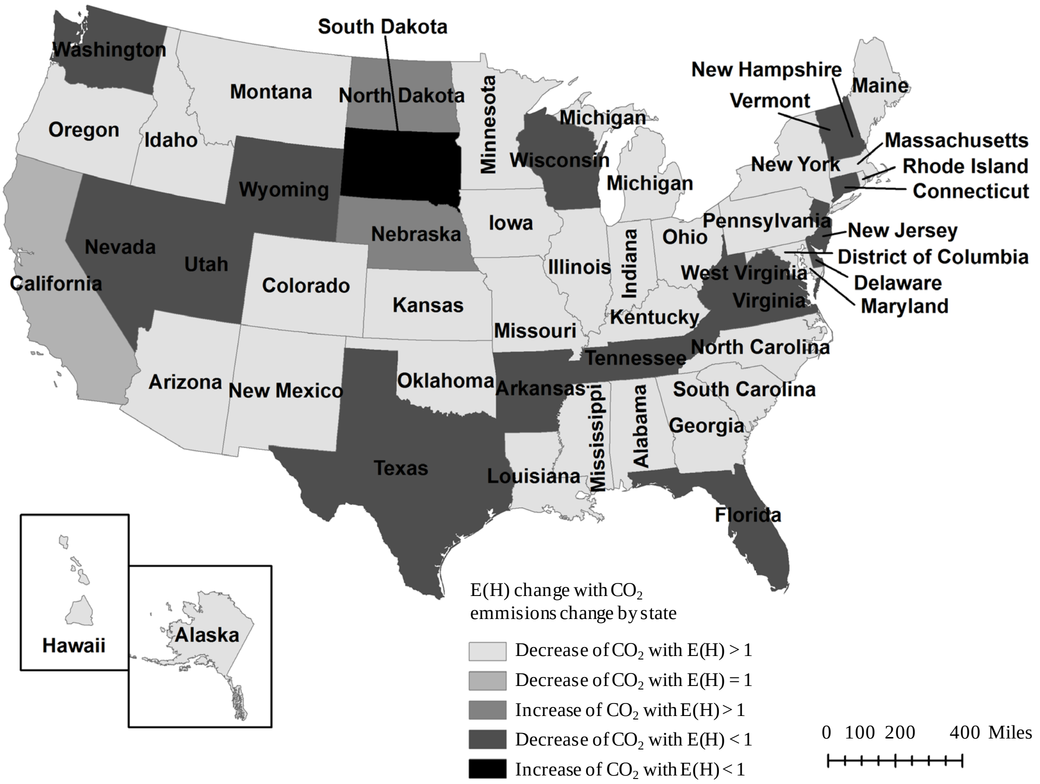


Figure 3. Malmquist environmental productivity index ($E(H)$) with the CO_2 emissions change by state means for 2002-2011 (Note: To represent a productivity growth ($E(H) > 1$) (or decline ($E(H) < 1$) (continuous values with graduated colors were used, not category values).

6. Conclusions

It can be assumed that CO_2 emissions reduction efforts in the transportation sector have a negative effect on productivity growth since reducing CO_2 emissions would lead to not only a decrease in fossil fuel consumption (mainly used to all transport modes), but also large-scale financial investments for developing CO_2 reduction technology and alternative energy.

By applying the Malmquist environmental productivity index in the US transportation sector by state, this study, however, revealed that the effects of a CO_2 emissions reduction can positively affect actual productivity growth. Most states experiencing such sustainable growth showed technological innovation increases going beyond efficiency decreases. Activities to reduce CO_2 emissions evidently affected decision making and acted as a heavy burden to actual productivity. However, new technology developments, making possible more fuel-efficient and carbon reduction transport modes as well as alternative transportation energy sources in recent years, have moved the ideal frontier further from the existing out-of-date frontier.

This might make us question why in the same nation each state had no choice but to experience individual and different efficiency and technological changes. Although new carbon reduction and fuel-efficient technologies were developed in the market, the usage of these at the initial stage required the payment of high costs to producers as well as consumers. Thus, once we understand that each state has different political tendencies with regard to subsidies and environmental regulations, cultural understanding, and concerns about CO_2 emissions, the result in this study could make sense.

Given the advancing low-carbon and energy-efficient technology and increasing environmental policies for the CO_2 emissions reduction in the transportation sector in the world, it will be possible in the near future for CO_2 emissions reduction efforts in the transportation sector to positively affect productivity growth.

This study, nevertheless, could not estimate the individual and quantified effect on actual productivity of a change in environmental policy, fuel-efficient and CO_2 reduction technology development, or each input used. We could only decompose actual productivity change into efficiency and technological changes based on the

Malmquist environmental productivity index, but those two factors might be two of many more possible driving forces. In addition, due to data confidentiality, this study had no choice but to focus on aggregate transportation sector data, not by each transport mode such as airlines, trucks, railways, sea vessels, pipelines, and so on. Thus, those limitations might be solved by a future study, if one can collect data by transport mode and use a multiple regression.

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