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Article

Diversification and Efficiency Assessment of Japanese Major Private Railways Using Data Envelopment Analysis and the Malmquist Index

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Abstract: Passenger transportation in Japan's main metropolitan areas is operated by the JR companies, which were privatized and divested from Japan National Railways (JNR) in 1987 and by 16 major private railway companies with large-scale operations. Although their core business is transportation, the major private railway companies have adopted a strategy of diversification, and they engage, e.g., in real estate and distribution businesses. This study examines the relationship between the degree of business diversification and the production efficiency of Japan's major private railway companies from the perspective of a future business model. To this aim, this study applies data envelopment analysis combined with the Malmquist index to the data of the railway companies from 1987 to 2019. We focus on four phases of activities: cost, operational resource, operational output, and total revenue. This study is the first to analyze the diversified management of Japanese railroad companies by evaluating their production efficiency and its changes over time. The results of the analysis reveal that, while all companies' earnings have generally increased, the less diversified they are, the more they struggle to optimize personnel and other overhead expenses and resources, lowering production efficiency.

Keywords: Japanese railways; diversification; efficiency; data envelopment analysis; Malmquist index



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1. Introduction

The construction of railroads in Japan has a long history along with the country's economic development. Japan's railroad started service between Shimbashi (Tokyo) and Yokohama in 1872. It contributed to the modernization of society and expanded the railroad network nationwide with the development of railroad technology. After World War II, the Shinkansen bullet train, which started service in 1964 during Japan's rapid economic growth, achieved mass high-speed transportation. The environment surrounding railroads has changed with the spread of automobiles. However, the global warming issue has triggered a modal shift to railroads since 1990 because railroads have a relatively low environmental impact. There were 146 railroad operators in Japan as of 2019. In Japan's passenger railroad sector, the 16 major private railway companies (PRCs) have the second largest business scale after the 6 JR companies¹, with operating revenue of 1717.6 billion Japanese yen, accounting for 23.8% of the total operating revenue of the railroad sector in Japan (calculated from the Statistical Yearbook of Railway Statistics; 1987–2019).

The major PRCs were established to develop transportation networks in metropolitan areas. Based on the concept that urban development along the railroad is important for

business development, they practiced a business model engaging in real estate, cultural and entertainment facilities, and department stores and restaurants at significant stations in addition to the transportation business. They promoted the diversification strategy, and many group companies were established to divest existing businesses and create new businesses. They have actively adopted “the internalization of externalities” as a management strategy (Yamauchi & Kamata, 2010). In fact, the transportation business accounts for less than 50% of the operating revenue of the major PRCs on average, although there are variations among the companies. The companies have produced synergies among their businesses by creating transportation demand through the development of neighborhoods of rail lines and increased revenue to the railroad business.

While the use of public transportation is promoted due to the increasing public interest in climate change issues and environmental protection, the current railroad business in Japan has been facing the problem of a declining population. In particular, it is estimated that the population of Tokyo will continue to increase, while that of the areas surrounding Tokyo will decrease (Regional Population Projections for Japan; National Institute of Population and Social Security Research, 2018). This will significantly impact the future deterioration of the profit structure of PRCs. Meanwhile, it is not easy to increase the revenue of the railroad business under the fare regulation. Fares, the source of operating revenue, are capped due to the public utility aspect of the railroad. Therefore, the promotion of diversification management in group companies to ensure profitability while maintaining the public interest has become a more important issue for PRCs than ever before.

Acknowledging the current situation of the railroad industry, it is evident that further diversifying or concentrating resources on the core business of railroad operations is a vital issue that needs further accumulation of research for stakeholders of the railroad industry, including corporate management and policy makers. This study aims to analyze the management efficiency of the railroad business for the major PRCs in Japan. Then, this study calculates the improvement in efficiency measures and examines the relationship of the measures with diversification management. From these empirical results, this study suggests ideas of productivity improvement for future management and policies for the railroad businesses. To this aim, this study applies data envelopment analysis (DEA) and the Malmquist index to the data of Japan’s PRCs.

The remainder of this paper is structured as follows. Section 2 reviews prior research on the business diversification and production efficiency of railroad companies. Section 3 describes the methodology used in this study. Section 4 explains the data, and Section 5 presents the empirical results and discussion. Finally, Section 6 concludes this study and discusses future research directions.

2. Prior Research on Railroad Companies

This study classifies previous studies of railroad companies into three groups: (1) research on business diversification, (2) research on production efficiency using DEA, (3) research on production efficiency using DEA and the Malmquist index.

2.1. Business Diversification

Diversification strategies of railroad businesses have been discussed in previous studies. Dumas (2007) summarized the diversified operations of passenger railroad companies in Japan, Europe, and the United States during 2003–2004. Wolmar (2009) described that the U.S. railroad industry was dominated by freight transportation and that passenger railroad companies such as Amtrak (National Railroad Passenger Corporation) concentrated on the railroad business by obtaining government subsidies due to the decrease in passengers caused by the motorization and the maintenance of unprofitable routes. Song (2004)

clarified that the diversification management of China's railroad began around 1984, and the railroad operation was supported by profits from side businesses in the 2000s. The first side business was the manufacture of building materials, machine parts, steel, cement, etc. necessary for the railroad industry. After 1990, the business expanded into the service industry such as warehousing, distribution, travel, and real estate under government policy. [Suzuki et al. \(2015\)](#) studied the business situation of the MTR (Mass Transit Railway) in Hong Kong. Although the company increased its earnings by engaging in real estate and distribution businesses along the railroad lines in addition to the transportation business, it claimed the pressure on earnings due to soaring labor, maintenance, and energy costs as issues for the railroad business.

Several studies have been conducted specifically on the diversification of Japanese railroad companies. Many studies examined the diversification strategies of Japanese railroad companies based on the aforementioned historical background. [Shoji \(1998\)](#) used open data such as annual securities reports from 1992 to 1995 of 15 major PRCs to analyze diversification management following [Rumelt \(1974\)](#)'s method and clarified the trend of each company. [Yamauchi and Kamata \(2010\)](#) applied a similar method to determine the correlation between degree of diversification and profitability during 1996–2008 for 13 major PRCs and 3 JR companies. [Song and Shoji \(2016\)](#) examined how diversification affects investment in the railroad business by focusing on capital allocation in the internal capital market. They predicted limits on growth and profitability due to financial support schemes. [Suzuki \(2017\)](#) evaluated the diversification of railroad companies into the real estate business using a model combining an urban land use equilibrium model and an optimal train operation problem. [Miki and Ieda \(2020\)](#) conducted a cluster analysis and diversification measurement of the management strategies of 15 major PRCs. They summarized the historical origins of the companies and the status of their efforts in each segment.

2.2. Assessment of Production Efficiency by DEA

Several studies have investigated the efficiency of railroad operations using DEA. DEA is a comprehensive method to analyze the relative efficiency of entities that was proposed by [Charnes et al. \(1978\)](#). The details are described later in the DEA model section. [Tomikawa and Goto \(2022\)](#) analyzed four types of efficiency by DEA for six JR companies in Japan. [Oum et al. \(1999\)](#) surveyed methods to measure the production efficiency of railroad operations. [Merkert et al. \(2010\)](#) evaluated European railroad operations, and [Cantos et al. \(2012\)](#) presented a comparative analysis of twenty-three European countries using DEA as an ex post evaluation of railroad company reforms. [Sameni et al. \(2016\)](#) used DEA to evaluate the efficiency of platform operations at ninety-six UK railroad stations for boarding and alighting passengers, ranked the stations, and verified the effectiveness of the service. [Djordjević et al. \(2021\)](#) evaluated the sustainability of railroads in the EU using a two-stage approach with DEA and Pearson's correlation. Interestingly, they evaluated diversification management from the perspective of production efficiency. [Geng \(2013\)](#) conducted an efficiency evaluation of railroad companies' diversification using DEA and found that the efficiency varies by industry, with those closer to transportation being more efficient. [Mahmoudi et al. \(2020\)](#) reviewed and categorized more than 600 papers that evaluated the transportation problem over 30 years from 1989 to 2018. They showed that DEA is useful for evaluating transportation systems. Recently, [Niu et al. \(2023\)](#) conducted an empirical study on the efficiency of railroad transportation and its influencing factors using a 3-stage DEA model for 16 countries around the world. [Zong et al. \(2023\)](#) ranked the efficiency of high-speed rail in each country from 2009 to 2018 using the multi-stage network DEA and Tobit model. They indicated China's high-speed railway performed moderately well, but its organizational structure needs to be examined to increase transport volume.

[Michali et al. \(2023\)](#) considered railway noise pollution problems as undesirable factors in evaluating the efficiency scores of railways in 22 European countries. The applicability of a bootstrap procedure, which approximates and evaluates DEA estimators, was tested.

Next, we present the primary studies conducted on Japanese railroads. [Sakamoto \(1997\)](#) classified third-sector railways using cluster analysis and measured their production efficiency using DEA. The third-sector railway is a business entity jointly established by the first sector (national and local governments) and the second sector (private companies) for the purpose of regional development and the promotion of new urban development. This study showed that the regional railroad continued to face difficult business situations due to the progress of motorization, declining birthrate, and aging population. Further, [Kuramoto and Hirota \(2008\)](#) and [Jitsuzumi and Nakamura \(2010\)](#) conducted DEA-based analyses of railroad efficiency. [Guo et al. \(2018\)](#) evaluated the efficiency of TOD (Transit-Oriented Development) on the Tokyu Line, one of Japan's major PRCs, using DEA and found that other influencing factors should also be considered. Using DEA and Tobit regression, [Le et al. \(2022\)](#) evaluated the efficiency of operations in 18 lines of 7 major urban railway operators in the Tokyo metropolitan area. The congestion rate on the train was used to measure the quality of the railway operation service.

2.3. Time-Series Evaluation of Production Efficiency

This study applies the Malmquist index to measure temporal changes in the production efficiency of PRCs. There are many studies in which DEA and the Malmquist index are applied to analyze efficiency, and the scope of analysis is wide. [Cantos et al. \(1999\)](#) used DEA and the Malmquist index to analyze productivity trends in European railroads during 1970–1995 and found that productivity growth was concentrated in the last period from 1985 to 1995, when most companies were engaged in reforms. [Abate et al. \(2013\)](#) investigated the relationship between the reliability (punctuality) and productivity of passenger rail services in seven rail systems in the EU using DEA and the Malmquist index. [Kabasakal et al. \(2013\)](#) used DEA to evaluate the efficiency of 31 railroad companies worldwide. They estimated the impact of corporate productivity on efficiency with panel regression analysis and confirmed, using the Malmquist index, that total factor productivity increased throughout the measurement period from 2000 to 2009. [Bhatia and Sharma \(2021\)](#) evaluated cost performance in 16 Indian railroad zones during 2017–2018 using DEA and the Malmquist index and proposed cost reduction strategies for each zone. [Liu et al. \(2022\)](#) analyzed the effect of China's high-speed rail on tourism development in mountainous areas during 2010–2019 using DEA, the Malmquist index, and the Tobit model. Using the Malmquist index, [Nakayama \(2013\)](#) evaluated the production efficiency of 15 Japanese major PRCs, excluding Tokyo Metro, between 1991 and 2001. The results showed that productivity changed after fare regulation was tightened in 1997, and the rate of frontier shift increased.

2.4. Position of This Study

Few studies have conducted efficiency analyses from the perspective of the diversified management of Japanese major PRCs. One reason is that, in transportation policy, people have paid more attention to Japan National Railways (JNR) and its privatization, while paying relatively less attention to private railways. However, the situation has changed in the more than 35 years since the privatization and divestiture of the JNR. This study is the first to evaluate the diversified management characteristics of Japan's major PRCs from the perspective of efficiency analysis using data over the long period from 1987 to 2019. Concretely, this study analyzes the production efficiency of 16 major Japanese PRCs using DEA and the Malmquist index. Focusing on the diversified management of each

company, we categorize the 16 companies into 3 groups based on segment information such as transportation, real estate, and distribution businesses.

3. Methodology

3.1. Framework

Figure 1 illustrates the framework used in this study. First, a conventional DEA model is used to calculate the production efficiency of railroad operations. It measures the impact of decision-making units (DMUs), railroad companies in this study, and determines their degree of efficiency. The degree of diversification is then calculated, and we classify companies using each company’s segmental financial data. Finally, a non-parametric rank sum test verifies the relationship between the efficiency values obtained by the DEA and the degree of diversification. Combining the DEA model and non-parametric statistical tests is useful for empirical research on the performance evaluation of major PRCs.

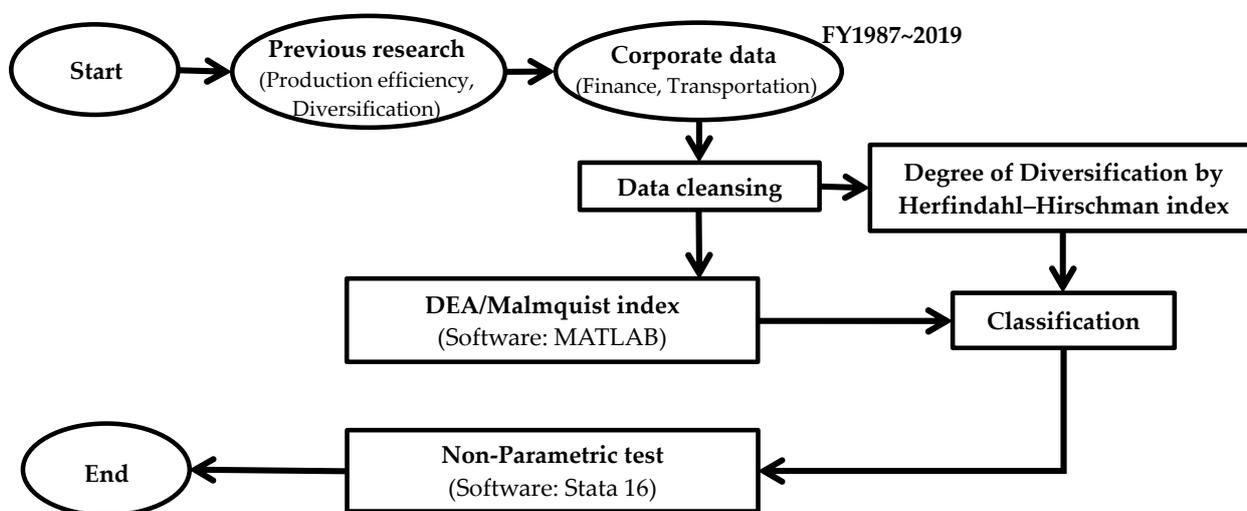


Figure 1. Methodology framework.

DEA is a non-parametric method dealing with multiple inputs and outputs to evaluate the relative efficiency of DMUs in production systems without identifying specific functional forms (Cooper et al., 2007). Various indexes/indicators are used for productivity evaluation (Sueyoshi & Goto, 2018, Table 19.A1). For example, the Luenberger indicator (Luenberger, 1992; Chambers & Pope, 1996; Chambers, 2002) uses a directional distance function to adjust inputs and outputs. The Luenberger indicator has an additive structure and expresses differences rather than ratios of distance functions. On the other hand, the Malmquist index employed in this study has a high affinity with DEA because it explicitly defines a distance function that is either input or output oriented and measures the efficiency in a ratio structure (Malmquist, 1953; Färe et al., 1994). The Malmquist index can calculate changes in efficiency over time by combining with DEA. The data used in this study are from 1987, when JNR was divided and privatized, to 2019. By applying the Malmquist index to the data, we examine whether there are distinctive differences in production efficiency in relation to degrees of business diversification in major PRCs and discuss whether the diversification strategy positively impacts the management of railroad businesses.

3.2. DEA Model

DEA is an analytical method to compare the relative efficiency of DMUs. Since Charnes et al. (1978) initiated DEA research by presenting a basic model that assumes

constant returns to scale (CRS) technology, many researchers have developed and applied various DEA models to the efficiency evaluation of DMUs. A DMU represents an entity to be evaluated, and this study deals with railroad companies as DMUs. Glover and Sueyoshi (2009) discussed the history of DEA from its conceptualization, and Ijiri and Sueyoshi (2010) described the philosophical background of DEA rooted in accounting and economics. Sueyoshi et al. (2017) reviewed approximately 700 DEA papers that applied DEA to energy and environmental issues.

The basic DEA model used in this study is described in Model (1). This model assumes CRS technology. We can change the setting to variable returns to scale (VRS) technology by adding a side constraint, $\sum_{j=1}^n \lambda_j = 1$, ($j = 1, 2, \dots, n$).

$$\begin{aligned} & \text{minimize } \theta \\ & \text{subject to } -\sum_{j=1}^n x_{ij}\lambda_j + \theta x_{ik} \geq 0, \quad (i = 1, 2, \dots, m), \\ & \quad \sum_{j=1}^n y_{rj}\lambda_j \geq y_{rk}, \quad (r = 1, 2, \dots, s), \\ & \quad \lambda_j \geq 0, \quad (j = 1, 2, \dots, n), \\ & \quad \theta : \text{unrestricted}, \end{aligned} \quad (1)$$

where x_i is the input factor for $i = 1, 2, \dots, m$; y_r is the output factor for $r = 1, 2, \dots, s$; j is the DMU for $j = 1, 2, \dots, n$; and k is the DMU to be evaluated. The θ represents the efficiency value of the k th DMU, $\theta = 1$ means the k th DMU is fully efficient, and $0 \leq \theta < 1$ means the k th DMU is inefficient. In this study, we employ the input-oriented CRS and VRS models considering the input minimization behavior of railroad companies under a certain level of output.

3.3. Malmquist Index

The Malmquist index is based on a concept proposed by Malmquist (1953) and applied to a productivity index by Caves et al. (1982) using distance functions. Färe et al. (1994) presented a method to measure the Malmquist index through DEA. The Malmquist index for two periods between t th and $t + 1$ th periods is described in Equation (4), which consists of distance functions of Equations (2) and (3). Goto et al. (2018) and Tone and Tsutsui (2017), among others, provide detailed descriptions of the construction of the Malmquist index.

First, the following input-oriented distance functions, D_i^t of Equation (2) for the t th period and D_i^{t+1} of Equation (3) for the $t + 1$ th period, can be defined in this study.

$$D_i^t(x^{t+1}, y^{t+1}) = \sup\{\phi > 0 : x^{t+1}/\phi, y^{t+1} \in S^t\} \quad (2)$$

$$D_i^{t+1}(x^t, y^t) = \sup\{\phi > 0 : x^t/\phi, y^t \in S^{t+1}\} \quad (3)$$

where $S^t = \{(x^t, y^t) : x^t \text{ can produce } y^t\}$ represents production technology in the t th period, in which y^t denotes the output vector of a DMU produced from the input vector x^t . The same descriptions are applicable to the $t + 1$ th period.

The input-oriented Malmquist index MI_i^t , with respect to the t th period, is expressed by Equation (4).

$$MI_i^t = \frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} = \frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \cdot \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \quad (4)$$

Similarly, the input-oriented Malmquist index MI_i^{t+1} , with respect to the $t + 1$ th period, is expressed by Equation (5).

$$MI_i^{t+1} = \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} = \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \cdot \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \quad (5)$$

To avoid arbitrary benchmark selection, the Malmquist productivity index (MPI) is defined as the geometric mean of Equations (4) and (5), as presented in Equation (6).

$$MPI = \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \cdot \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \quad (6)$$

A decomposition of MPI in Equation (6) yields Equation (7).

$$\begin{aligned} MPI &= \frac{D^{t+1}(x^{t+1}, y^{t+1})}{D^t(x^t, y^t)} \cdot \left[\frac{D^t(x^{t+1}, y^{t+1})}{D^{t+1}(x^{t+1}, y^{t+1})} \cdot \frac{D^t(x^t, y^t)}{D^{t+1}(x^t, y^t)} \right]^{\frac{1}{2}} \\ &= \text{Efficiency change} \cdot \text{Technical change}. \end{aligned} \quad (7)$$

In the right-hand side of Equation (7), the component outside the square brackets measures the technical efficiency change or catch-up effect between periods t and $t + 1$, while the component inside the square brackets measures the production frontier shift or technical change effect over time. In general, both components with more than unity indicate regress, while those with equal to or less than unity indicate the status quo or progress. Therefore, the Malmquist productivity index can be expressed in Equation (7).

For the input-oriented CRS model, the linear programming problem expressed in Equation (1) is solved, and the optimized θ or θ^* is obtained with the other optimized variables. From the definition of the distance function and the construction of the DEA model, the relationship between the distance function and the DEA efficiency measure is described as $D = 1/\theta$. We can change the combination of data period t and $t + 1$ pertaining to the production frontier and the DMU when we solve Model (1) of the DEA that calculates all distance functions to measure MPI. In addition, there are some details to note here when applying the Malmquist index to empirical studies. Grifell-Tatjé and Lovell (1995), Coelli (1996), and Casu et al. (2004) noted that the Malmquist index under the CRS distance function can correctly measure changes in productivity, while that under VRS technology cannot. Thus, this study employs the CRS model for the measurement of the distance function when we calculate the Malmquist index.

4. Data

This study defines the inputs and outputs used in DEA with reference to Sakamoto (1997), who analyzed the efficiency of Japanese third-sector railroads. Concretely, we classify the business activities of railroad companies into four phases and combine them to stipulate inputs and outputs in DEA to examine four efficiency measures: cost efficiency, operational efficiency, revenue-earning efficiency, and profit-earning efficiency. The data in this study are summarized in Table 1. Table 2 summarizes the input and output combinations of four efficiency measures, and Figure 2 describes the four phases from (a) to (d) and the variables to calculate the four efficiency measures.

The dataset covers 33 years, from 1987, when JNR was privatized and divested, to 2019. The impact of the COVID-19 pandemic is not included in this study. We discuss it as a future extension of this study in Section 6. The data source is the Statistical Yearbook of Railway Statistics; 1987–2019. This yearbook provides reliable financial and operating data

on railroads, tracks, and cableway operators. Table 3 presents the descriptive statistics for the 16 major PRCs.

Table 1. Four activity phases of the railroad business.

Activity Phase	Item	Remark
(a) Cost	Personnel expenses	Personnel expenses for railroad business
	Non-personnel expenses	Total expenses except for personnel expenses, which include operating costs, capital expenditures comprising maintenance and depreciation costs, and general and administrative expenses
(b) Operational resource	Number of employees	Number of employees for railroad business, including management and operation sectors
	Number of railroad vehicles	Number of railroad vehicles, including locomotives, passenger cars, freight cars, and special cars
(c) Operational output	Vehicle kilometers	Calculated by multiplying the number of rail coaches by the distance traveled in kilometers under operation
	Number of passengers carried	Total number of passengers carried
(d) Total revenue	Total operating revenue	Total operating revenue from railroad business

Table 2. Four efficiency measures and input and output combinations.

Performance Measure	Input (Phase)	Output (Phase)
Cost efficiency	(a) Cost	(b) Operational resource
Operational efficiency	(b) Operational resource	(c) Operational output
Revenue-earning efficiency	(c) Operational output	(d) Total revenue
Profit-earning efficiency	(a) Cost	(d) Total revenue

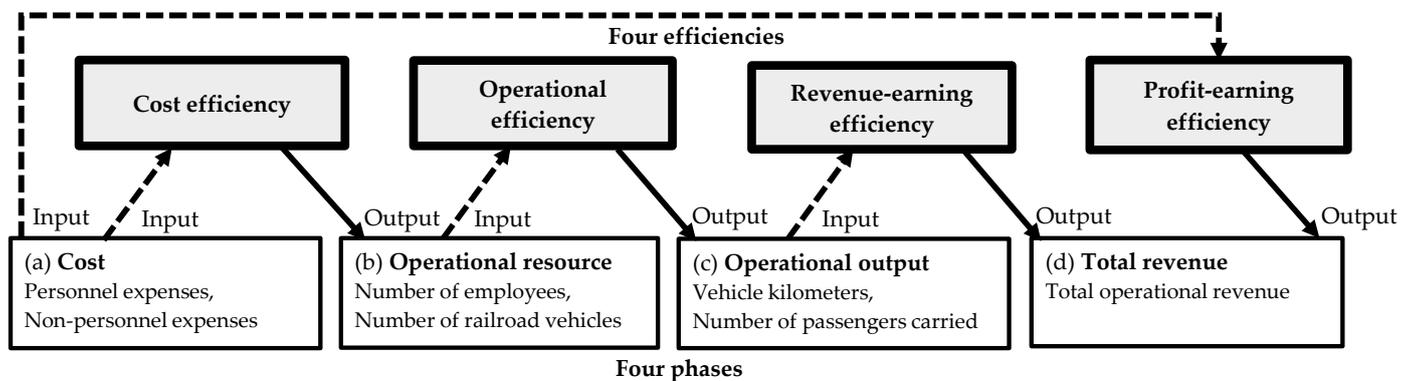


Figure 2. Input and output relationship on each of four efficiency measures. Source: Developed by the authors based on Sakamoto (1997) and Tomikawa and Goto (2022).

The data used to measure the degree of diversification were taken from consolidated financial statements (segment information by business type) in each company's annual securities report published on EDINET (<https://disclosure2.edinet-fsa.go.jp/WEEK0020.aspx> (accessed on 17 July 2024)) and eol (<https://ssl.eoldb.jp/Eoldb/UserLogin.php> (accessed on 14 October 2022)). Annual securities reports provide basic information about a company's profile, including an overview, business, facilities, shares, and accounting status. They must be disclosed as long as the company is listed on a stock exchange. Although consolidated financial statements have limitations in data acquisition and do not include all related group companies, we apply this as highly reliable public information. In Japan, as in other countries, the Accounting Standards Act requires the disclosure of information based on "the management approach." Under this approach, constituent units are determined based on the manner in which the management divides the enterprise

into business component units to make management decisions and evaluate performance (Touhara, 2010).

Table 3. Descriptive statistics of 16 major PRCs.

Name of Company	Abbreviation in This Paper	Service Area	(a) Cost		(b) Operational Resource	(c) Operational Output		(d) Total Revenue	
			Personnel Expenses (Million JPY)	Non-Personnel Expenses (Million JPY)	Number of Employees	Number of Railroad Vehicles	Vehicle Kilometers (1000 km)	Number of Passengers Carried (1000 Persons)	Total Operational Revenue (Million JPY)
Tobu Railway Co., Ltd.	Tobu	Kanto (Tokyo, Saitama, Gunma, Tochigi, Chiba)	46,415	78,521	5786	1908	251,749	892,864	150,563
Seibu Railway Co., Ltd.	Seibu	Kanto (Tokyo, Saitama)	31,069	45,272	3575	1240	157,021	634,420	94,322
Keisei Electric Railway Co., Ltd.	Keisei	Kanto (Tokyo, Chiba)	18,052	27,163	2057	536	83,695	264,596	54,008
Keio Corporation	Keio	Kanto (Tokyo)	22,947	40,365	2343	832	107,492	606,418	76,076
Odakyu Electric Railway Co., Ltd.	Odakyu	Kanto (Tokyo, Kanagawa)	34,127	52,507	3463	1045	148,489	703,299	107,282
Tokyu Railways Co., Ltd.	Tokyu	Kanto (Tokyo, Kanagawa)	34,267	70,989	3293	1125	122,259	1,017,636	129,364
Keikyu Corporation	Keikyu	Kanto (Tokyo, Kanagawa)	18,901	39,959	2109	765	100,561	435,616	71,652
Sagami Railway Co., Ltd.	Sotetsu	Kanto (Kanagawa)	10,523	14,121	1144	426	45,611	234,200	31,120
Tokyo Metro Co., Ltd.	Tokyo Metro	Kanto (Tokyo, Chiba, Saitama)	93,006	151,118	9527	2511	252,447	2,242,971	307,132
Nagoya Railroad Co., Ltd.	Nagoya	Nagoya (Aichi, Gifu, Mie)	31,659	41,538	4436	1108	186,368	365,311	84,785
Kintetsu Railway Co., Ltd.	Kintetsu	Kansai (Osaka, Kyoto, Nara), Nagoya (Aichi, Mie)	67,897	76,172	9103	1986	306,654	666,534	171,037
Nankai Electric Railway Co., Ltd.	Nankai	Kansai (Osaka, Wakayama)	21,146	29,016	2829	694	92,267	259,854	60,019
Keihan Electric Railway Co., Ltd.	Keihan	Kansai (Osaka, Kyoto)	19,641	27,912	2207	730	90,392	328,657	55,936
Hankyu Corporation	Hankyu	Kansai (Osaka, Kyoto, Hyogo)	33,430	48,807	3141	1313	166,003	682,817	101,743
Hanshin Electric Railway Co., Ltd.	Hanshin	Kansai (Osaka, Kyoto, Hyogo)	9783	15,969	1231	333	41,466	213,433	29,893
Nishi-Nippon Railroad Co., Ltd.	Nishi-Nippon	Kyushu (Fukuoka)	6924	13,441	894	357	42,948	120,073	23,470

Note: Average from 1987 to 2019. JPY represents Japanese yen.

Our study uses an index to measure the degree of diversification. Diversification indices have been used as a numerical method to express the degree of industry diversification; Gort (1962), Berry (1971), Utton (1977), and Jacquemin and Berry (1979) are known examples. In this study, we applied the Hirschman–Herfindahl index by Berry (1971) as shown in Equation (8), which has a practical achievement used by the Fair Trade Commission of Japan (<https://www.jftc.go.jp/en/index.html> (accessed on 16 January 2025)) and the Antitrust Division of the U.S. Department of Justice (<https://www.justice.gov/atr/herfindahl-hirschman-index> (accessed on 16 January 2025)) for corporate business sector shares.

$$DI = 1 - \sqrt{\sum_{i=1}^n P_i^2} \quad (8)$$

The composition of the i th sector of a company with n businesses is denoted by P_i . The interior of the right side $\sqrt{\quad}$ of the index is called the Hirschman–Herfindahl index, which is also used in economics to measure market concentration. The higher the value of DI , the more diversified the business. Table 4 presents the DI for each company of PRCs.

Although some companies structure their related businesses into multiple segments, this study does not merge these related segments in line with the disclosure information.

Table 4. Diversification index of 16 major PRCs.

Year	Tobu	Seibu	Keisei	Keio	Odakyu	Tokyu	Keikyu	Sotetsu	Tokyo Metro	Nagoya	Kintetsu	Nankai	Keihan	Hankyu	Hanshin	Nishi-Nippon
1987~1989	0.1729	0.3813	0.1320	0.1916	0.3040	0.4420	0.3059	0.3708	na	0.2353	0.1605	0.2867	0.3748	0.3062	0.3580	0.2728
1990~1992	0.3127	0.4594	0.3081	0.4396	0.3655	0.5028	0.4990	0.4906	na	0.3856	0.3274	0.4030	0.4705	0.4391	0.4535	0.4805
1993~1995	0.3591	0.4675	0.4190	0.4585	0.3740	0.4993	0.5020	0.5041	na	0.3897	0.3965	0.4253	0.4723	0.4514	0.4922	0.4874
1996~1998	0.3853	0.4026	0.4164	0.4683	0.3901	0.4947	0.5064	0.5127	na	0.4211	0.3927	0.4210	0.4885	0.4619	0.5160	0.5028
1999~2001	0.4867	0.3378	0.4403	0.4755	0.5008	0.5194	0.5095	0.5226	na	0.4756	0.4103	0.4740	0.4902	0.4775	0.5298	0.5196
2002~2004	0.4850	0.3505	0.4488	0.4671	0.5056	0.5534	0.5126	0.5073	na	0.4724	0.4541	0.5122	0.4855	0.5073	0.5270	0.5322
2005~2007	0.4875	0.3859	0.4469	0.4762	0.4993	0.4816	0.5209	0.4709	0.1758	0.4606	0.4605	0.5029	0.4644	0.5773	0.5509	0.5314
2008~2010	0.4857	0.4173	0.4244	0.4790	0.4489	0.4952	0.5066	0.4723	0.1708	0.4949	0.4681	0.4961	0.4716	0.5717	0.5313	0.5460
2011~2013	0.4914	0.5000	0.4104	0.4857	0.4494	0.4767	0.4987	0.4644	0.1445	0.5676	0.4672	0.4980	0.4657	0.5483	0.4950	0.5771
2014~2016	0.4977	0.5083	0.4064	0.5017	0.4557	0.4033	0.5088	0.4804	0.1276	0.5668	0.4660	0.5063	0.4738	0.5356	na	0.5757
2017~2019	0.4954	0.5085	0.4020	0.5095	0.4643	0.3679	0.5119	0.4996	0.1251	0.5710	0.4686	0.5087	0.4695	0.5492	na	0.5765
Average	0.4236	0.4290	0.3868	0.4503	0.4325	0.4760	0.4893	0.4814	0.1494	0.4582	0.4065	0.4576	0.4661	0.4932	0.4949	0.5093
S.D.	0.1029	0.0656	0.0970	0.0853	0.0639	0.0545	0.0595	0.0415	0.0238	0.0990	0.0944	0.0687	0.0312	0.0771	0.0578	0.0832
Max.	0.4993	0.5134	0.4574	0.5111	0.5109	0.5709	0.5266	0.5347	0.1891	0.5750	0.4774	0.5146	0.4976	0.5856	0.5877	0.5790
Min.	0.1600	0.3297	0.1169	0.1828	0.2906	0.3635	0.2907	0.3601	0.1167	0.2257	0.1417	0.2340	0.3717	0.2750	0.3510	0.2583

Note: Each value is a three-year average. na: Due to the management integration of the Hankyu and the Hanshin Group in 2006, Hanshin became a member of the Hankyu Group. Hanshin disclosed the annual securities report until 2013 following the group's disclosure policy.

To facilitate the observation of annual changes in the *DI*, 16 major PRCs were classified into 3 groups based on quartiles and listed from the highest *DI* to the lowest. Table 5 presents the classification results.

Table 5. Classification of 16 major PRCs by the diversification index.

Group	Name of Company	Diversification Index in 2019
A (The first quartile)	Nagoya	0.5750
	Nishi-Nippon	0.5741
	Hankyu	0.5564
	Hanshin	0.5564
B (The second quartile)	Keikyu	0.5137
	Seibu	0.5133
	Nankai	0.5115
	Keio	0.5090
(The third quartile)	Sotetsu	0.5000
	Tobu	0.4902
	Keihan	0.4726
	Kintetsu	0.4719
C (The fourth quartile)	Odakyu	0.4709
	Keisei	0.4056
	Tokyu	0.3690
	Tokyo Metro	0.1276

Note: Group B is merged in the second and third quartiles groups to clarify the diversification index trends.

We set Groups A, B, and C in the order of relative diversification. It is interesting to note this group classification from a regional concentration perspective. Group A (Nagoya, Nishi-Nippon, Hankyu, and Hanshin) are all outside the Kanto region², Group B (Keikyu, Seibu, Nankai, Keio, Sotetsu, Tobu, Keihan, and Kintetsu) are region-independent, and Group C (Odakyu, Keisei, Tokyu, and Tokyo Metro) are all inside the Kanto region. Group A tends to have a relatively high degree of diversification. Hankyu has diversified its management to include real estate and distribution businesses since its establishment. Other railroad companies have emulated this business model. On the other hand, Group C tends to have a relatively low degree of diversification. Like Hankyu in Group A, Tokyu in Group C has been operating railroad construction and real estate businesses. It also operates the regional development business along its rail lines, and the distribution business has been generating outstanding revenues in recent years, although the diversification index in 2019 is still relatively low. Among them, Tokyo Metro is the only subway company, and it has an extensive transportation network in the heavily populated metropolitan area. It has the largest number of passengers carried of the 16 major PRCs (1987–2019) and is highly dependent on its transportation business. The results suggest the possibility that historical background and regional characteristics have influenced each railroad company’s diversification strategy.

5. Empirical Results and Discussion

Table 6 shows the computational results of efficiency by DEA and the Malmquist index for PRCs summarized in each group, from A to C.

Table 6. Descriptive statistics of efficiency by DEA (VRS) and the Malmquist index (CRS).

Performance Measure	Group	Efficiency by DEA (1987–2019)			Malmquist Index (1988–2019)		
		A	B	C	A	B	C
Cost efficiency	Average	0.8683	0.8373	0.7379	0.9102	0.8328	0.7458
	S.D.	0.0404	0.0368	0.0507	0.0548	0.0485	0.0559
	Max.	0.9412	0.9585	0.9062	1.0187	0.9609	0.9191
	Min.	0.8028	0.7833	0.6635	0.8320	0.7533	0.6643
Operational efficiency	Average	0.8839	0.8677	0.9342	1.1979	1.0133	0.9716
	S.D.	0.0391	0.0344	0.0285	0.1126	0.0739	0.0572
	Max.	0.9459	0.9144	0.9890	1.4259	1.1165	1.0607
	Min.	0.8186	0.8151	0.8969	1.0308	0.9024	0.8959
Revenue-earning efficiency	Average	0.8815	0.8460	0.8927	1.1902	1.2635	1.2746
	S.D.	0.0485	0.0415	0.0485	0.0826	0.0848	0.0836
	Max.	0.9252	0.8875	0.9361	1.2562	1.3337	1.3406
	Min.	0.7678	0.7426	0.7628	0.9801	1.0589	1.0583
Profit-earning efficiency	Average	0.8877	0.8949	0.9040	1.1174	1.0794	1.0727
	S.D.	0.0397	0.0202	0.0195	0.0825	0.0776	0.0594
	Max.	0.9552	0.9250	0.9398	1.2711	1.1984	1.1556
	Min.	0.8208	0.8507	0.8619	0.9954	0.9468	0.9709

Note: Grouping from A to C is based on the diversification index (DI) in 2019.

5.1. DEA

The results for the four efficiencies obtained by DEA are shown in Figures 3–6.

Cost efficiency decreased from 1987 to 2000 for all three groups. Group A decreased from 0.9412 (1987) to 0.8028 (1997), Group B decreased from 0.9585 (1987) to 0.7833 (1997), and Group C decreased from 0.9062 (1987) to 0.6635 (2003). The more diversified a company is, the higher its cost efficiency. After 2003, all three groups showed moderate improvement toward 2019, but resulted in low degrees compared with 1987. Although each company has been working to reduce personnel expenses and the number of employees, non-personnel expenses have increased. Of these, Odakyu and Tokyu in Group C showed the lowest change in efficiency, with increasing operating expenses and numbers of employees. In the other groups, Tobu, Keikyu, Nagoya, and Hankyu reduced the number of employees by outsourcing their operations and curbing overall expenses, including personnel expenses. In particular, Nishi-Nippon in Group A made remarkable reductions in personnel expenses related to railroad operations (ratio FY2019 to FY1987 = 47.2%) and in the number of employees (ratio FY2019 to FY1987 = 43.8%). The growth rate of the total operational revenue is also low, so Nishi-Nippon appears to be practicing contractionary balance management.

Operational efficiency showed an increasing trend in all groups. Group C kept a high-efficiency value of 0.9286 to 0.9793 between 1987 and 2019. Group C includes Keisei, Odakyu, Tokyu, and Tokyo Metro, which are all railroad companies in the Kanto region. This trend is mainly caused by an increase in the number of vehicle kilometers and the number of passengers carried. By contrast, five railroad companies (Nishi-Nippon, Hankyu, Kintetsu, Nankai, and Keihan) outside the Kanto region have reduced their number of passengers. One possible factor for this is the influence of demographic changes. According to the Roundtable Conference on the Concentration of Companies in Tokyo (Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Government of Japan, 2021), the Tokyo metropolitan area (Tokyo, Kanagawa, Saitama, and Chiba prefectures) has continued to have an excess inflow of population, except in 1991, after the collapse of the bubble economy. The excess inflows in the Osaka metropolitan area (Osaka, Hyogo, Kyoto, and Nara prefectures), located in the central western area of the mainland, and in the Nagoya area (Aichi, Gifu, and Mie prefectures), located in the middle of the Japanese archipelago, are generally in equilibrium. In rural areas, there continues to be an excess outflow of population. Therefore, although the difference is not as large as the cost efficiency, the more the company’s business area is in the Kanto region and the degree of diversification is relatively low, the more its operational efficiency tends to be superior to that of Groups A and B.

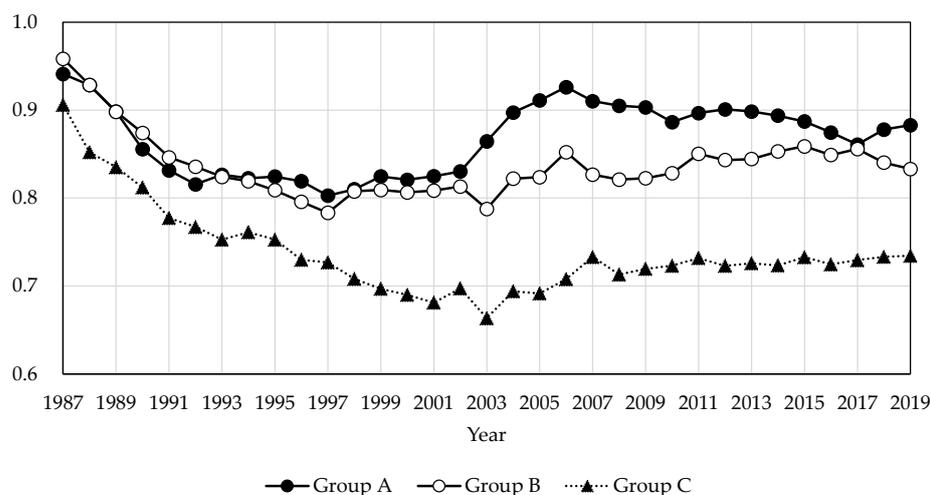


Figure 3. Cost efficiency.

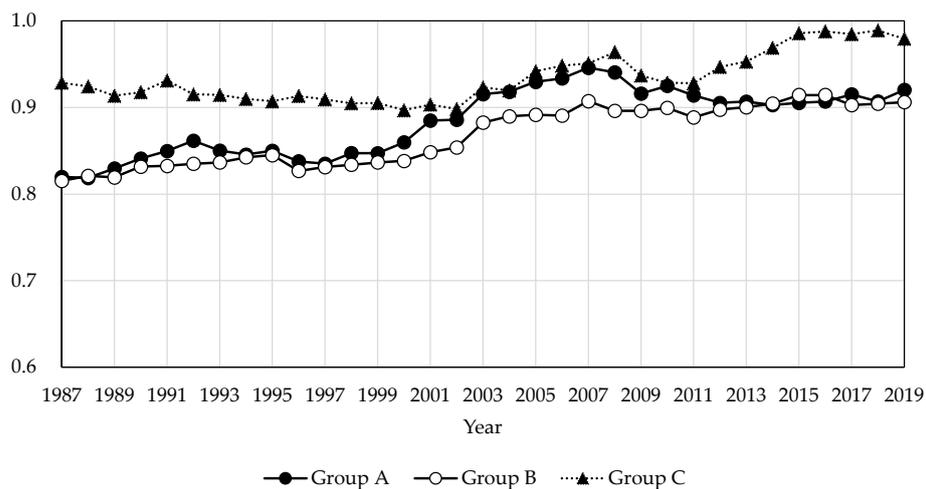


Figure 4. Operational efficiency.

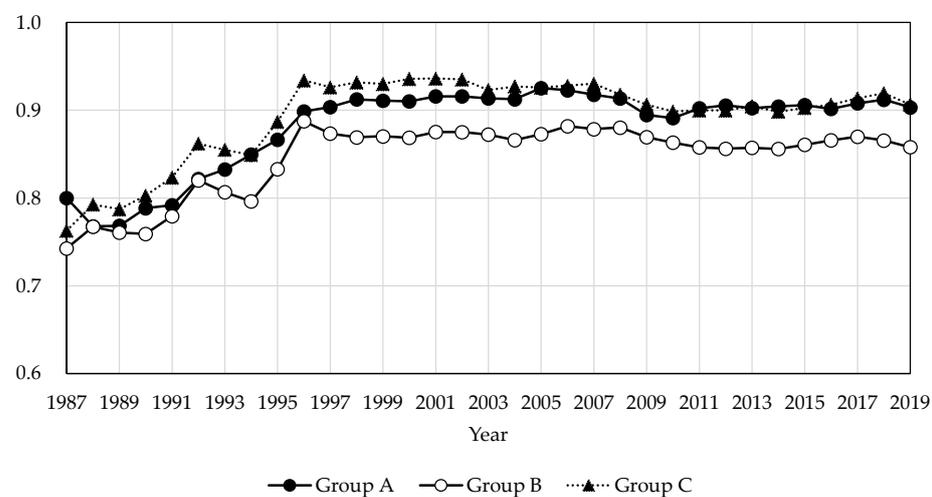


Figure 5. Revenue-earning efficiency.

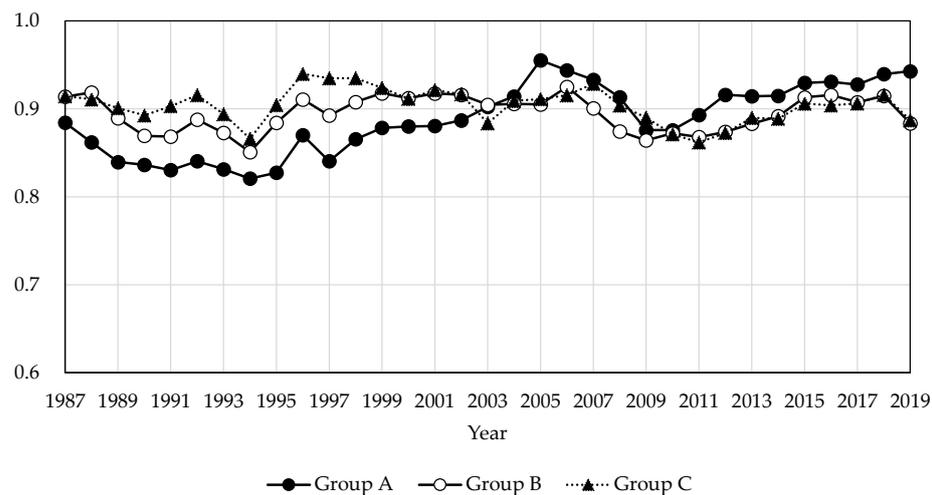


Figure 6. Profit-earning efficiency.

Revenue-earning efficiency increased from 1987 to 1996 and then slowed. Group B, consisting of eight companies, showed a slightly lower trend from 1987 to 2019, with an efficiency value of 0.7426 to 0.8580. Although the operating revenues were close to the average of the three groups, the increase or decrease in passenger traffic differed among the groups (increased: five companies; decreased: three companies). A possible reason is the lack of

optimization between the number of vehicle kilometers and the number of passengers carried, which are input values, and the operating revenue, which is the output value. Therefore, in terms of revenue-earning efficiency, no significant differences in the degree of diversification could be confirmed, owing to the different business conditions of the companies.

Profit-earning efficiency has shown a mixed trend of increasing and decreasing. Group A was the highest among the three groups in 2019, while it was the lowest in 1987. The efficiency values of Group A range from 0.8843 to 0.9428. Although Group A’s operating revenues tended to be smaller than those of Group C, the relatively high reduction in labor costs and other factors may have contributed to the superior results in Group A. Companies in Group A have a relatively high degree of diversification.

5.2. The Malmquist Productivity Index

The MPI is defined based on the distance function, as shown in Section 3.3, Equations (4) and (5). the Malmquist index measures the degree of changes in productivity over time. Here, for descriptive convenience, we define the “inverse MPI (iMPI) = 1/MPI” and present the iMPI results in Figures 7–10. By this definition, it is easy to understand that in these figures, when the measure of the iMPI is equal to or larger than 1, productivity is status quo or increasing, while when it is less than 1, productivity is decreasing. Figures 7–10 show the results of the change in the iMPI for the three groups classified by the degree of diversification, with 1987 as the base year with unity.

Among the MPIs related to the four efficiency indicators, only cost efficiency showed negative growth, and the other MPIs presented positive growth over the period, as shown in Figures 7–10. In particular, Group C (in Figure 7), which includes companies with a relatively low degree of diversification, was sluggish from 1988 to 2019, with efficiency values ranging from 0.9191 to 0.7426. Operational efficiency, shown in Figure 8, stagnated in Groups B and C until around 2000, but has since recovered. Group A showed a high transition from 1988 to 2019, with efficiency values ranging from 1.0308 to 1.2766. It reached its maximum value of 1.4239 in 2007. Similar trends were observed in MPIs for cost and profit-earning efficiencies. We confirmed that personnel expenses (one of the input values in cost efficiency and profit-earning efficiency) and the number of staff members (one of the input values in operational efficiency) have been decreasing since their peaks in 2007. These changes contribute to improvements in MPIs. The revenue-earning efficiency and profit-earning efficiency, shown in Figures 9 and 10, respectively, indicated positive growth, and each group has similar trends.

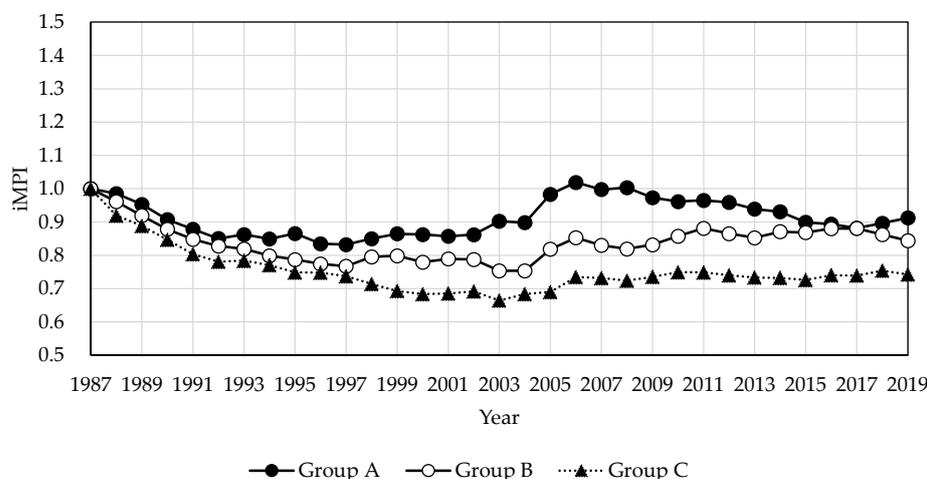


Figure 7. Malmquist productivity index: cost efficiency.

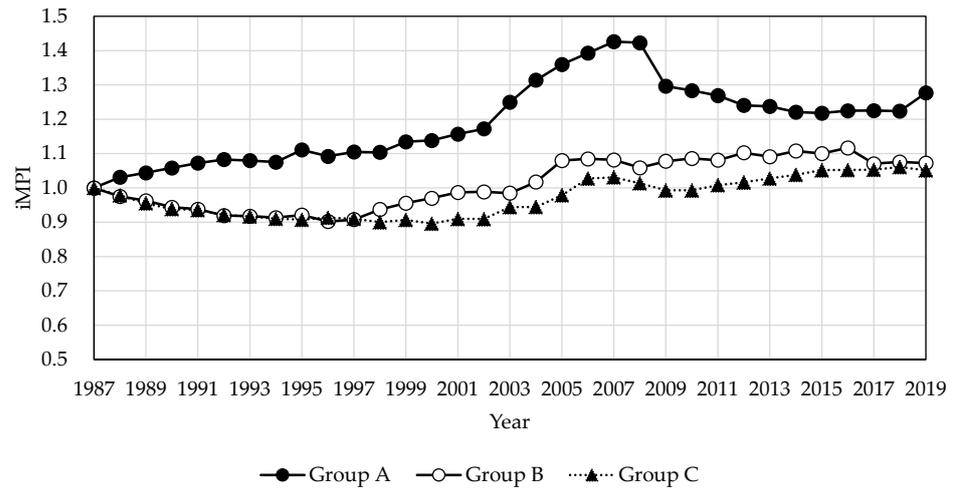


Figure 8. Malmquist productivity index: operational efficiency.

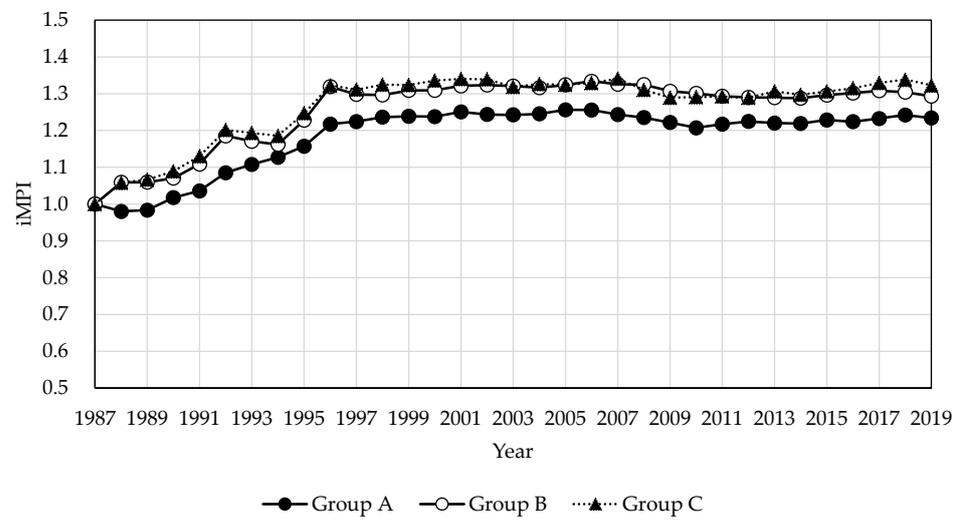


Figure 9. Malmquist productivity index: revenue-earning efficiency.

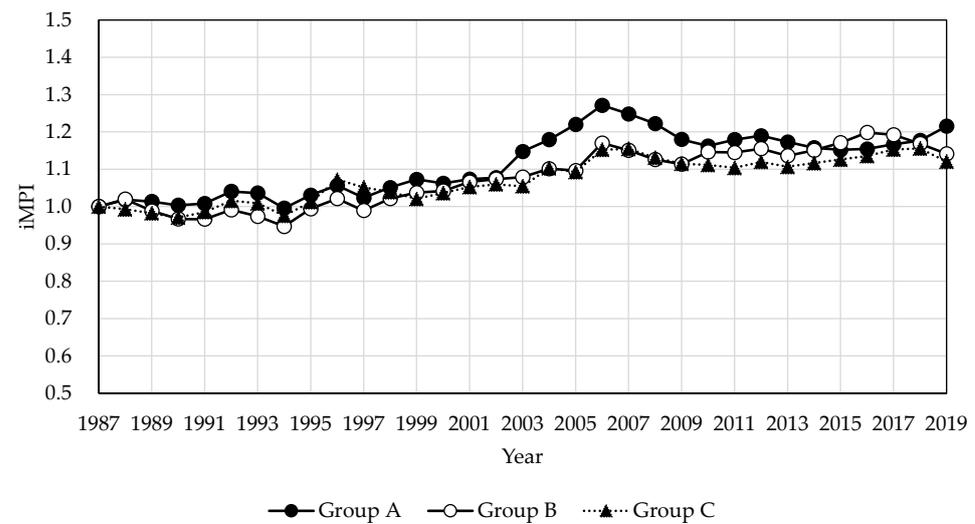


Figure 10. Malmquist productivity index: profit-earning efficiency.

5.3. Non-Parametric Tests

Non-parametric tests were performed to verify whether there were statistically significant differences in the efficiencies obtained by DEA measures among the three groups

of major PRCs classified by the degree of diversification. The Kruskal–Wallis rank sum test was used to examine (a) whether the differences in the four efficiency measures were statistically significant among the 16 major PRCs and (b) whether the differences in the four efficiency measures were statistically significant among the three groups (Groups A, B, and C) classified by the diversification index. Further, the Wilcoxon rank sum test was used to examine (c) whether the differences in the four efficiency measures were statistically significant among the two largest and smallest groups (Groups A and C) classified by the diversification index. The results are summarized in Table 7.

Table 7. Results of non-parametric test for efficiency by DEA.

Item	Degree of Freedom	Cost Efficiency	Operational Efficiency	Revenue-Earning Efficiency	Profit-Earning Efficiency
(a) Difference among sixteen companies (Kruskal–Wallis)	15	347,986 ***	288,575 ***	346.061 ***	136,902 ***
(b) Difference among three groups (A, B, C) (Kruskal–Wallis)	2	54.724 ***	44.549 ***	25.099 ***	3.313
(c) Difference among two groups (A, C) (Wilcoxon)	1	6.290 ***	−4.457 ***	−1.654 *	−1.603

Note: *** $p < 0.01$, * $p < 0.1$. The numbers in the table indicate test statistics; H-scores are for the Kruskal–Wallis rank sum test in (a) and (b), and z-values are for the Wilcoxon rank sum test in (c).

Table 7 (a) shows the statistically significant differences among the 16 major PRCs for the 4 efficiency measures at the 1% level. Table 7 (b) and (c) show the statistically significant differences at the significance level of 10% or 1% in the three efficiency measures, except for profit-earning efficiency. The cost, operational, and revenue-earning efficiencies maintained differences among three groups (A, B, C) and two groups (A, C) over the period from 1987 to 2019, although each company took measures to improve its business performance. No statistically significant differences were found in profit-earning efficiency. This may be attributed to the small differences in mean values among the groups.

The MPI was also examined to confirm whether there were any differences among the companies and groups of major PRCs classified by degree of diversification. The results are summarized in Table 8.

Table 8. Results of non-parametric test for efficiency by the Malmquist index.

Item	Degree of Freedom	Cost Efficiency	Operational Efficiency	Revenue-Earning Efficiency	Profit-Earning Efficiency
(a) Difference among sixteen companies (Kruskal–Wallis)	15	263.157 ***	179.543 ***	218.62 ***	232.231 ***
(b) Difference among three groups (A, B, C) (Kruskal–Wallis)	2	59.868 ***	54.918 ***	26.127 ***	6.796
(c) Difference among two groups (A, C) (Wilcoxon)	1	6.405 ***	6.707 ***	−4.418 ***	2.390

Note: *** $p < 0.01$. The numbers in the table indicate test statistics; H-scores are for the Kruskal–Wallis rank sum test, and z-values are for the Wilcoxon rank sum test.

Table 8 (a) shows the statistically significant differences among the 16 major PRCs for the 4 efficiency measures at the 1% significance level. Table 8 (b) and (c) show statistically significant differences at the significance level of 1% in all efficiency measures except for profit-earning efficiency. For cost efficiency, operational efficiency, and revenue-earning efficiency, the differences in the MPI were maintained over the period from 1987 to 2019. No statistically significant differences were found in profit-earning efficiency. This can be attributed to the small differences in the means between the groups as well as to the results in Table 7.

6. Conclusions

We examined the influence of business diversification on 16 major Japanese PRCs using 4 efficiency measures and related MPIs. We classified each company's business activities from 1987 to 2019 according to the degree of diversification in 2019 and examined the relationship between the degree of diversification and the four efficiencies. Companies outside the Kanto region tended to have a relatively high degree of diversification, and companies with a relatively high degree of diversification, especially Nishi-Nippon, developed management strategies based on a contraction equilibrium. Despite efforts to reduce personnel expenses and the number of employees, non-personnel expenses increased over the study period. Operating expenses, which are the sum of personnel and non-personnel expenses, tended to increase for less-diversified companies. The operational efficiency slightly increased, while revenue- and profit-earning efficiencies changed little in recent years and appear to have stagnated. These results indicate that improving cost efficiency is an important issue for all companies, because only this efficiency measure clearly decreased over the period, particularly from 1987 to 2003. The input elements for the cost efficiency calculation are personnel and non-personnel expenses. Some companies have already implemented personnel expense reductions by reducing the number of employees and replacing them with outsourcing work. However, it is possible to improve efficiency by using information technology and digital transformation for facility maintenance, the introduction of environmentally friendly high-performance vehicles, and realization of automatic driving. These efforts would also reduce overhead costs.

We have three future issues. First, as railroads are public service businesses, fares, which are the source of operating revenue, are set based on the total cost method. This is essentially the regulated rates, which are calculated by adding profits to personnel and non-personnel expenses. The setting or change in maximum amounts for passenger fares is subject to government approval, and railroad operators can set the maximum amount by submitting a notification in advance (Subcommittee on the railway fare and charge system; [Ministry of Land, Infrastructure, Transport and Tourism \(MLIT\), Government of Japan, 2022](#)). Under the current cost system, yardstick regulations are applied to personnel and non-personnel expenses to provide incentives for efficiency. Conversely, penalties are imposed when management efforts are deemed necessary. There is room to review the fare system and examine the influence on the four efficiency measures, including the investment incentives by railroad companies, with the goal of balancing user benefits and company revenues.

In addition, the government's financial support system and financial impacts on railroad companies are interesting topics to follow. PRCs receive subsidies for earthquake resistance, safety measures, etc. from the national and local governments and loans from banks. Related to such financial support, for example, the taxation system and rail fares and charges are important national transportation policies that directly affect the profits and losses of railroad companies. In this study, all samples are Japanese companies that operate only in Japan, so they face the same tax policies and impacts on costs and profits; therefore,

the analysis may be easier than those that include foreign companies. As an example of a foreign case study, we address French railroad companies that have introduced a transportation tax (Versement Mobilité: VM). The transportation tax is levied dedicated to urban transportation such as railroad, metro, LRT (Light Rail Transit), and bus. The issue is to reduce inefficiencies in the transportation network (Bouf & Faivre d'Arcier, 2015). In Japan, discussions have begun regarding the introduction of a transportation tax to be paid by local residents to secure financial resources to maintain local public transportation systems³. The transportation policy should be formulated on public consensus in terms of both profitability and efficiency.

Second, to identify human capital issues in railroad companies, it is interesting to examine efficiencies from the perspective of companies' organizational management. For example, Hongo (2023) analyzed the ranking data of the Best Workplaces to Work in Japan by the Great Place to Work Institute Japan⁴. A positive relationship has been identified between job satisfaction and firm stock price returns. The results show that initiatives to increase job satisfaction, even if they put pressure on short-term profits, have the potential to increase stock prices through expectations of improved financial performance. Such human capital development and financial performance aspect is also an important future issue of this study to analyze the productivity and efficiency of Japan's PRCs. These are topics left for future research.

Third, this study does not include the period of the COVID-19 pandemic. The principal data source cited in this study is the Statistical Yearbook of Railway Statistics (1987–2019), which is well-summarized, consistent data among railroad companies, but currently available only through FY2021; therefore, the accumulation of data is insufficient to measure the impact of the COVID-19 pandemic. We acknowledge that the social environment surrounding the railroad business is changing, including changes in commuting conditions due to telework, difficulties in securing human resources in the railroad industry, and an increase in foreign tourists. In light of this social background, evaluating railroad management using extended data from the efficiency perspective will provide important insights for the future.

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Data Availability Statement: The data presented in this study are available on request from the corresponding authors.

Conflicts of Interest: The authors declare no conflicts of interest.

Notes

- ¹ JR companies were established in 1987 as a result of the privatization and division of Japan National Railways (JNR). JR companies consist of six passenger railway companies, one freight railway company, and two non-service companies. The six companies are JR Hokkaido (Hokkaido Railway Company), JR East (East Japan Railway Company), JR Tokai (Central Japan Railway Company), JR West (West Japan Railway Company), JR Shikoku (Shikoku Railway Company), and JR Kyushu (Kyushu Railway Company).
- ² The Kanto Region is in the eastern part of main island in Japan. It comprises the Tokyo Metropolis and the six prefectures of Ibaraki, Tochigi, Gunma, Saitama, Chiba, and Kanagawa. About 40 million people, or a third of Japan's population, reside in this region (Ministry of Internal Affairs and Communications (MIC), Government of Japan, 2023).

- ³ Shiga Prefecture, located east of Kyoto, formulated the “Shiga Regional Transportation Vision,” which aims to secure sustainable regional transportation for the 2040s. It is the first time in Japan that a “transportation tax” is specified as a source of finance. <https://www.pref.shiga.lg.jp/ippan/kendoseibi/koutsu/337120.html> (in Japanese). (accessed on 16 January 2025).
- ⁴ Great Place To Work is a professional organization that conducts research and analysis on job satisfaction. It conducts activities in approximately 170 countries around the world to announce companies and organizations recognized as having reached a certain standard in the leading media in each country. See the official website of Great Place To Work. Available online: <https://www.greatplacetowork.com/about> (accessed on 17 July 2024).

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