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Is Railway Transportation Sector a Natural Monopoly: Empirical Evidence from Turkish State Railways (TCDD)

Demiryolu Sektörü Doğal Tekel Mi: Türkiye Cumhuriyeti Devlet Demiryolları (TCDD) Üzerine Ampirik Çalışma

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Öz

Bu makale, Türk demiryolu endüstrisinin doğal tekel özelliklerini taşıyıp taşımadığını incelemektedir. Bu amaçla, iki farklı senaryo çerçevesinde eklenemezlik (subadditivity) analizi kullanılarak 1990- 2016 yıllarında Türkiye Cumhuriyeti Devlet Demiryolları'nın (TCDD) tekel koşullarında gösterdiği verimlilik düzeyi analiz edilmiştir. Bulgularımız, maliyet fonksiyonunun izin verilen aralık içinde eklenemez (subadditivite) olduğunu ortaya koyarak, rekabet öncesi dönemde TCDD'nin doğal tekel özelliklerini sergilediğini göstermektedir. Başka bir ifade ile, Türk demiryolu sektöründe iki firmanın faaliyet gösterdiği durumda üretim maliyetlerinde bir azalmanın olası olmadığı ortaya çıkmaktadır. Tek bir şirket olarak faaliyet gösteren doğal tekelin, uygulayacağı fiyatların sosyal olarak istenilen seviyelerin üzerine çıkmasına yol açabileceği göz önüne alındığında, politika yapıcıların eş zamanlı olarak hem tüketicileri koruyan hem de demiryolu sektörü içindeki doğal tekelin bütünlüğünü koruyan düzenlemeleri yürürlüğe koyması önerilmektedir. Burada; potansiyel tekelci suiistimalleri önlerken karşılanabilirlik, erişilebilirlik ve verimlilik arasında dikkatli bir denge kurabilmek ön plana çıkmaktadır.

Anahtar Kelimeler: Doğal Tekel, Eklenemezlik, Tutarlılık Bölgesi, Demiryolları Sistemi, Rekabet

Abstract

This paper analyses whether the Turkish railway industry possesses features indicative of a natural monopoly. For this purpose, we utilize subadditivity analysis to assess and compare the efficiency levels of TCDD under monopoly conditions with hypothetical duopoly scenarios, considering the time span from 1990 to 2016. Our findings reveal that the cost function displays subadditivity for all configurations within the permissible range, confirming TCDD's classification as a natural monopoly before the separation in 2016. This suggests that a decrease in production costs is improbable when two firms engage in activities within the Turkish railway sector. Given that a natural monopoly with a single company may result in prices surpassing socially desirable levels, it becomes imperative for policymakers to enact regulations that simultaneously safeguard consumers and maintain the integrity of the natural monopoly within the railway sector. Striking a careful balance between ensuring affordability, accessibility, and efficiency is essential while preventing potential monopolistic abuses.

Keywords: Natural Monopoly, Subadditivity, Consistency Region, Railways System, Competition

Introduction

Playing a crucial role in shaping economic activities, transportation is a fundamental element of society, encompassing the conveyance of goods or individuals from one location to another. According to Cooley (1894, p. 13), the most suitable method of transportation is one that facilitates the movement of products at the lowest cost and in the shortest time. He also asserts that these two factors remain fundamental benchmarks of efficiency, even in the most sophisticated advancements in transportation.

The railway system, originally founded by private and unregulated companies in the mid-19th century, underwent government intervention in the late 19th and early 20th centuries. With the advent of industrialization, railroad systems assumed a pivotal role in facilitating efficient transportation, particularly for heavy and voluminous commodities such as coal, iron, and steel on a near-global scale. Nevertheless, as Cebeci, Tüydeş-Yaman, and Islam (2022, p. 1) mentions by the 1950's railways encountered a downturn in freight transportation attributed to external factors such as economic crises, failure to align activities with competitive market demands, and an escalating financial deficit. Internal factors, including a decline in service quality and resistance to innovations, also contributed to this decline. Following de Rus (2006), public intervention primarily targeted the regulation of railway tariffs and safety and by the mid-20th century, most states had taken steps to nationalize their railway networks, acknowledging them as state-owned monopolies. However, in a short span of time, it became evident that the public monopoly model could not achieve the desired profitability rates and was underperforming. Railways were grappling to discover efficient solutions to confront competition from alternative modes of transportation and adjust to the evolving patterns of freight and passenger demand.

As Karamanoğlu (2012, p. 13) indicates, the historical evolution of railway reforms has predominantly centered on two core concepts: reducing state intervention in railway management and introducing competition to the sector. Competition within the railway sector may be also characterized by two dimensions. The first involves intermodal competition, highlighting the rivalry among transportation subsystems, including railways that currently hold a monopoly position. The second dimension is intramodal competition, which envisions competition specifically within transportation activities, particularly within the railway sector.

Evans and Heckman (1983a, 1983b, 1984, 1986) conducted pioneering research on natural monopoly tests, particularly focusing on the United States landline telephone industry. The prominent empirical assessment of natural monopoly is Evans and Heckman (1984). This study employs a trans-log cost function to investigate whether the costs of the Bell System between 1947 and 1977 displayed subadditivity. Their research has garnered considerable recognition in the literature for introducing an innovative test for the subadditivity of the cost function, a method widely employed in numerous studies investigating the efficiency of diverse private and public establishments (Chang and Mashruwala (2006), Cubukcu and Guldmann (2008), Gordon, Gunsch, and Pawluk (2003), Won (2007)). This test requires less information about the cost function which is easily computable and provides a streamlined rejection criterion for evaluating the hypothesis of subadditivity (Evans and Heckman, 1986, p. 621).

The assessments of natural monopolies within the railway industry find their roots in these seminal studies. For instance, Sanchez (2000) examines whether the operational cost function of a group of European rail companies exhibits subadditivity in monopoly scenarios compared to hypothetical duopoly situations, using the methodology proposed by Evans and Heckman (1984). According to the findings of this study, particularly for larger rail companies, enhancing efficiency could be achieved by dividing the existing companies into two separate entities of smaller size. Wills-Johnson (2007) also explores the possibility of competition by employing an analysis of subadditivity for Australian railways, finding limited support both for the above-rail competition and vertical separation which may lead to efficiency losses. Ivaldi and McCullough (2008) emphasizes the technological dimensions of vertically integrating networks, specifically in sectors like electricity and railroads, where the primary cost sources revolve around service-related operations and infrastructure maintenance activities. This study employs an approach grounded in the definition of cost subadditivity and suggests that the segregation of rail freight operations from the infrastructure leads to a decline in technical efficiency ranging from 20-40 percent, whereas the separation of rail operations results in a substantial decrease of 70 percent in operational efficiency.

Within the body of research exploring the Turkish railway sector, Kabasakal and Solak (2009, p. 32) indicates the necessity of introducing competition to the state-owned railway sector. Moreover, Tangül (2014, p. 1) highlights that the liberalization experiences observed in European Union countries may serve as a model for Turkey.

In light of global efforts to enhance transportation efficiency and sustainability, structural reform in the railway sector has taken on renewed importance. Many governments, influenced by the European Union's rail liberalization directives and global environmental commitments, are revisiting the balance between market liberalization and public oversight. This is especially pertinent in economies with historically centralized rail systems, such as Turkey. Understanding whether such systems display characteristics of natural monopoly is not only a theoretical concern, but also has practical implications for regulatory design, infrastructure investment, and public service provision. Against this backdrop, the study of subadditivity in railway cost structures offers critical insight into the economic rationality of introducing competition or maintaining integration.

As can be seen from the studies above, the ongoing discourse surrounding the ownership structure of railways, which play a pivotal role in curbing greenhouse gas emissions and serve as an environmentally astute method for global transportation of people and goods, remains relevant today. While this topic has undergone extensive scrutiny in numerous academic studies, there remains a lack of unanimous results or consensus regarding the implications derived from these research endeavors. Additionally, as far as we are aware, an examination of the literature pertaining to railway ownership structures indicates a lack of empirical studies exploring whether the Turkish railway industry possesses features indicative of a natural monopoly. To address this gap in the existing literature, this research employs subadditivity analysis to compare the efficiency levels of TCDD under monopoly conditions with those in hypothetical duopoly scenarios spanning the period from 1990 to 2016.

The remaining sections of this study are structured into four parts. The initial section provides a concise overview of the Turkish State railway industry. The second section introduces the empirical method employed in the study, while the third section outlines the dataset and presents applied results. The concluding section deliberates on the results and policy implications.

Briefly about Turkish State Railways

The railway system in Turkey operates as a monopoly, under the exclusive management and operation of the state-owned Turkish State Railways (TCDD). This monopolistic control can be traced back to the concession granted for the 130 km Izmir-Aydin Railway line in 1856. The railway lines that were built before the republican era and operated by foreign companies were acquired and brought under national ownership by 1948[1].

As mentioned by Perçin and Çakır (2012, p. 30), in Turkey, like many other countries, railway infrastructure investments and operating activities are traditionally carried out by the public sector. This sector has functioned as a monopoly, with entry barriers restricting private operators until the recent past. Following Özcan (2006, p. 1058), the lack of competitive conditions results in the railways becoming a sector that is constantly subsidized by the public sector to offset operational losses and fails to adopt an efficient operating structure.

In recent decades, TCDD has plunged into a financial crisis, necessitating a fundamental reorganization of its management and organizational framework for recovery. In response to the economic crisis that unfolded in the country during the 2000s, the government embarked on a series of economic reforms aimed at fiscal management and deficit reduction. In this period the Turkish state railway sector observed a significant decline in service quality as a consequence of administrative shortcomings arising from reduced demand during the

1 See: 2018-2022 Annual Statistics https://static.tcdd.gov.tr/webfiles/userfiles/files/istrapor/20182022.pdf

crisis period and the increased involvement of the state, compounded by years of inefficiency in production. Compounded by escalating financial deficits, the industry has exhibited resistance to innovation, hampering its ability to align with the dynamic contours of the evolving economic structure. Simultaneously, within the framework of the European Union enlargement process, Turkey was officially recognized as a candidate country and initiated an extensive reform program in accordance with EU Harmonization laws. This initiative extended across multiple sectors, with particular emphasis on the railway industry. In this context, the liberalization of railway transport was initiated through the legislation[2] enacted in 2013 and was effectively implemented in 2016, envisioning a substantial revamping of TCDD's governance and organizational framework.

According to the new regulation, while TCDD remains responsible for infrastructure services, the operation of trains is managed by the newly established enterprise, TCDD Transport (TCDDT). Moreover, both domestic and international companies now have the capacity to operate their own trains, whether for passenger or freight transportation. Consequently, the deregulation of railways resulted in the termination of TCDD's monopoly in rail passenger and freight transport, paving the way for the entry of new entities into the sector, involved in both infrastructure and train operations.

Table 1.

Income Statement of TCDD 2018-2022

	2018	2019	2020	2021	2022
Total Expenditures (TL)	3.797.331.047	4.504.780.149	5.818.753.173	6.624.421.895	11.238.677.317
Total Revenues (TL)	1.239.368.530	1.957.885.054	1.952.329.517	2.590.188.801	4.852.620.220
Profit (TL)	-2.557.962.517	-2.546.895.096	-3.866.423.656	-4.034.233.094	-6.386.057.097

Source: 2018-2022 TCDD Annual Statistics

2 See: Law on the Liberalization of Railway Transport in Turkey.

Table 2.

Income Statement of TCDD Transport 2018-2022.

	2018	2019	2020	2021	2022
Total Expenditures (TL)	3.010.350.245	3.789.885.204	3.669.110.237	4.786.219.618	9.800.971.677
Total Revenues (TL)	2.131.160.413	2.702.832.526	2.335.939.616	3.144.991.549	7.289.537.242
Profit (TL)	-879.189.832	-1.087.052.678	-1.333.170.620	-1.641.228.069	-2.511.434.435

Source: 2018-2022 TCDD Transport Annual Statistics

Following Yilmaz, Kasap, and Budak (2018, p. 696), with the liberalization process of the Turkish State Railways, it is expected that all railway enterprises, aligning with market conditions, will compete effectively by delivering public services efficiently at reduced costs, avoiding financial losses, and operating within a framework where market entry and exit are unrestricted. Nevertheless, as it is clear from the tables presented above, in the years following the deregulation of the railway system in Turkey, both TCDD and TCDD Transport have been characterized by persistent financial losses increasing every year. This observation implies that even competitive public enterprises may demonstrate diminished efficiency.

According to the organizational division, as indicated in Tables 1 and 2, both TCDD and TCDD Transportation have been operating at a financial loss. Detailed data specific to TCDD Transportation is provided in Table 2. Since TCDD Transportation was established only after 2018, no comparative data from earlier periods are available for analysis. However, a comparison of TCDD's performance before and after the division reveals a decline in the income-to-expense coverage ratio for railway services, indicating a deterioration in financial efficiency. As observed, the data in Table 3 further substantiates this conclusion.

Table 3.

Income-To-Expense Coverage Ratio of TCDD 2014-2022.

2014	45	**2017**	23	**2020**	27
2015	46	**2018**	22	**2021**	31
2016	39	**2019**	35	**2022**	35

Source: TCDD Annual Statistics

The trend illustrates a significant decline in the income-expenditure coverage ratio after 2016, reaching its lowest points in 2017 and 2018. Nevertheless, a gradual recovery is evident from 2019 onward, with the ratio stabilizing at approximately 35 by 2022. These figures highlight the persistent difficulties TCDD faces in maintaining a balanced financial position during the examined period.

Applied Methodology

The analysis is started by specifying the cost function defined as $TC = TC(q,w)$. Here, q represents the output vector, and w denotes the input-price vector. After examining the works of Evans and Heckman (1984), Jara-Diaz and Munizaga (1992), Salvanes and Tjøtta (1998), Sanchez (2000), Wills-Johnson (2007), and Ivaldi and Mccullough (2008), the relatively straightforward functions proposed by Sanchez (2000), which can be constructed with TCDD's dataset, have been adopted.

Let the output vector be expressed as $q = (q_{FR}, q_{PA})$, where q_{FR} represents freight train-kilometers, and q_{PA} denotes passenger train-kilometers[3]. In this study, we define the input-price vector as $w = (w_L, w_E, w_M)$, where w_L symbolizes unit labor cost, w_E denotes unit energy and fuel cost, and w_M is unit material and other expenses. Many studies, including but not limited to those mentioned above, use the cost of materials instead of other expenses, and the other expenses are ignored because it is a small proportion. However, in TCDD's data set, the other expenses correspond to approximately 46% of the annual expenses on

3 The term "train-kilometer" serves as a standardized unit of measurement denoting the distance covered by a train over a span of one kilometer. This metric has gained recognition and universal acceptance from the International Union of Railways (UIC) as the standard criterion for quantifying the services offered by railway enterprises (Eurostat, 2019, p. 35)

average in the review period, making it impossible to disregard such a considerable component of total expenditure. To determine labor costs, one can compute w_L by dividing the total expenditure on workforce by the overall number of workers. The calculation for energy and fuel costs involves dividing the total expenses within this category by the number of train-kilometers, denoted as w_E. Finally, w_M is obtained by dividing material and other spendings by the total train-kilometers.

Given TCDD's multiple structure, encompassing the administration of railways, ports, piers, the Van Lake ferry, and subsidiaries, it is important to note that all data presented has been consolidated specifically to cover only railways. Given the lack of data for the post-reform period, this paper focuses on assessing the sector during the period immediately preceding liberalization. Additionally, the data utilized throughout the research period has been sourced exclusively from the annual statistics reports of TCDD. To maintain consistency, we convert all inputs to constant 2003 Turkish Liras using the Domestic Producer Price Index (2003=100) which is obtained from The Central Bank of the Republic of Türkiye Electronic Data Delivery System.

In alignment with previous research conducted by Salvanes and Tjøtta (1998), Sanchez (2000), and Wills-Johnson (2007), this study also adopts a translog cost function. As it is well known the translog function's adaptable structure proves to be sufficiently comprehensive, allowing for the extraction of all essential properties inherent in a cost function, encompassing the functional value, the gradient vector, and the Hessian matrix. In light of the output vector $q = (q_{FR}, q_{PA})$ and the input-price vector $w = (w_L, w_E, w_M)$ defined above, the translog cost function may be formed as follows:

$$\ln TC = \alpha_0 + \sum_i \alpha_i \ln w_i + \sum_i \beta_i \ln q_i + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln w_i \ln w_j + \frac{1}{2}\sum_i \sum_j \delta_{ij} \ln q_i \ln q_j + \frac{1}{2}\sum_i \sum_j \rho_{ij} \ln w_i \ln q_j + e \quad (1)$$

The input cost share or participation equations are obtained by applying Shepard's lemma to Equation (1):

$$S_i = \frac{\partial \ln TC}{\partial \ln w_i} = \alpha_i + \sum_j \gamma_{ij} \ln w_j + \sum_j \rho_{ij} \ln q_j + e_i \quad \textit{for all inputs } i \quad (2)$$

where e and e_i are error terms. The restrictions for linear homogeneity and symmetric Hessian matrix are:

$$\sum_i \alpha_i = 1, \ \sum_j \gamma_{ij} = 0, \ \sum_j \rho_{ij} = 0, \ \gamma_{ij} = \gamma_{ji} \text{ and } \delta_{ij} = \delta_{ji}$$

The classification of an industry as a natural monopoly hinges on the prerequisite that the cost functions of the firms within it should demonstrate subadditivity (Evans and Heckman, 1984, p. 615). On the other hand, the condition for the cost function to be considered subadditive for a specific output vector is that the output vector should be less costly to produce by one firm than to be produced by two or more hypothetical firms (Salvanes and Tjøtta, 1998, p. 675).

Tirole (2001, p. 18) defines subadditivity as follows. If;

$$\sum_{i=1}^{n} TC(q_i) > TC(\sum_{i=1}^{n} q_i)$$

for any n-tuple of outputs, q_1, q_2, ..., q_n, the cost function is strictly subadditive.

Hence, the determination of the cost function for TCDD being judged as subadditive would lead to the conclusion that TCDD operated as a natural monopoly. To ensure the favorable performance of the cost function, we will define standard conditions, including requirements for well-behaved characteristics such as symmetry in the estimated parameters and adherence to the linear homogeneity condition in input prices.

As previously indicated, the equations for input cost share or participation are derived through the application of Shepard's lemma to Equation (1). The simultaneous estimation of both the cost function and participation equations enhances the efficiency of the estimation process without diminishing the degrees of freedom. Given the presence of three inputs, a set of participation equations naturally accompanies each input. Since the three participation equations add up to unity, two of the three are used for estimation which are linearly independent (Sanchez, 2000, p. 279). Through the imposition of essential constraints, the model undergoes estimation using Zellner's two-step procedure for estimating seemingly unrelated regressions (SUR). Following the estimation process, the Evans-Heckman Test is employed to examine the presence of a natural monopoly. The initial phase of the test involves defining the admissible region.

Given Evans-Heckman's definition of a highly restrictive region, we opt to adopt the approach introduced by Sanchez (2000) and define an expanded region that encompasses the entirety of the observed outputs. The key constraint in the admissible region is that in a duopoly scenario, both companies must not produce less than half of the smallest output observed in the monopoly. In our model, a vector, Q_M, is defined by minimum output levels for both companies in hypothetical duopoly regime.

$$Q_M = \left(\frac{\min Q_F}{2}, \frac{\min Q_P}{2} \right) = \left(\frac{Q_{FM}}{2}, \frac{Q_{PM}}{2} \right) \tag{3}$$

The output vector in year t is:

$$Q_t = \left(Q_{Ft}^{*}, Q_{Pt}^{*} \right) \tag{4}$$

The duopolistic company A and B will produce:

$$Q_t^A = \left(\alpha Q_{Ft} + \frac{Q_{FM}}{2}, \beta Q_{Pt} + \frac{Q_{PM}}{2} \right)$$
$$Q_t^B = \left((1-\alpha) Q_{Ft} + \frac{Q_{FM}}{2}, (1-\beta) Q_{Pt} + \frac{Q_{PM}}{2} \right) \quad (5)$$

where α and β = 0.1, 0.2, 0.3, . . ., 0.9. In constructing a hypothetical duopoly scenario, the initial step involves creating the respective shares of freight and passenger services for both Company A and Company B. Here, α represents the proportion of freight train-km provided by Company A relative to the total freight train-km observed in the monopoly, and β signifies the proportion of passenger train-km offered by Company A relative to the total passenger train-km observed in the monopoly. Likewise, *(1-α)* denotes the proportion of freight train-km provided by Company B relative to the total freight train-km observed in the monopoly, and *(1-β)* represents the proportion of passenger train-km offered by Company B relative to the total passenger train-km observed in the monopoly.

Aggregating the output vector involves summing the individual output contributions from each duopolistic company:

$$Q_{Ft}^* = Q_{Ft} + Q_{FM}$$
$$Q_{Pt}^* = Q_{Pt} + Q_{PM} \quad (6)$$

With another representation:

$$Q_{Ft} = Q_{Ft}^* - Q_{FM}$$
$$Q_{Pt} = Q_{Pt}^* - Q_{PM} \quad (7)$$

Equations on (7) lead to condition $Q_{it}^* > Q_{iM}$. This condition suggests that testing will be restricted to duopoly configurations where the output of each product in the industry is, at a minimum, equal to the lowest level of output present in the original sample. Figure 1 shows our admissible region.

The costs for the two companies forming the hypothetical duopoly are specified as follows:

$$TC_t^A(\alpha,\beta) = TC_t^A(\alpha P + \beta F)$$
$$TC_t^B(\alpha,\beta) = TC_t^B((1-\alpha)P + (1-\beta)F) \quad (8)$$

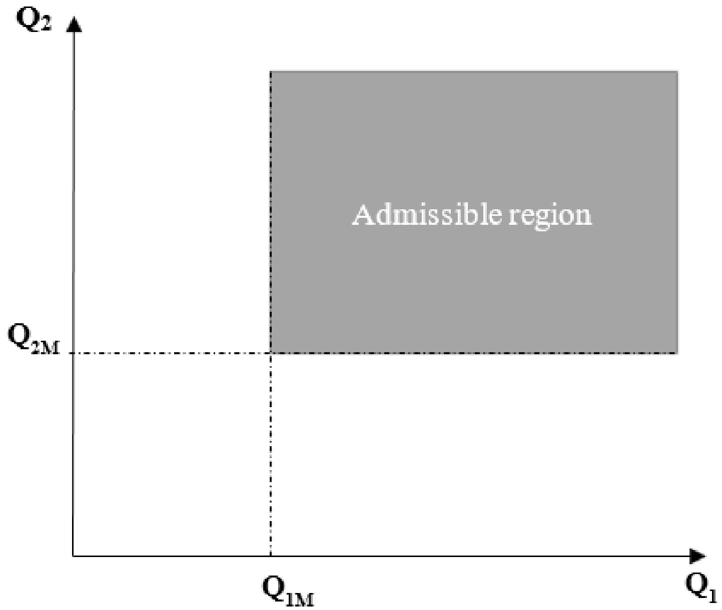
The equation that determines the index measuring the degree of subadditivity in the cost function is as follows:

$$Sub_t\ (\alpha,\beta) = \frac{TC_t^* - TC_t^A(\alpha,\beta) - TC_t^B(\alpha,\beta)}{TC_t^*} \quad (9)$$

where TC_t^* is the observed cost of monopoly. If $Sub_t(\alpha, \beta)$ is negative the cost function will be subadditive, if $Sub_t(\alpha,\beta)$ is zero the cost function will be additive and if $Sub_t(\alpha, \beta)$ is positive the cost function is superadditive for a given (α,β) configuration.

Figure 1.

The admissible region



In the final step of the natural monopoly test, we compute the α and β values that optimize equation (9), $Max_{(\alpha,\beta)}Sub_t(\alpha,\beta)$, for each respective year. If all the resultant values are negative and statistically different from zero, this implies that the cost function exhibits subadditivity for all configurations within the admissible region. Conversely, if certain values are positive and significantly distinct from zero, the hypothesis asserting the subadditivity of the cost function will be rejected for that specific year.

Estimation Results

The estimation of the cost function (1) and participation equations (2) conducted employing Zellner's two-step procedure for estimating seemingly unrelated regressions (SUR). The outcomes are detailed in Table A1 in Appendix A. It is noteworthy that while the parameter estimates are provided, they do not constitute the primary focus of this study. The estimation results indicate that a significant majority of the parameters differ significantly from zero at the 5% level or higher. Furthermore, noteworthy high R^2 values are observed for both the cost function and individual participation equations, ranging from 0.91 in the cost function to 0.57 and 0.97 in the cost share equations, respectively.

As previously mentioned, to characterize a well-behaved cost function, the estimated model should exhibit a monotonically increasing and concave nature concerning the input prices. To establish the monotonically increasing feature, it is imperative to validate that the estimated participation equations for each input are non-negative, this requirement has been verified for each participation equation. To ascertain concavity, the Hessian matrix formed by the second-order price coefficients should be negative semi-definite. This condition is maintained when the demand elasticities of each factor concerning their own prices are negative. Verification of this requirement was conducted by computing Allen-Uzawa substitution elasticities, and it was satisfied for nearly all observations. A succinct summary table is provided in Appendix Table A2..

As previously mentioned, a key constraint in the admissible region is that in a duopoly scenario, both companies must produce no less than half of the smallest output observed in a monopoly. The determination of the admissible region is quided by these minimum output thresholds. Specifically, the minimum observed freight train-kilometers ($minQ_F$) is 14,063,000, and the minimum observed passenger train-kilometers

($minQ_p$) is 14,732,000 in a monopoly setting. Utilizing these values, a vector, Q_M, is established to represent the minimum output levels for both companies in a hypothetical duopoly regime, as indicated in Equation (3). Furthermore, Equation (5) is employed to construct a hypothetical duopoly scenario for all possible values of α and β (where α and β range from 0.1 to 0.9 in increments of 0.1).

The testing is confined to duopoly configurations in which the output of each product in the industry is, at a minimum, equal to the lowest output level observed in the original sample. The costs for the two companies in the hypothetical duopoly are calculated as described in Equation (8).

Subsequently, a subadditivity test is performed on 2,187 potential output bundles within the admissible region. The configurations (α, β) that maximize the expression $Max_{(\alpha, \beta)} Sub_t(\alpha, \beta)$ are calculated for each year and presented in Appendix Table A3. Notably, all values are consistently negative and statistically significant, indicating that the cost function is subadditive for all configurations within the admissible region. This finding suggests that producing the output vector is less costly for one firm than for two hypothetical firms, thereby affirming TCDD's status as a natural monopoly prior to its separation.

Concluding Remarks

In this study, we investigate whether the Turkish railway industry exhibits characteristics consistent with a natural monopoly from 1990 to 2016. We utilize subadditivity analysis to compare the efficiency levels of TCDD under monopoly conditions with those in hypothetical duopoly scenarios.

The main finding of the research is that the cost function for the Turkish railway sector (TCDD) is subadditive across all configurations within the admissible region, confirming that it operates as a natural monopoly. It indicates that a single firm can provide services at a lower total cost than multiple firms, supporting the view that separating or liberalizing the sector was an inefficient decision. So, having two firms in the railway sector would not reduce production costs and might lead to inefficiencies. This result contradicts the conclusions drawn by Sanchez (2000, p. 285) regarding the European railway system which indicates that especially for larger rail companies, improving efficiency could be accomplished by subdividing the current entities into two distinct smaller-sized entities.

In this context, the primary policy recommendation of the study is to reunify TCDD and TCDD Transport, as this consolidation is expected to result in lower output costs. However, it is important to note that establishing a natural monopoly with a single company may lead to prices that exceed socially desirable levels. Therefore, it is essential for policymakers to implement regulations that protect both consumers and the natural monopoly within the railway sector in Türkiye. Achieving a careful balance between affordability, accessibility, and efficiency is crucial to prevent potential monopolistic abuses. By integrating price and entry regulations, policymakers can safeguard consumers from monopolistic pricing practices while ensuring the long-term viability and sustainability of the natural monopoly in the railway sector.

Beyond the empirical confirmation of subadditivity, this study contributes to the broader understanding of how structural characteristics in emerging market railway systems differ from those in liberalized economies. The findings suggest that policy transfer from European models should be approached with caution, particularly when cost conditions are not comparable. The results reinforce the importance of evidence-based infrastructure reform that accounts for local institutional, economic, and technological contexts.

Moreover, the subadditive nature of TCDD's cost structure emphasizes the continued relevance of integrated network management in sectors with high fixed costs and operational interdependencies. Rather than pursuing structural separation as a means of promoting competition, Turkish railway policy should focus on strengthening governance, service quality, and investment efficiency within a unified institutional framework.

Declaration

In all processes of the article, TESAM's research and publication ethics principles were followed.

There is no potential conflict of interest in this study.

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Appendix Tables

Table A1.

Estimation Results

Parameters	Coefficient estimate	Standard error
Constant	84.850	(160.585)
Labor	-0.351	(0.965)
Energy	0.154	(0.588)
Freight	4.940	(16.820)
Passenger	-13.610	(8.563)
$(Labor)^2$	0.207	(0.019)
(Labor) (Energy)	-0.027	(0.011)
(Labor) (Material)	-0.092	(0.012)
$(Energy)^2$	0.102	(0.016)
(Energy) (Material)	-0.073	(0.008)
$(Freight)^2$	-0.310	(0.832)
(Passenger) (Freight)	0.148	(0.701)
$(Passenger)^2$	0.600	(0.679)
(Labor) (Freight)	-0.297	(0.107)
(Energy) (Freight)	0.066	(0.039)
(Material) (Freight)	-0.482	(0.548)
(Labor) (Passenger)	0.173	(0.071)
(Energy) (Passenger)	-0.030	(0.046)
Summary statistics	R^2	Adjusted R^2
Cost function	0.91	0.74
Labor share equation	0.65	0.57
Energy share equation	0.97	0.97

Table A2.

Allen-Uzawa partial elasticities

Year	Labor	Energy	Material
1990	-0.2011	-0.7824	-1.5930
1991	-0.1692	1.3655	-1.2031
1992	-0.2044	1.2180	-1.4321
1993	-0.2064	3.9523	-1.5167
1994	0.2102	9.9269	-0.7376
1995	0.1810	6.3276	-0.7744
1996	0.0895	2.1846	-0.8764
1997	-0.0675	1.8425	-1.0032
1998	-0.1520	2.2282	-1.1243
1999	-0.1998	0.7975	-1.3967
2000	-0.2067	-0.5686	-1.6681
2001	-0.1352	0.9498	-1.1360
2002	-0.2048	-0.8418	-1.6712
2003	-0.2068	-1.1256	-1.8367
2004	-0.1978	-0.9881	-1.6085
2005	-0.1951	-1.1848	-1.6581
2006	-0.2068	-1.3657	-2.0316
2007	-0.2074	-1.1402	-1.8923
2008	-0.2012	-1.3086	-1.8152
2009	-0.2037	-1.1198	-1.7402
2010	-0.1984	-1.3410	-1.8077
2011	-0.1727	-1.2829	-1.5700
2012	-0.2058	-1.4211	-2.1059
2013	-0.1874	-1.2485	-1.6314
2014	-0.2021	-1.3330	-1.8536
2015	-0.1919	-0.6382	-1.4760
2016	-0.1961	-0.0011	-1.4257

Table A3.

The statistic MaxSub

Year	MaxSub	Standard Error	Configuration
1990	-0.33138	0.01228	α=0.1 β=0.8
1991	-0.43689	0.00999	α=0.1 β=0.8
1992	-0.46087	0.01031	α=0.1 β=0.7
1993	-0.43291	0.00964	α=0.1 β=0.7
1994	-0.50554	0.00807	α=0.1 β=0.7
1995	-0.50698	0.00908	α=0.1 β=0.7
1996	-0.50635	0.00990	α=0.1 β=0.7
1997	-0.49495	0.00998	α=0.1 β=0.7
1998	-0.52898	0.01077	α=0.1 β=0.7
1999	-0.52481	0.01124	α=0.1 β=0.7
2000	-0.48647	0.01186	α=0.1 β=0.8
2001	-0.64959	0.01080	α=0.1 β=0.7
2002	-0.59811	0.01320	α=0.1 β=0.8
2003	-0.55614	0.01423	α=0.1 β=0.8
2004	-0.52804	0.01380	α=0.1 β=0.8
2005	-0.57192	0.01414	α=0.1 β=0.8
2006	-0.54291	0.01544	α=0.1 β=0.8
2007	-0.56187	0.01438	α=0.1 β=0.8
2008	-0.56494	0.01368	α=0.1 β=0.8
2009	-0.62775	0.01366	α=0.1 β=0.8
2010	-0.67342	0.01311	α=0.1 β=0.8
2011	-0.67272	0.01242	α=0.1 β=0.8
2012	-0.68768	0.01164	α=0.1 β=0.8
2013	-0.90913	0.00936	α=0.1 β=0.7
2014	-0.61315	0.01316	α=0.1 β=0.8
2015	-0.71403	0.01240	α=0.1 β=0.7
2016	-0.75912	0.01228	α=0.1 β=0.7