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Effect of privatizing Japanese expressway companies on maintenance and management efficiency

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ABSTRACT

In 2005, Japan privatized its four public highway corporations, resulting in the establishment of three NEXCO companies. Although these entities remain fully government-owned, future stock exchange listing is envisioned. To inform discussions on this transition, it is essential to analyze the effects of privatization on management efficiency and identify factors influencing efficiency changes. While a certain degree of progress has been observed in achieving the three objectives articulated by the Japanese government at the time of privatization—namely, the steady repayment of interest-bearing debt, the early and inexpensive construction of expressways, and the provision of various services—these initial goals did not encompass maintenance and operation, which have become increasingly important over time. As a result, the impact of privatization on these aspects remains insufficiently examined. This study therefore focuses on existing expressway segments and investigates changes in maintenance and operational efficiency before and after privatization. Using data envelopment analysis (DEA), we evaluate efficiency based on indicators such as management costs and toll revenue, comparing performance in the pre-privatization period, immediately after privatization, and 14 years later. The results indicate that network-wide efficiency showed little change immediately after privatization. However, route-level analysis reveals a decline in efficiency over time. These findings suggest that privatization, even in the form of a joint stock company, may have limited capacity to enhance long-term management efficiency in expressway operations.

1. Introduction

In October 2005, Japan privatized four public road corporations, including the Japan Highway (JH) Public Corporation, to establish six expressway companies. This privatization restructured these public corporations into joint-stock companies ("privatization as a joint-stock company"). Specifically, the JH was split into three expressway companies—East Nippon Expressway Company Limited (NEXCO East), Central Nippon Expressway Company Limited (NEXCO Central), and West Nippon Expressway Company Limited (NEXCO West)—collectively referred to as the "NEXCO Three Companies." As of 2024, the three companies continued to operate as special companies, with 100 % of their shares owned by the Minister of Finance. According to the agreement reached on December 22, 2003, between the government and ruling parties (Basic Framework for the Privatization of the Four Public Road Corporations), the privatization framework aimed to (1) ensure the repayment of interest-bearing debt, (2) promptly construct roads with minimal fiscal burden on the public, and (3) provide a diverse range of services. Although these expressway companies aim to be listed on the stock exchange, no concrete progress or discussions have been achieved regarding further privatization, including stock market listing, leaving the issue unresolved. Article 2 of the Supplementary Provisions of the Act for Enforcement of Acts Related to Privatization of the Japan Highway Public Corporation, etc., stipulates that the implementation status of the Act must be reviewed within ten years of privatization. In line with this requirement, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) convened the "Expressway Agency and Companies Business Inspection Study Group" from May to July 2015 to assess the progress toward achieving the privatization objectives. However, since none of the three objectives explicitly address the operation of expressways in existing sections, the report of the study group made only limited references to such operations. Therefore, it remains unclear whether privatization has improved the efficiency of maintenance and management operations—an issue of increasing importance. Against this backdrop, this study aimed to analyze the impact of privatizing expressways on operational efficiency, with the

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goal of promoting further debate on additional privatization measures. Specifically, to compare efficiency scores before and after privatization, we applied Data Envelopment Analysis (DEA), a method proposed by Charnes et al. [1] and Banker et al. [2], using metrics such as maintenance costs and toll revenue. Additionally, we calculated route-level efficiency scores to evaluate improvements in management efficiency 14 years after privatization.

2. Review of previous research and positioning of this study

According to previous studies, the privatization of public enterprises typically demonstrates positive effects. Boardman and Vining [3] compared the financial indicators of large non-U.S. private enterprises, public enterprises, and mixed-ownership enterprises and reported that private enterprises generally exhibit higher profitability and efficiency. In a country-specific context, Arocena et al. [4] examined 20 privatized firms across various industries in Spain using DEA and found that the transition from government to private ownership improves efficiency. Similarly, Aivazian et al. [5] reported that converting state-owned enterprises in China into joint-stock companies improved efficiency indicators, such as return on assets and output per employee. They attributed these improvements in part to reforms in internal governance structures. Megginson and Netter [6] compared various privatization studies and concluded that several privatized enterprises showed improved profitability and productivity, along with lower costs, indicating that privatization generally has a positive impact.

In the context of expressways, international literature predominantly focuses on expressway projects operated through public-private partnerships (PPPs). Daito et al. [7] used DEA to calculate efficiency scores based on construction costs, construction period, number of lanes, and construction length in both PPP and non-PPP highway projects in the U. S. They concluded that the two project types did not significantly differ in efficiency. Sarmento et al. [8] applied DEA to seven PPP expressway projects in Portugal, using operating and maintenance expenses, total assets, and number of employees as input data, with average daily traffic and revenue as output data. They found that efficiency scores decreased over time. Unlike these examples, expressways in Japan do not follow a typical PPP scheme, where private sector investors assume financial risk and maintain an equitable contractual relationship with the public sector.

Kimura et al. [9] and Kim et al. [10] employed DEA and other methods to compare the management efficiency in Japanese expressways before and after privatization. Kimura et al. [9] analyzed data from the JH and expressway companies between 2002 and 2011, using tangible fixed-asset values as inputs and operating revenue as outputs in DEA. Subsequently, they employed a Tobit model, treating an efficiency score as the dependent variable and a privatization dummy and gross domestic product as the explanatory variables. Their findings suggest that privatization positively influences efficiency. Kim et al. [10] analyzed data from 2000 to 2010 using cost and total assets as inputs and revenue and service length as outputs in DEA. In contrast to the findings of Kimura et al., Kim et al. found no improvement in post-privatization efficiency. The former did not focus specifically on maintenance, while the latter included total assets—which depreciate over time—as inputs, potentially biasing efficiency scores upward in later years. Furthermore, both studies are limited to assessing the short-term effects—approximately five years—following privatization, without incorporating a medium- to long-term perspective. Moreover, neither study mentions any adjustment for price changes using deflators, suggesting that the analyses may have been conducted using nominal values. While both papers examine changes in efficiency, their analysis of the underlying factors—specifically institutional and structural determinants—is limited.

In addition, Kaino et al. [11] examined the three objectives of the Japan Highway Public Corporation Privatization and demonstrated that its effects were limited. However, as these objectives did not address maintenance and management, they called for further research on this issue. The aforementioned Study Group report [12] also provided only limited remarks on maintenance and management, noting merely that "maintenance-related costs per kilometer have been increasing in recent years." While maintenance expenses were anticipated to rise with increasing traffic volume, the report does not analyze the relationship between traffic volume and toll revenue. Furthermore, both Kaino et al. [11] and the study group [12] focused on the entire network rather than on individual routes.

This study reexamines the effects of privatization on the maintenance, management, and operation of Japan's expressways, addressing several limitations identified in prior research. To enable a more robust mid- to long-term evaluation—an aspect insufficiently explored in earlier studies—the analysis focuses on a period of approximately 15 years following privatization. In addition, efficiency analyses were conducted not only at the aggregate network level but also at the individual route level, thereby allowing for a more granular and precise assessment. The DEA parameters employed in previous studies were refined to more appropriate specifications, and both nominal and real (deflated) values were used to better capture actual conditions. The resulting findings were then examined from institutional and structural perspectives, providing valuable insights for reconsidering the future trajectory of expressway privatization in Japan.

The remainder of this paper is organized as follows. Section 3 presents an overview of the expressway companies. Section 4 examines maintenance and management, analyzing changes in management efficiency over time while treating each route as a single network. Section 5 discusses route-specific efficiency scores obtained using the same method. Section 6 discusses the results of the examinations outlined in Sections 4 and 5.

3. Overview of expressway companies in Japan

3.1. Business scheme of expressway companies

The JH—established in 1956—was the sole organization responsible for building and managing national expressways until its privatization in 2005. Subsequently, it was restructured using a vertical separation method and replaced by two entities: the Expressway Company (hereafter, "the Company"), which manages and operates expressways, and the Japan Expressway Holding and Debt Repayment Agency (hereafter, "the Expressway Agency"), an independent administrative corporation responsible for owning expressway assets and repaying construction-related debts. The Company and Expressway Agency entered into an agreement concerning expressway operations pursuant to Article 13 of the Act on the Japan Expressway Holding and Debt Repayment Agency, Independent Administrative Agency.

Under this agreement, the company transfers newly constructed or repaired expressway assets and the associated debts to the Expressway Agency. In addition, the Expressway Agency leases these expressway assets to the Company, which pays a leasing fee to the Expressway Agency. As of January 1, 2025, the Minister of Finance held 100 % of the shares of the three companies (NEXCO East, Central, and West). In addition, Article 23, Paragraph 5, Item (iii) of the Act on Special Measures concerning Road Construction and Improvement stipulates that tolls may be collected on expressways until as late as September 30, 2115.

3.2. Privatization in this study

According to the Japanese Cabinet Office, a "special corporation" is a corporation established through a special act under a specific law, whereas a "special company" is a company formed under the Commercial Code. "Full privatization" occurs when individual governing laws of an entity are abolished and all government-owned shares are sold, making the entity identical in status to a private-sector company.

Expressway companies are classified as special companies because they were founded as joint-stock companies under the Act on Expressway Companies. Other examples include Nippon Telegraph and Telephone Corporation (NTT), founded under the NTT Act, and Japan Tobacco Inc. (JT), founded under the Japan Tobacco Inc. Act.

We categorized the privatization process into four stages (see Table 1) based on stock issuance and government shareholding status: "public corporations, privatization as a joint-stock company, partial privatization, and privatization." The JH and the three NEXCO companies operated as public corporations until September 2005. In October 2005, they transitioned to "privatized joint-stock companies," wholly owned by the government via the Minister of Land, Infrastructure, Transport and Tourism and the Minister of Finance.

This study focused on comparing the "public corporations" and "privatization as a joint-stock company" stages through pre- and post-privatization analysis.

4. Changes in management efficiency across the entire network before and after privatization

4.1. Data and analysis method

For analyzing the management efficiency of the JH Public Corporation prior to privatization, we used data from the "assumed private-company profit and loss statements" published by JH from 2000 to 2003. For the three NEXCO companies after privatization, we used data from their publicly released profit and loss statements from 2006 to 2019. Since the three NEXCO companies were spun off from JH through privatization, we compared their combined figures with those of JH. Data for 2004 and 2005 were unavailable and thus excluded from the analysis. Additionally, data from 2020 onward were not included due to the exceptional circumstances arising from the COVID-19 pandemic.

This study employed DEA, using total managed length and management costs as inputs and traffic volume and toll revenue as outputs (Table 2). In the expressway business, the company invests in infrastructure (total managed length), maintenance, and management (management costs) to ensure a reliable road network for the public. Road usage (traffic volume) generates revenue through toll payments. This causal relationship can be summarized as input (total managed length and management costs) → road use (traffic volume) → financial outcome (toll revenue).

While total assets were considered as an input variable, as used in the studies by Kimura et al. [9] and Kim et al. [10], this was deemed inappropriate because expressway assets are owned by the Japan Expressway Holding and Debt Repayment Agency and not by the operating companies, and because the effects of depreciation need to be taken into account. Therefore, managed expressway length was adopted as the input variable instead.

Management costs refer to expenditures that are expensed under accounting rules, such as inspection costs and routine pavement repairs. They do not include capital expenditures—such as bridge replacements—that are treated as long-term assets and recorded on the balance sheet rather than as expenses.

Table 1
Types of privatizations using Japanese companies as examples.

Status	Examples of companies in Japan	Government stock ownership
Full privatization	East Japan Railway Company	None
Partial privatization	NTT, JT, and others.	Partial ownership
Privatization as a joint-stock company	East Nippon Expressway Company Limited, Development Bank of Japan Inc., and others.	All holdings
Public corporations and public companies	JH (No longer extant), Japan National Railways (No longer extant), and others.	No shares issued

Table 2
Parameters used in DEA.

Input data	Unit	Output data	Unit
Management length	km	Traffic volume	1 million vehicles/year
Management costs	¥1 billion/year	Toll revenue	¥1 billion/year

The trends in each parameter value are shown in Table 3 and Fig. 1.

For DEA calculations, we used both the Charnes, Cooper, and Rhodes (CCR) and Banker, Charnes, and Cooper (BCC) models, which assume constant returns to scale and variable returns to scale, respectively. Furthermore, as this study focused on maintenance and management, we adopted an input-oriented model that evaluates management efficiency based on the total managed length and management costs.

To ensure comparability over time and eliminate the effects of price fluctuations, we prepared both nominal and deflated values for the input (management costs) and the output (toll revenue) variables. The deflated values were derived using official indices: for management costs, we applied the construction cost deflator for expressway companies published by Japan's Ministry of Land, Infrastructure, Transport and Tourism; for toll revenue, we used the Consumer Price Index (CPI) for expressway tolls released by Japan's Ministry of Internal Affairs and Communications. Specifically, we calculated annual adjustment factors as the reciprocal of the deflator values (i.e., adjustment factor = 1 / deflator), and applied them to convert nominal values into deflated (real) values. This adjustment process enabled consistent year-to-year comparison by removing the influence of inflation. Details of the deflators and adjustment factors used are shown in Table 4.

DEA analyses were conducted separately using nominal values and deflated values, allowing us to evaluate management efficiency under both nominal and inflation-adjusted conditions. This dual approach enhances the robustness of the findings and provides deeper insight into the effects of privatization, independent of price-level changes.

4.2. Management efficiency across the network

Table 5 presents the efficiency scores calculated using DEA for the fiscal years from FY2000 to FY2019. The efficiency score ($0 \leq \theta \leq 1$) indicates that the closer the value is to 1, the higher the efficiency. The average efficiency scores before privatization ranged from 0.964 to 0.971, while those after privatization ranged from 0.957 to 0.969. Given that the values are generally similar across both periods, it is difficult to conclude that overall efficiency improved following privatization. This result is consistent with the findings of Kim et al. [10].

The lowest efficiency scores, ranging from 0.903 to 0.921, were observed in FY2008. As shown in Table 3 and Fig. 1, traffic volume declined from 2361 million in FY2007 to 2324 million vehicles in FY2008. This drop was likely due to the Lehman Shock in September 2008, which reduced traffic and lowered efficiency. The second-lowest efficiency scores, ranging from 0.911 to 0.935, were recorded in FY2009. Although traffic volume increased to 2416 million vehicles—surpassing the FY2008 level of 2324 million—the "¥1000 unlimited weekend ride policy", introduced at the end of FY2008, led to substantial toll discounts and thus reduced toll revenue. This decline in revenue likely contributed to lower efficiency.

By contrast, in FY2010, the government implemented a "free expressway social experiment" from June 2010 to June 2011. Although toll revenue declined by approximately 2.3 % from the previous year, traffic volume rose sharply by approximately 12.5 % year-on-year to 2718 million vehicles. This significant increase in traffic volume is considered the primary factor behind the attainment of the maximum efficiency score of 1.000 under both the CCR and BCC models in FY2010.

Table 3
Input and output data.

Fiscal year	Input data		Output data		
	Management length (km)	Management costs (¥1 billion/year)	Traffic volume (1 million vehicles/year)	Toll revenue (¥1 billion/year)	Privatization phase
2000	7,675	329.895	2,247	2,096.233	Pre
2001	7,810	324.234	2,225	2,152.252	Pre
2002	8,078	402.432	2,219	1,957.051	Pre
2003	8,222	360.423	2,244	1,971.409	Pre
2004	N/A	N/A	N/A	N/A	Pre
2005	N/A	N/A	N/A	N/A	Privatization
2006	8,299	471.010	2,334	1,983.080	Post
2007	8,412	471.020	2,361	1,964.895	Post
2008	8,516	460.234	2,324	1,836.176	Post
2009	8,601	458.943	2,416	1,543.230	Post
2010	8,700	479.832	2,718	1,507.333	Post
2011	8,734	488.864	2,688	1,562.329	Post
2012	9,009	522.276	2,636	1,724.999	Post
2013	9,111	533.125	2,747	1,775.915	Post
2014	9,282	590.085	2,661	2,129.701	Post
2015	9,353	597.637	2,720	2,203.870	Post
2016	9,404	631.972	2,772	2,233.582	Post
2017	9,461	650.317	2,797	2,280.963	Post
2018	9,564	650.842	2,870	2,336.296	Post
2019	9,628	664.425	2,892	2,345.697	Post

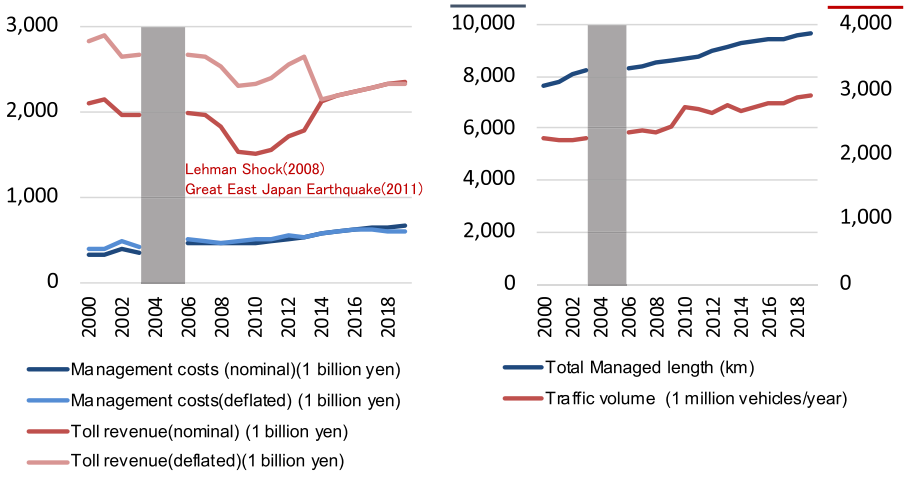


Fig. 1. Transition of parameter values over time (blue: input data and red: output data).

5. Changes in management efficiency by route after privatization

5.1. Data used

This section examines management efficiency trends over the 14 years following privatization, focusing on 94 routes managed in FY2006 and FY2019—representing the year immediately after privatization and that just before the spread of COVID-19, respectively. Specifically, we used figures published by the Expressway Agency in the Expressway Agency Fact Book. This dataset is publicly available for individual routes and is independently sourced from, rather than derived from, the data used in the previous chapter. As described in the previous section, the total managed length and management costs served as the input data for DEA, while traffic volume and toll revenue were used as the output data (see Table 2).

An example of an excluded route is the Sendai Southern Road, which is currently managed by NEXCO East. This road was not managed by NEXCO East in FY2006 and was only transferred from the Miyagi Prefectural Road Public Corporation to NEXCO East in July 2013. As it was not managed in both FY2006 and FY2019, it was excluded from analysis. Table 6 presents the summary statistics of the route-specific input and output data used in this calculation. Among the 94 routes analyzed, 37 are operated by NEXCO East, 19 by NEXCO Central, and 38 by NEXCO West.

5.2. Changes in route-level management efficiency

Fig. 2 presents the efficiency scores for each route, calculated using the DEA CCR and BCC models based on data from FY2006 and FY2019. The results are shown for each company as well as for the combined total of the three NEXCO companies. Fig. 3 shows the corresponding efficiency scores calculated using deflated values for management costs and toll revenues. For both models, the Shapiro–Wilk test indicated that the efficiency scores were not normally distributed. Therefore, we conducted significance testing using the non-parametric Wilcoxon signed-rank test. According to Fig. 2 (nominal values), the average efficiency scores for the three NEXCO companies combined were 0.493 (CCR) and 0.598 (BCC) in FY2006, the year immediately after privatization, and declined to 0.467 (CCR) and 0.563 (BCC) in FY2019, fourteen years later. Both differences were statistically significant ($p < 0.01$), indicating a decline in overall management efficiency over time. At the individual company level, NEXCO East showed statistically significant decreases of 0.060 (CCR) and 0.065 (BCC) ($p < 0.01$), while NEXCO

Table 4
Deflator and correction factor.

Fiscal year	Management costs		Toll revenue	
	Deflator	Adjustment factors	Deflator	Adjustment factors
2000	84.4	1.185	74.0	1.351
2001	83.1	1.203	74.0	1.351
2002	82.7	1.209	74.0	1.351
2003	84.4	1.185	74.0	1.351
2004	-	-	-	-
2005	-	-	-	-
2006	90.2	1.109	74.0	1.351
2007	93.8	1.066	74.0	1.351
2008	98.7	1.013	72.7	1.376
2009	92.1	1.086	66.7	1.499
2010	93.7	1.067	64.9	1.541
2011	95.8	1.044	64.9	1.541
2012	94.7	1.056	67.3	1.486
2013	97.9	1.021	67.3	1.486
2014	101.4	0.986	98.7	1.013
2015	100.0	1.000	100.0	1.000
2016	100.1	0.999	100.0	1.000
2017	102.9	0.972	100.2	0.998
2018	107.5	0.930	100.2	0.998
2019	110.1	0.908	101.1	0.989

Central exhibited statistically significant declines of 0.070 (CCR) and 0.066 (BCC), both at the $p < 0.05$ level. In contrast, NEXCO West recorded slight increases of 0.028 (CCR) and 0.009 (BCC), neither of which was statistically significant.

Fig. 3, which presents the results based on deflated values, shows a similar trend. The average efficiency scores for the three NEXCO companies combined were 0.501 (CCR) and 0.606 (BCC) in FY2006, and declined to 0.476 (CCR) and 0.560 (BCC) in FY2019. Both declines were statistically significant ($p < 0.01$), reaffirming the conclusion that overall management efficiency decreased after privatization. Company-level results using deflated values also showed statistically significant decreases: NEXCO East declined by 0.056 (CCR) and 0.072 (BCC) ($p < 0.01$), while NEXCO Central declined by 0.084 (CCR) and 0.082 (BCC), both of which were statistically significant at the $p < 0.05$ level. NEXCO West showed a 0.034 increase in CCR and a 0.001 decrease in BCC, neither of which was statistically significant. One likely reason why NEXCO West did not show statistically significant changes despite a rise in its average scores is the substantial improvement observed for the Daini Keihan Road. Specifically, the efficiency scores for this route increased by 0.252 (CCR) and 0.358 (BCC) under nominal values, and by 0.276 (CCR) and 0.347 (BCC) under deflated values. These sharp increases contributed to an overall higher average in FY2019 but did not result in statistical significance for the company as a whole. The Daini Keihan Road experienced a major increase in both traffic volume and toll revenue in FY2019, partly due to the integration of the Kamogawa Higashi IC–Oguraike Hon Line segment of the Hanshin Expressway No. 8 Kyoto Line into its network.

Fig. 4 depicts the efficiency scores for each route in FY2006 (horizontal axis) plotted against those in FY2019 (vertical axis). Two separate scatter plots are presented: one based on nominal values and the other on deflated values. Among the 94 routes analyzed, 60 routes (63.8 %)

Table 5
Efficiency scores for the JH (before privatization) and the three NEXCO companies (after privatization).

FiscalYear	**CCR efficiency**				**BCC Efficiency**				Privatization phase
	Nominal values		**Deflated values**		**Nominal values**		**Deflated values**		
		Average		Average		Average		Average	
2000	1.000		1.000		1.000		1.000		Pre
2001	1.000		1.000		1.000		1.000		Pre
2002	0.929		0.934		0.950		0.950		Pre
2003	0.928	0.964	0.925	0.965	0.933	0.971	0.933	0.971	Pre
2004	N/A	-	N/A	-	N/A	-	N/A	-	Pre
2005	N/A	-	N/A	-	N/A	-	N/A	-	Privatization
2006	0.945		0.941		0.948		0.948		Post
2007	0.940		0.933		0.943		0.942		Post
2008	0.909		0.903		0.921		0.921		Post
2009	0.912		0.911		0.935		0.935		Post
2010	1.000		1.000		1.000		1.000		Post
2011	0.989		0.989		0.990		0.989		Post
2012	0.952		0.949		0.953		0.950		Post
2013	0.979		0.974		0.986		0.980		Post
2014	0.954		0.941		0.955		0.95		Post
2015	0.969		0.957		0.970		0.971		Post
2016	0.981		0.970		0.982		0.987		Post
2017	0.985		0.971		0.986		0.989		Post
2018	1.000		0.981		1.000		1.000		Post
2019	1.000	0.965	0.980	0.957	1.000	0.969	1.000	0.969	Post

Table 6
Summary statistics of input and output variables for 2006 and 2019.

year	Variable	Unit	N	Mean	SD	Min	25th Percentile	Median	75th Percentile	Max
2006	Total managed length	km	94	87.63	127.53	3.70	14.13	31.00	102.25	698.00
	Management costs (Nominal)	billion yen/year	94	49.41	80.46	0.80	4.28	20.20	50.83	450.10
	Management costs (Deflated)	billion yen/year	94	54.80	89.23	0.89	4.74	22.40	56.37	499.16
	Traffic volume	million vehicles /year	94	24.15	32.35	0.73	3.29	12.05	27.74	157.68
	Toll revenue (Nominal)	billion yen/year	94	208.76	390.16	0.80	13.25	69.00	169.10	2358.80
	Toll revenue (Deflated)	billion yen/year	94	282.04	527.11	1.08	17.90	93.22	228.45	3186.74
2019	Total managed length	km	94	99.75	131.73	4.00	14.50	39.00	131.25	698.00
	Management costs (Nominal)	billion yen/year	94	67.82	94.63	1.10	7.30	28.30	99.90	467.80
	Management costs (Deflated)	billion yen/year	94	61.58	85.92	1.00	6.63	25.70	90.71	424.76
	Traffic volume	million vehicles /year	94	29.38	33.81	0.73	5.20	16.97	39.15	152.94
	Toll revenue (Nominal)	billion yen/year	94	241.08	369.13	0.90	25.33	83.40	296.00	2010.30
	Toll revenue (Deflated)	billion yen/year	94	238.42	365.07	0.89	25.05	82.49	292.75	1988.19

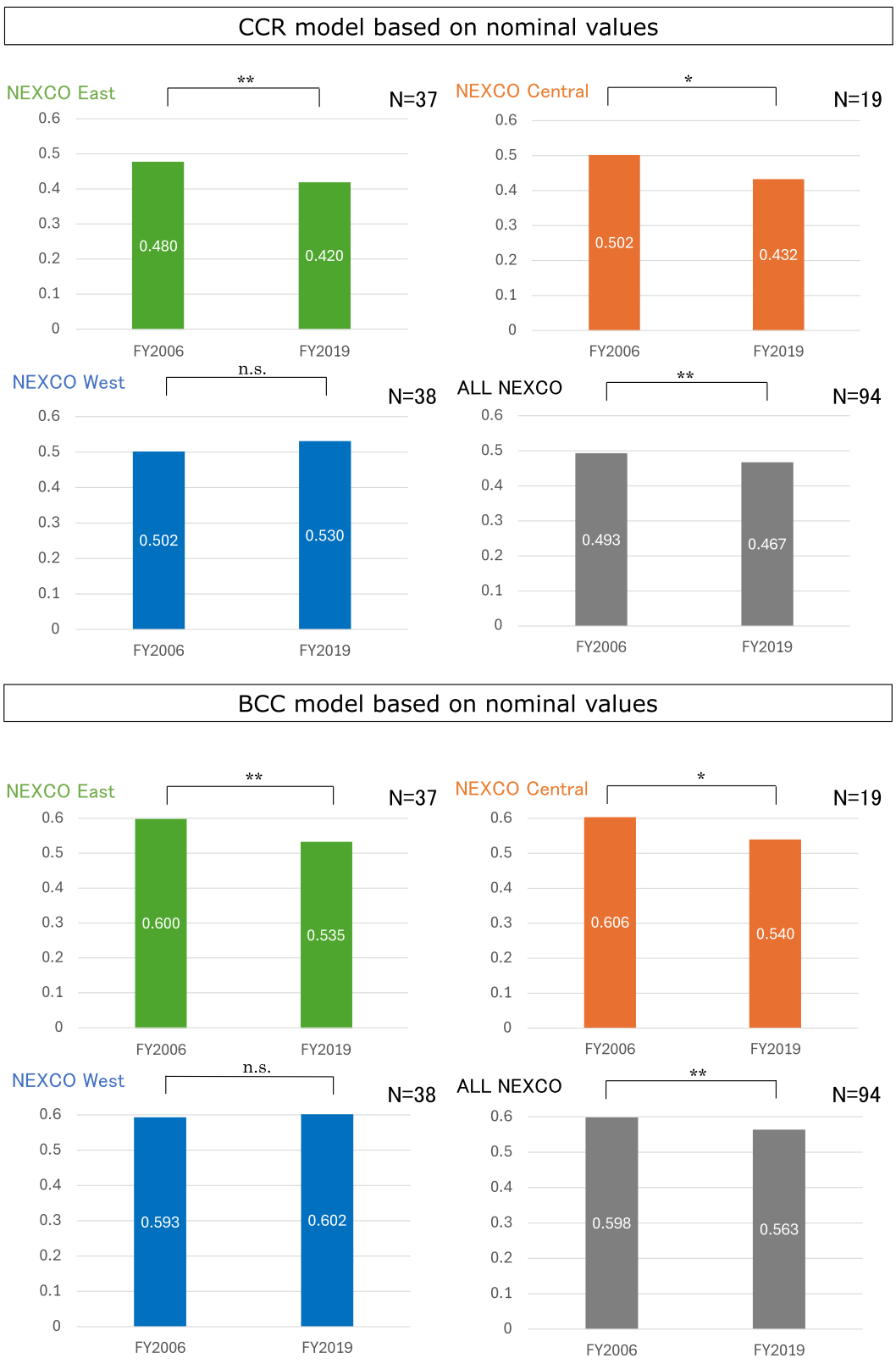


Fig. 2. Efficiency scores by route based on nominal values for 2006 and 2019.

Wilcoxon signed rank test
*: $p<0.05$
**: $p<0.01$

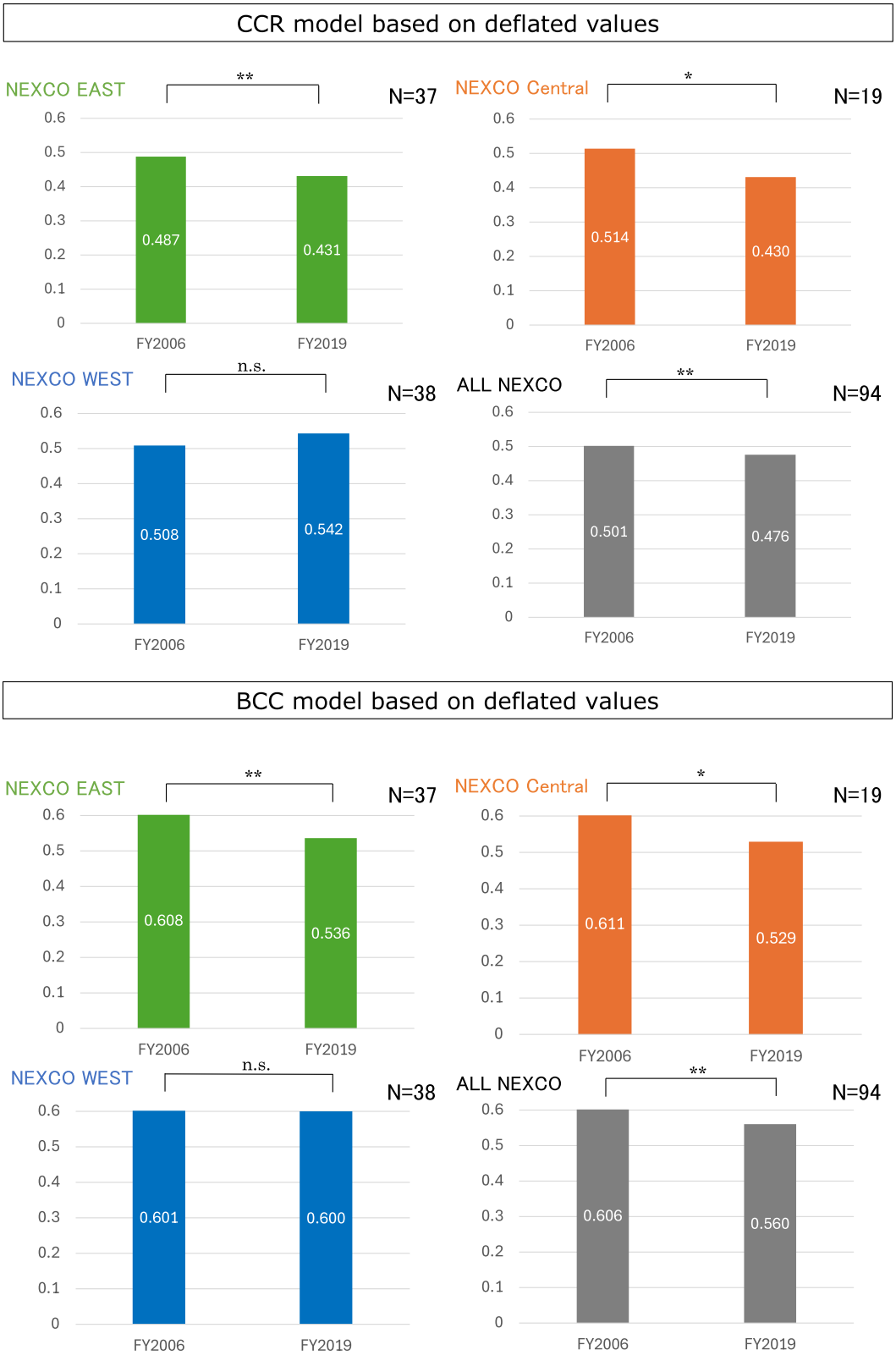


Fig. 3. Efficiency scores by route based on deflated values for 2006 and 2019.

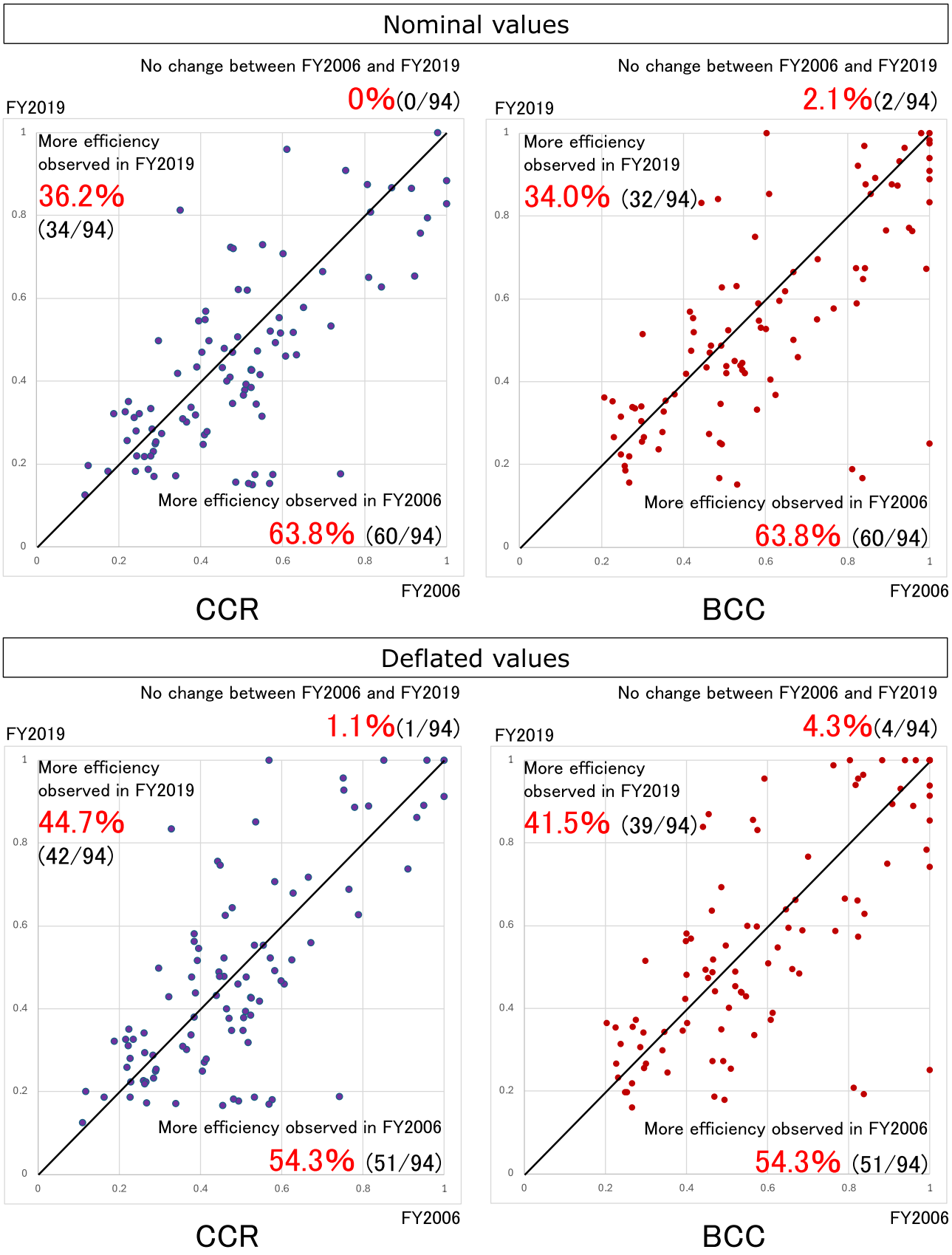


Fig. 4. Efficiency scores by route for FY2006 and FY2019.

showed higher efficiency in FY2006 than in FY2019 under both the CCR and BCC models when using nominal values. When using deflated values, 51 routes (54.3 %) were more efficient in FY2006 under both models. These results suggest a general decline in route-level management efficiency over time since privatization. Fig. 5 shows the input and output data used in these calculations for each route. Among the four variables, management costs and toll revenue are provided in both nominal and deflated forms. While all four indicators tended to have higher absolute values in FY2019 than in FY2006, the efficiency scores were generally higher in FY2006. This discrepancy can be attributed to the fact that the rate of increase in inputs exceeded that of outputs. However, since the total managed length—used as the input—remained unchanged for approximately 70 % of the routes between FY2006 and FY2019, the changes in efficiency scores are primarily driven by fluctuations in management costs. As discussed in the previous section, network-wide average efficiency remained largely stable over the period. Nevertheless, the route-level results reveal notable disparities immediately after privatization. This suggests that the current toll revenue pooling system has functioned effectively, allowing revenue redistribution across the entire network to offset inefficiencies on individual routes.

In efficiency analysis using Data Envelopment Analysis (DEA), it has been noted that technological progress over time may shift the production frontier, potentially introducing bias when directly comparing efficiency across different time periods (Färe et al. [14]). To address this limitation, this study complements the static DEA analysis by calculating the Malmquist Productivity Index (MPI). The calculation follows the methodology of Färe et al. (1994) and employs the BCC model to decompose productivity change into two components: technical efficiency change (TECI) and technical change (TCI). These indices capture changes between FY2006 and FY2019, with 1.000 serving as the baseline: values above 1 indicate improvement, while values below 1 indicate deterioration. The results show that the average MPI score was 0.902, and the Wilcoxon signed-rank test confirmed that this was significantly below 1 ($p < 0.01$), indicating a statistically significant decline in overall productivity during the study period. Similarly, the

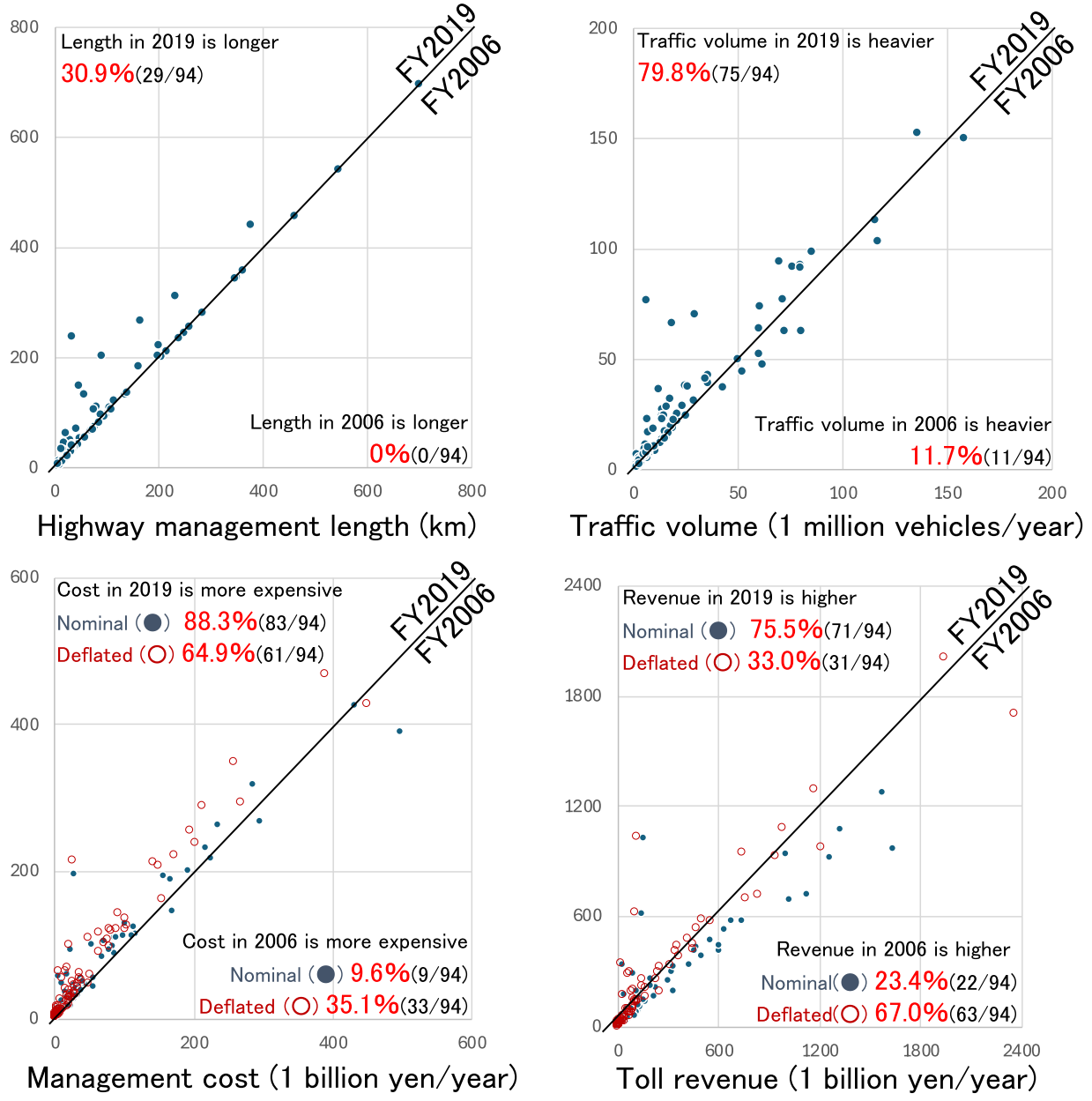


Fig. 5. Input and output values for FY2006 and FY2019.

average TCI score was 0.904, which was also significantly lower than 1 ($p < 0.01$), suggesting that no meaningful technological progress occurred during this time. In contrast, the average TECI score was 0.983, and the difference from 1 was not statistically significant ($p = 0.107$), indicating that the efficiency in utilizing existing technology remained largely unchanged. These findings imply that, although firms did not experience a significant decline in their ability to use existing technology efficiently, there was no evidence of technological advancement contributing to productivity gains. This dynamic analysis aligns with the results from the static DEA-based efficiency analysis, which found no clear improvement in efficiency before and after privatization. Together, these results reinforce the central argument of this study: that even over approximately 15 years following privatization, there were no substantial gains in technical or productivity efficiency.

6. Discussion

6.1. Factors preventing efficiency improvements before and after privatization

As described in Section 4, we identified three factors that prevented efficiency improvements both before (FY2000–FY2003) and after privatization (FY2006–FY2019).

The first is the divergence between the growth rates of the number of vehicles and road length. Fig. 6 illustrates the number of vehicles owned and the length of expressways used over time. Before privatization, the rate of expressway construction was generally proportional to the rate of increase in the number of vehicles. However, around 2005, the number of cars in Japan plateaued, while the length of expressways in use continued to increase. Consequently, although traffic volume and toll revenue (the output variable in this analysis) were unlikely to increase, management costs (a key input variable) were likely to increase in proportion to the length of the roads managed. This imbalanced structure rendered profit-making increasingly difficult.

Second, inefficiencies emerged owing to the privatization of the three companies. One example is the increased administrative burden of adjusting tolls when crossing between expressway networks operated by different companies. Additionally, each company had to establish its own corporate departments, further contributing to inefficiencies. Consequently, while traffic volume and toll revenue (the output variables) did not increase, management costs (the input variable) rose. Mizutani et al.[15] analyzed maintenance and management costs using pre-privatization data from JH. They reported that the optimal size of the expressway network for minimizing management costs was 2841 km. As of FY2019, however, the lengths of roads managed by NEXCO East, NEXCO Central, and NEXCO West were 3943, 2151, and 3534 km, respectively, suggesting potential inefficiencies in management.

Thirdly, privatization has induced minimal fundamental changes in business processes. Although the expressway companies have been privatized as joint-stock companies, more than half of their capital continues to remain government-funded. Hence, the companies must comply with the Act for Promoting Proper Tendering and Contracting for Public Works. Consequently, expressway construction and maintenance projects are classified as public works, necessitating public procurement. In other words, privatization has induced no significant changes in the procurement system, restricting the ability of companies to act independently. Specifically, while low-cost procurement would directly lead to profits for a typical private company, public procurement requires that the contract ceiling price be determined based on the "cost estimation standard." Subsequently, bids are examined to ensure that they fall below this ceiling price; otherwise, the contract cannot be awarded. This makes it difficult to actively pursue low-cost procurement strategies. In addition, while tax payments represent a major expense for ordinary companies, expressway companies are exempted from fixed asset tax and city planning tax under Article 348 of the Local Tax Law and Article 14 of the Supplementary Provisions of the same law. This exemption exists because, although these companies were privatized as joint-stock companies, the Expressway Agency continues to own the expressway assets. Furthermore, expressway companies are also exempted from business office tax under Article 701–34, Paragraph 3, and Item 29 of the Local Tax Law. Hence, despite privatization, no significant changes have been observed compared to the JH era.

6.2. Factors contributing to the decline in efficiency scores immediately after privatization

In this section, we discuss two factors contributing to the decline in efficiency scores in FY2019 compared to those in FY2006, immediately after privatization, as outlined in Section 5.

The first factor is the increase in management costs per kilometer. Fig. 7 illustrates the management costs of each company from FY2006 to FY2019, indexed to FY2015 (FY2015 = 100). The black line represents the average management costs of the three NEXCO companies. The gray line denotes the construction cost deflator, also set at 100 for FY2015. The management costs of the three NEXCO companies show an upward trend, aligning with the trend in price fluctuations (construction cost deflators). However, the average management costs for the three NEXCO companies from FY2006 to FY2014 were 89.26, while the average from FY2016 to FY2019 rose to 106.65. This indicates that the increase in management costs was higher than the rate of inflation and that cost reductions were not achieved. This disparity may be due to the

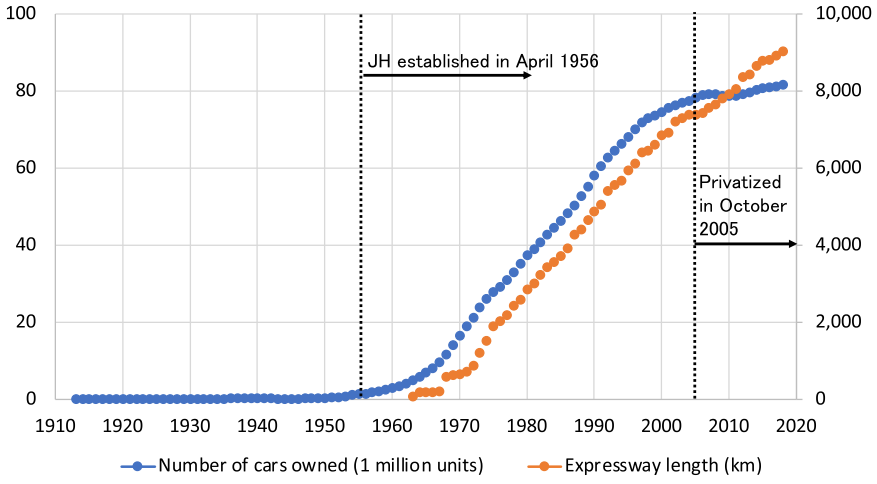
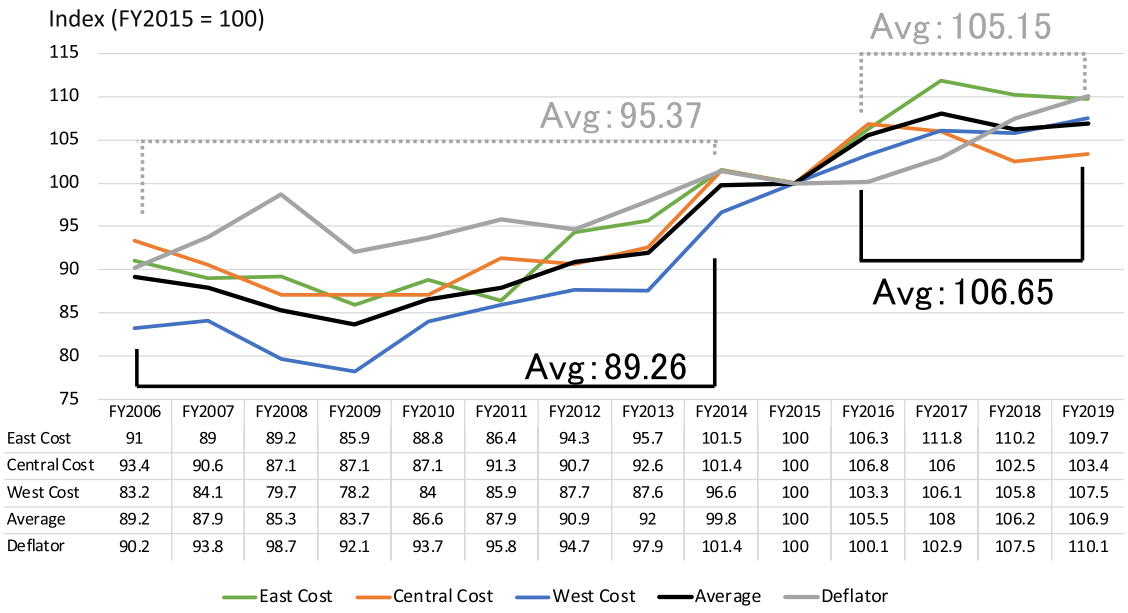


Fig. 6. Number of Cars Owned and Length of Expressways in Japan.



	FY2006	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016	FY2017	FY2018	FY2019
East Cost	91	89	89.2	85.9	88.8	86.4	94.3	95.7	101.5	100	106.3	111.8	110.2	109.7
Central Cost	93.4	90.6	87.1	87.1	87.1	91.3	90.7	92.6	101.4	100	106.8	106	102.5	103.4
West Cost	83.2	84.1	79.7	78.2	84	85.9	87.7	87.6	96.6	100	103.3	106.1	105.8	107.5
Average	89.2	87.9	85.3	83.7	86.6	87.9	90.9	92	99.8	100	105.5	108	106.2	106.9
Deflator	90.2	93.8	98.7	92.1	93.7	95.8	94.7	97.9	101.4	100	100.1	102.9	107.5	110.1

Fig. 7. Trends in management costs (per kilometer).

rise in management costs, ultimately rendering the system inefficient.

The second factor is the highway tolls, which have remained unchanged despite rising prices. Table 7 presents the changes in highway tolls per kilometer. Since the establishment of the JH, tolls have been revised 12 times based on distance, with highway tolls in 1997 being 2.5 times higher than in 1963. However, following privatization in 2005, there have been no changes in tolls based on distance. As a result, tolls have not accounted for rising management costs, implying that the toll revenue (output) has not increased in proportion to management costs (input). This imbalance may have contributed to the decline in efficiency scores calculated in this study. In contrast, tolls were revised as required for overseas expressways. As shown by the deflated toll revenue in Fig. 1, actual toll revenue has declined in real terms. For example, in the UK, a toll of £ 3.5 was imposed on standard cars for a 43-km section of the M6 toll in October 2005, around the same time as the privatization of the JH. However, by January 2024, the toll was increased to £ 8.6, approximately 2.5 times the original amount, following nine revisions. Although the length of the M6 toll extension remained unchanged, the tolls were revised to improve services. These improvements included the introduction of automatic number plate recognition technology and a new payment system that allowed payment via smart devices. However, Express Highway Research Foundation of Japan [13] has stated that, in Japan, tolls are not necessarily determined by the cost of the service but are primarily set to recover construction and maintenance costs. While this approach is inefficient, it fulfills its purpose if the overall construction and maintenance costs are recovered. In the future, policymakers should consider setting tolls as compensation for the service provided, while also enhancing the quality of services to meet emerging social demands, such as automated driving.

Table 7
Historical trends in expressway tolls (per kilometer).

Year	1963-	1972-	1975-	1989-	1997-
Motorcycle	7.5	8.0	13.0 (+100)	18.4 (+150)	19.68 (+150)
Standard passenger car	9.5	8.0	13.0 (+100)	23.0 (+150)	24.6 (+150)
Standard freight car (less than 8 tons)	11.5	8.0	19.5 (+100)	24.38 (+150)	29.52 (+150)
Standard freight car (8 tons or more)	11.5	12.0	19.5 (+100)	35.65 (+150)	40.59 (+150)
Large special vehicle	22.0	22.0	33.75 (+100)	63.25 (+150)	67.65 (+150)

Unit: ¥/km (excluding tax)
Figures in parentheses represent the terminal charge

6.3. *Effects of further privatization*

This section examines two effects of transitioning from the current state of privatization—called "incorporation"—to more advanced states of privatization: "partial privatization" and "full privatization." These privatization stages involve listing on the stock exchange.

The first effect is a reduction in management costs (inputs) owing to a shift from public procurement. Under full privatization, procurement for expressway projects would no longer be subject to the "Act for Promoting Proper Tendering and Contracting for Public Works." Additionally, procurement can potentially be promoted as a private company.

According to the Basic Policy on Contracts between the State and Small and Medium-sized Enterprises (Cabinet Decision on April 19, 2024), public works projects should be separated and divided into smaller orders. However, dividing orders prevents the realization of scale benefits and increases the general administrative expenses for the contractor. Based on the calculation standards for general administrative expenses at the three NEXCO companies [16], if direct construction costs total ¥20 billion, dividing the work into 10 separate orders of ¥2 billion each would result in ¥376 million higher general administrative expenses compared to a single order of total ¥20 billion. One approach to reducing costs is to discontinue the system of public procurement, thereby improving efficiency.

Second, toll revenue (output) increased owing to the freedom in setting fees. As discussed in Section 6.2, the current highway tolls have not been revised since 2005, when the distance-based toll system—the basis for calculating tolls—was introduced. Consider the example of Japan Railways (formerly Japan National Railways), a public transport service that has been privatized. Article 16 of the Railway Business Act stipulates that the maximum passenger fare must be approved by the MLIT. Additionally, it mandates that the fare must not exceed the reasonable cost of efficient management and a fair profit. In other words, even fully privatized companies like the East Japan Railway Company lack the autonomy to determine their own fares. However, unlike

railways, expressways are not allowed to include "profit" in their fare estimations, as stipulated by the privatization framework for the four road-related public corporations (agreed upon by the government and ruling party on December 22, 2003). While the principle of free public roads is upheld, the debt repayment period was revised from 45 to 60 y in 2014 and to 110 y in 2023. To pursue profitability and ensure the premise of a going concern when listing on the stock exchange, further discussions should be conducted on discontinuing the existing scheme of excluding current profits and making roads permanently toll roads.

7. Conclusion

In this study, we focused on the expressways in the already-in-use section and examined whether management efficiency had improved based on management costs, toll revenue, and others. Specifically, we applied DEA to analyze whether management efficiency improved after privatization, immediately after privatization, and 14 years after privatization and confirmed whether efficiency scores had increased. No difference in efficiency scores was observed across the entire expressway network. This was attributed to the divergence between the growth rate of the number of cars and road length, the inefficiency caused by split privatization, and the lack of change in fundamental business processes. In addition, by comparing individual routes immediately after privatization and 14 years after privatization, the efficiency scores were found to decrease over time. This was ascribed to the increase in management costs, while the toll system remained unchanged after privatization.

In this study, we calculated efficiency scores for each individual expressway route, using management costs primarily based on routine maintenance and inspection expenditures. However, major renewal works—such as bridge replacements—were not included in the analysis. To enhance future research, it will be necessary to incorporate the costs associated with large-scale renewal projects initiated by the NEXCO companies since 2015, which may significantly affect long-term efficiency evaluations. These results suggest the limitations of improving management efficiency solely through privatization under the joint-stock company model. While route-level efficiency was assessed quantitatively, further case-based investigations are needed to identify the specific factors contributing to financial deficits on particular routes and to examine the long-term sustainability of the overall expressway network. In addition, to deepen the discussion on privatization, future studies should analyze companies that have undergone each stage of privatization—incorporation, partial privatization, and full privatization—and continue to examine how these stages have affected corporate governance, investment decisions, and operational performance. Such analysis will provide a more comprehensive understanding of the institutional and structural effects of privatization in the expressway sector.

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CRediT authorship contribution statement

Tsubasa Kaino: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kazuyoshi Hidaka:** Writing – review & editing, Supervision, Project administration, Methodology.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests. Tsubasa Kaino reports a relationship with East Nippon Expressway Co Ltd that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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