<論　　文>

軌道改良が鉄道事業者の線路メンテナンス費用に与える長期的効果：分布ラグモデルを用いた実証分析

Long-run Impact of Track Improvements on Railroad Track Maintenance Cost: Empirical Analysis Using Distributed Lag Model

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ABSTRACT:

By adopting panel data of small and medium-sized regional passenger railroad companies in Japan, this study clarifies the extent to which track maintenance cost can be reduced over the years by implementing track improvements, such as replacing existing rails with heavier ones and replacing wooden sleepers with concrete ones. We found that if the adoption rate of concrete sleepers increased by 1 percentage point every year, track maintenance cost would be reduced by 0.714% in 18 years. On the other hand, no reduction in track maintenance cost was observed with regard to introducing heavy rails.

キーワード：鉄道、軌道改良、線路メンテナンス費用、長期弾力性

Keywords:　Railroad, Track improvement, Track maintenance cost, Long-run elasticity

1. Introduction

Regional small and medium-sized passenger railroad companies in Japan have been facing difficult management situations. On one hand, the number of passengers has decreased due to a population decline along the railroad line and on the other hand, facilities maintenance costs have grown, making up a larger percentage of the total cost. In the first half of 2017, train derailment accidents caused by ageing wooden sleepers occurred one after another in the three small and medium-sized passenger railroad companies, and safety measures for these companies have become an important issue.

Many regional small and medium-sized passenger railroad companies in Japan have implemented track improvements such as replacing light rails with heavier ones and replacing wooden sleepers with concrete ones. Based on the data in this study, more than 70% of Japanese regional small and medium-sized passenger railroad companies have introduced heavy rails or concrete sleepers in the 20 years from FY 1994 to FY 2013. Such track improvements not only increase the strength of the track equipment and improve safety, but also reduce the frequency of required track maintenance, which is expected to reduce costs [Japan Railway Construction, Transport and Technology Agency, 2008a, b]. However, track improvement is a large capital investment, and it is difficult for railroad companies to implement it with their own funds, so the national and local governments provide subsidies for track improvements.

Here, a certain period of time (for example, 10 years) is required before the track maintenance cost reduction effect appears after the implementation of track improvements because track maintenance workers need to be skilled [Board of Audit of Japan, 2016]. It is important to determine exactly after how many years the cost reduction effect would occur and how much cost reduction can be expected, as it would help railroad companies and governments gain clarity on the policy implications of track improvements, and help them take well-informed decisions.

Regarding the effect of track improvements on track maintenance cost, many quantitative analyses have been made. For example, Johansson and Nilsson [2004] conducted an empirical analysis of Swedish and Finnish railroads, Wheat and Smith [2008] analyzed British railroads, and Odolinski and Smith [2016], and Odolinski and Nilsson [2017] analyzed Swedish railroads. However, these studies have produced inconsistent conclusions. Some of them found that costs can be reduced by track improvements, while others did not. For example, in Swedish and Finnish railroads, track maintenance cost is significantly lower if the track quality (track weight, type of sleepers, and welded rail usage) is high [Johansson and Nilsson, 2004], while in British railroads, track maintenance cost is significantly higher if the track quality (welded rail usage) is high [Wheat and Smith, 2008]. On the other hand, empirical studies by Odolinski and Smith [2016] and Odolinski and Nilsson [2017] found no significant correlation between track quality and maintenance costs in Swedish railways.

All these previous studies, except Odolinski and Nilsson [2017], estimated static models, which did not take into consideration the time period required for the cost reduction effect to appear after track improvements. Odolinski and Nilsson [2017] used a dynamic panel model. However, estimating how much the cost changes in a certain period and also estimating its precise standard errors for null hypothesis testing is difficult with a dynamic panel model. These might be the reasons for the uneven conclusions of these previous studies.

Kitamura [2017, 2018] adopted Japanese small and medium-sized passenger railroad companies' data, estimated distributed lag model, and found that an increase in the adoption rate of concrete sleepers every year might increase total factor productivity (TFP) after more than 10 years, and found no significant correlation between the adoption rate of heavy rails and TFP. However, the study did not shed light on the effect on track maintenance costs.

Therefore, the current study aims to determine the period after which the effect of track improvements on track maintenance cost appears and the long-run savings in track maintenance costs for regional small and medium-sized passenger railroad companies in Japan. To achieve this objective, this study estimates the distributed lag model as Kitamura [2017, 2018] did. We regress the track maintenance cost on the current and past adoption rates of heavy rails and concrete sleepers and obtain the long-run impact of installing heavy rails and concrete sleepers on track maintenance costs.

The remainder of this paper is structured as follows. Section 2 explains the background of this study. Section 3 explains the empirical analysis method, and Section 4 explains the data used for the analysis. Section 5 presents the results of the analysis, and Section 6 discusses the results. Section 7 presents the conclusions of this study and the remaining issues.

2. Background

1) Track Improvements in Japanese Railroad Companies

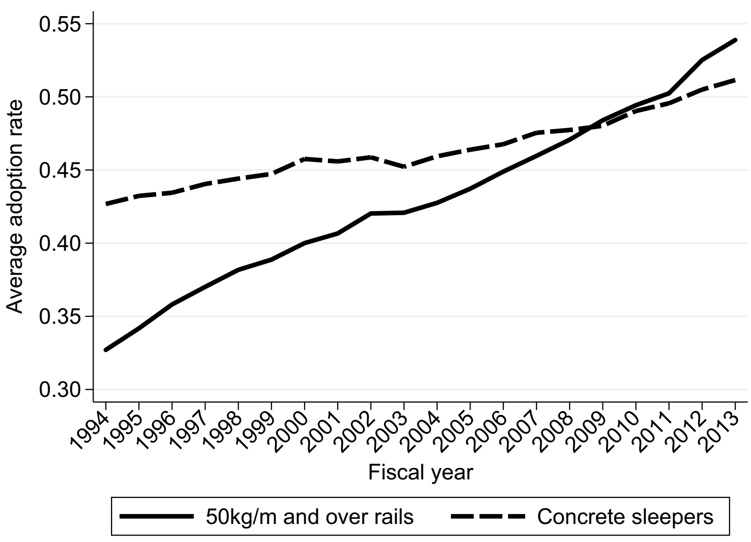
In Japan, track weight is measured in weight per meter. Some companies use rails of less than 30kg/m, while others use rails of 60kg/m and over. Replacing light rails with heavier ones not only increases the strength and improves safety, but also reduces the maintenance cost of the track and labor costs for maintenance [Japan Railway Construction, Transport and Technology Agency, 2008a]. Therefore, a reduction in track maintenance cost is expected due to the introduction of heavy rails.

There are several types of sleepers. Originally, many railroad companies used wooden sleepers. However, an increasing number of companies are replacing them with concrete sleepers. Concrete sleepers not only increase strength and durability of the tracks, but also reduce the frequency of track maintenance [Japan Railway Construction, Transport and Technology Agency, 2008b]. Therefore, there is a possibility that the track maintenance cost can be reduced by installing concrete sleepers. Track improvements, such as introducing heavy rails and concrete sleepers, have been on the rise, especially in regional small and medium-sized passenger railroad companies in Japan. Based on the data in this study, out of 32 companies that existed consistently from FY 1994 to FY 2013, 29 companies (91%) exhibit an increased adoption rate of 50kg/m and over rails or concrete sleepers in the 20 years. Of the 29 companies, 23 companies increased both the adoption rate of 50kg/m and over rails and concrete sleepers, while 3 companies have increased only the adoption rate of 50kg/m and over rails, while the remaining 3 companies have increased only the adoption rate of concrete sleepers over the 20 years from FY 1994 to FY 2013. The average adoption rate of 50kg/m and over rails and concrete sleepers among the 32 companies mentioned above has also increased over the 20 years. Figure 1 shows the transition of the average adoption rate of 50kg/m and over rails and concrete sleepers among 32 companies. According to this figure, the average adoption rate among 32 companies has increased by about 21 percentage points for 50kg/m and over rails, and by about 8 percentage points for concrete sleepers over the 20 years, respectively.

2) Derailment Accidents Due to Track Deterioration

In the first half of 2017, three train derailment accidents occurred in Japanese small and medium-sized passenger railroad companies. First, a train derailed on January 22, 2017 at Kishu Railway, followed by February 22 at Kumamotodentetsu, and on May 22 at Watase Keikoku Railway. These

Figure 1　Changes in Average Adoption Rates of Improved Tracks of the 32 Railroad Companies in This Study



Source: Author's diagram using annual rail statistics data.

derailment accidents were all caused by ageing wooden sleepers and rail fastening devices [Japan Transport Safety Board, 2018a, b].

In response to these incidents, the Japan Transport Safety Board submitted "Opinion Regarding Prevention of Train Derailment Accidents due to Track Gauge Spread" to the Minister of Land, Infrastructure, Transport and Tourism, the regulatory minister, on June 28, 2018. In that document, the Board urged the Minister to instruct each railroad company to promote measures to prevent derailment accidents such as introducing concrete sleepers [Japan Transport Safety Board, 2018a]. The Minister acted upon this recommendation by instructing the director of the railroad department of each regional transportation bureau to review the management of sleepers and take necessary measures.

As a result, track improvements, such as introducing concrete sleepers, came to be viewed as an important and urgent issue.

3. Methodology

This study assumes the following distributed lag model in order to measure the long-run impact of track improvements, such as introducing heavy rails and concrete sleepers, on track maintenance cost.

$$\ln TMC_{it} = \beta_0 + \sum_{s=0}^{S} \delta_s^{HR} HR_{i,t-s} + \sum_{s=0}^{S} \delta_s^{CS} CS_{i,t-s} + \beta_Q \ln Q_{it} + \beta_N \ln N_{it} + u_{it}, \quad (1)$$

where TMC_{it} is the track maintenance cost for company i in year t , HR_{it} is the adoption rate of heavy rails (for example, 50kg/m and over rails), CS_{it} is the adoption rate of concrete sleepers, Q_{it} is the transport volume, N_{it} is the network size, and u_{it} is the disturbance term. Because $HR_{i,t-s}$ is not logarithmic, the coefficient of it, δ_S^{HR}, indicates that the track maintenance cost in year t will increase by δ_S^{HR}% if the adoption rate of heavy rails at year $t-s$ increases by 1 percentage point. Similarly, $CS_{i,t-s}$ is not logarithmic. We define θ^{HR} and θ^{CS} as follows:

$$\theta^{HR} = \sum_{s=0}^{S} \delta_s^{HR}, \quad (2)$$

$$\theta^{CS} = \sum_{s=0}^{S} \delta_s^{CS}. \quad (3)$$

θ^{HR} is the long-run elasticity of track maintenance cost with respect to the adoption rate of heavy rails. This indicates that the track maintenance cost will increase by θ^{HR}% after S years if the adoption rate of heavy rails increases by 1 percentage point every year. Similarly, θ^{CS} is the long-run elasticity of track maintenance cost with respect to the adoption rate of concrete sleepers. This indicates that the track maintenance cost will increase after S years if the adoption rate of concrete sleepers increases by 1 percentage point every year. The long-run elasticity θ^{HR} and θ^{CS} are the parameters of interest in this study.

Substituting (2) and (3) into (1), we obtain

$$\begin{aligned} \ln TMC_{it} = \beta_0 + \theta^{HR} HR_{it} + \sum_{s=1}^{S} \delta_s^{HR}\left(HR_{i,t-s} - HR_{it}\right) + \theta^{CS} CS_{it} \\ + \sum_{s=1}^{S} \delta_s^{CS}\left(CS_{i,t-s} - CS_{it}\right) + \beta_Q \ln Q_{it} + \beta_N \ln N_{it} + u_{it}. \end{aligned} \quad (4)$$

By estimating this form of equation, it becomes possible to obtain the standard error of long-run elasticity θ^{HR} and θ^{CS} while relaxing the multicollinearity of the lagging explanatory variables in (1) [Wooldridge, 2013]. Therefore, this study estimates (4). For details on the distributed lag model, see Wooldridge [2013].

4. Data

In this study, we use annual panel data for regional small and medium-sized passenger railroad companies in Japan. The data was obtained from annual rail statistics (each year edition) published by the Ministry of Land, Infrastructure, Transport, and Tourism. The period for analysis was 20 years from FY 1994 to FY 2013. The companies to be analyzed are those that use only electric cars among private and third sector companies. In Japan, third sector companies are companies that have both private and public stakeholders. Companies that use diesel cars may have a different cost structure from those that use only electric cars, and if they are included in our data, they may affect the analysis results. For similar reasons, third-sector companies with routes that are along high-speed lines and were operated by private operators before the opening of the high-speed lines were also excluded from the sample. As a result, the number of companies in the sample was 45. However, some companies entered or exited during the 20 years, while 32 companies existed throughout the 20-year period. The total number of observations was 785.

In this study, large railroad companies and urban railroad companies were excluded from the sample. This is because these companies had almost 100% adoption rate of heavy rails and concrete sleepers as of FY 1994.

Among the variables in the model in the previous section, the track maintenance cost is a monetary variable, so it is transformed into a real variable by dividing it by the domestic corporate price index (gross average) published by the Bank of Japan. In this study, a heavy rail is defined as a rail weighing 50kg/m or more, and its adoption rate variable is created by dividing the distance of its main track by the main track length. The adoption rate variable of concrete sleepers was created by dividing the distance along which concrete sleepers were adopted by the total distance along which the sleepers were laid. The transport volume and network size are the passenger kilometers and operating kilometers, respectively. The passenger kilometers index becomes 1 unit if a passenger travels 1km. Table 1 shows the descriptive statistics for each variable used in the empirical analysis in this study. From this table, it can be seen that there are companies that do not adopt 50kg/m and over rails at all in a year, while there are companies in which all tracks are installed with 50kg/m and over rails in a year. Regarding the adoption rate of concrete sleepers, there are companies that do not adopt them all in a year, while there are companies where the adoption rate of concrete sleepers is 97% in a year.

5. Empirical Results

We estimated the distributed lag model (4), described in Section 3, beginning from maximum lag $S=0$ order and then progressively increased value of S by one ($S=1$, $S=2$, and so forth). If S is 18 or less, we can estimate the models. Table 2 shows the estimation results from "the model taking up to 10 years lag ($S=10$)" to "the model taking up to 18 years lag ($S=18$)."(1) The number of observations is not necessarily "20 minus the lag length" multiplied by the number of companies because some companies entered or dropped during the sample period—20 years. In addition, for almost all companies, the operating kilometers, one of the explanatory variables of the model, is constant over time, so we did not assume a fixed effect model.(2)

The coefficients of adoption rate of concrete sleepers indicate the long-run elasticity of track maintenance

Table 1 Descriptive Statistics

Variables' name	Mean	Median	Minimum	Maximum	Standard Deviation
Track maintenance cost (thousand JPY)	133,843.42	87,379.30	7,140.45	1,436,267.08	137,845.25
Adoption rate of 50kg/m and over rails	0.43	0.34	0.00	1.00	0.37
Adoption rate of concrete sleepers	0.44	0.45	0.00	0.97	0.33
Passenger kilometers (thousand people times kilometers)	61,574.96	32,040.00	1,287.00	746,895.00	94,791.08
Operating kilometers (kilometers)	28.36	20.60	4.20	100.50	21.31

Note: The number of observations was 785.

Table 2　Estimation Results of Distributed Lag Models

	10 lags		11 lags		12 lags		13 lags		14 lags		15 lags		16 lags		17 lags		18 lags	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
50kg/m and over rails ratio	0.262	0.218	0.287	0.228	0.322	0.228	0.366	0.223	0.419	0.229*	0.480	0.224**	0.481	0.214**	0.568	0.230**	0.456	0.273
50kg/m and over rails ratio(t-1)-50kg/m and over rails ratio(t)	−1.374	1.198	−1.840	1.338	−1.116	1.052	−1.670	0.959*	−1.514	1.004	−1.511	1.134	0.461	0.936	−0.971	0.925	0.293	2.046
50kg/m and over rails ratio(t-2)-50kg/m and over rails ratio(t)	0.940	0.702	0.849	1.261	1.376	1.416	2.391	1.140**	2.699	1.581*	2.362	1.051**	−1.049	2.200	0.430	2.785	−13.318	3.536***
50kg/m and over rails ratio(t-3)-50kg/m and over rails ratio(t)	0.069	0.736	0.065	0.811	−0.910	1.355	0.302	0.993	−0.297	1.757	−0.034	1.190	2.832	2.794	0.208	4.329	10.895	6.336*
50kg/m and over rails ratio(t-4)-50kg/m and over rails ratio(t)	0.162	0.849	0.143	0.925	−0.747	0.660	−1.333	1.406	2.177	1.850	1.641	1.169	0.896	3.046	2.475	4.590	11.110	9.456
50kg/m and over rails ratio(t-5)-50kg/m and over rails ratio(t)	−0.677	0.796	−0.941	0.741	−0.151	0.959	−1.606	0.779**	−4.575	2.256*	−1.459	1.402	−0.627	3.365	−2.573	4.959	−12.836	7.797
50kg/m and over rails ratio(t-6)-50kg/m and over rails ratio(t)	0.824	0.758	0.707	0.681	−0.126	0.739	−0.335	0.954	−0.823	1.104	−3.396	2.534	−0.699	2.455	2.293	4.256	7.487	3.506**
50kg/m and over rails ratio(t-7)-50kg/m and over rails ratio(t)	0.129	1.160	0.252	1.400	0.588	1.192	0.493	1.068	0.299	1.115	−0.047	2.023	−2.450	2.755	−1.374	3.533	0.704	7.775
50kg/m and over rails ratio(t-8)-50kg/m and over rails ratio(t)	−0.959	0.611	−0.560	0.821	−0.637	0.949	−0.800	0.860	−1.237	0.900	−1.542	1.183	−3.995	2.044*	−6.413	3.168*	−6.708	5.005
50kg/m and over rails ratio(t-9)-50kg/m and over rails ratio(t)	−0.499	0.762	−0.707	0.807	−0.381	0.716	−0.796	0.686	−0.828	0.725	−1.168	0.591*	−0.001	1.242	−0.999	1.532	−2.346	2.677
50kg/m and over rails ratio(t-10)-50kg/m and over rails ratio(t)	1.558	1.016	1.010	0.839	0.980	0.630	2.656	0.838***	2.959	1.088**	3.539	0.928***	2.991	1.191**	4.209	1.630**	−0.079	2.236
50kg/m and over rails ratio(t-11)-50kg/m and over rails ratio(t)			0.613	1.000	−0.379	1.130	−0.551	0.966	0.017	1.293	−0.154	1.007	−0.773	1.450	−1.661	1.692	2.459	2.042
50kg/m and over rails ratio(t-12)-50kg/m and over rails ratio(t)					1.165	1.091	0.197	2.142	0.675	1.890	2.326	2.315	3.732	2.797	4.825	3.306	5.716	5.553
50kg/m and over rails ratio(t-13)-50kg/m and over rails ratio(t)							0.770	1.640	0.124	2.027	0.985	2.136	0.415	3.315	−0.740	4.146	3.771	9.760
50kg/m and over rails ratio(t-14)-50kg/m and over rails ratio(t)									0.306	1.886	−3.437	1.786*	−1.912	2.701	−4.860	3.254	−7.253	9.702
50kg/m and over rails ratio(t-15)-50kg/m and over rails ratio(t)											1.727	1.457	−0.050	3.145	3.467	3.856	−5.944	3.682
50kg/m and over rails ratio(t-16)-50kg/m and over rails ratio(t)													0.939	1.997	2.730	3.311	9.715	3.595**
50kg/m and over rails ratio(t-17)-50kg/m and over rails ratio(t)															−1.719	2.125	−7.319	6.950
50kg/m and over rails ratio(t-18)-50kg/m and over rails ratio(t)																	4.409	4.366
Concrete sleepers ratio	−0.330	0.202	−0.370	0.209*	−0.453	0.215**	−0.537	0.224**	−0.627	0.244**	−0.688	0.241***	−0.777	0.253***	−0.884	0.323**	−0.714	0.386*
Concrete sleepers ratio(t-1)-Concrete sleepers ratio(t)	−0.146	0.960	1.372	1.580	0.967	1.719	−0.102	1.732	−0.926	1.749	−4.013	1.637**	−5.058	2.167**	3.148	4.236	2.414	5.397
Concrete sleepers ratio(t-2)-Concrete sleepers ratio(t)	0.341	0.791	−1.135	1.704	3.168	1.988	5.270	2.826*	5.045	2.073**	6.296	2.339**	6.507	3.187**	2.007	3.438	−1.169	4.500
Concrete sleepers ratio(t-3)-Concrete sleepers ratio(t)	−0.148	0.872	0.002	0.842	−4.330	2.025**	−1.508	1.646	−0.120	1.348	1.850	1.466	0.228	1.903	1.647	2.198	−4.874	4.583
Concrete sleepers ratio(t-4)-Concrete sleepers ratio(t)	−0.762	0.919	−0.855	1.104	0.649	0.496	−4.009	2.253*	1.251	1.877	0.709	2.625	4.782	3.408	6.835	4.500	18.924	10.288*
Concrete sleepers ratio(t-5)-Concrete sleepers ratio(t)	0.721	0.644	0.901	0.768	−0.441	1.038	1.201	0.810	−4.798	2.459*	0.754	1.863	−1.741	2.582	2.314	2.670	−7.205	12.350
Concrete sleepers ratio(t-6)-Concrete sleepers ratio(t)	0.524	0.718	0.656	0.717	1.356	0.871	0.959	0.679	1.739	0.819**	−3.373	2.503	2.828	2.152	−4.684	4.254	4.100	7.330
Concrete sleepers ratio(t-7)-Concrete sleepers ratio(t)	−1.111	1.349	−0.784	1.373	−0.994	1.177	−0.899	1.181	−0.739	1.078	−0.439	1.417	−7.040	2.984**	2.671	4.101	−9.094	5.944
Concrete sleepers ratio(t-8)-Concrete sleepers ratio(t)	0.368	0.670	−0.284	0.746	0.021	0.880	0.130	0.715	0.350	0.907	0.882	0.949	2.527	1.516	−5.541	3.984	7.911	5.479
Concrete sleepers ratio(t-9)-Concrete sleepers ratio(t)	−0.027	0.713	0.348	0.669	−0.078	0.798	0.377	0.802	0.164	0.929	−0.328	0.856	−0.736	1.252	0.718	1.483	−8.066	3.643**
Concrete sleepers ratio(t-10)-Concrete sleepers ratio(t)	−0.251	1.179	−1.898	0.801**	−1.715	0.675**	−3.123	0.869***	−2.923	1.086**	−3.166	0.808***	−2.709	1.301**	−3.722	1.602**	−0.708	2.398
Concrete sleepers ratio(t-11)-Concrete sleepers ratio(t)			1.382	0.953	−1.375	1.293	−0.520	1.515	−1.315	1.680	−1.462	2.379	−1.269	2.643	−2.485	2.881	−7.842	2.660***
Concrete sleepers ratio(t-12)-Concrete sleepers ratio(t)					2.581	1.443*	−2.519	2.172	−2.007	1.813	−2.944	2.074	−4.220	3.139	−3.215	3.569	1.642	1.917
Concrete sleepers ratio(t-13)-Concrete sleepers ratio(t)							4.628	1.470***	−0.103	2.084	2.039	1.905	2.311	2.627	4.761	4.536	−0.892	9.252
Concrete sleepers ratio(t-14)-Concrete sleepers ratio(t)									4.356	2.271*	2.959	5.213	11.193	5.617*	15.788	9.264*	20.994	13.199
Concrete sleepers ratio(t-15)-Concrete sleepers ratio(t)											0.180	3.790	−12.188	5.727**	−5.946	8.232	1.929	12.980
Concrete sleepers ratio(t-16)-Concrete sleepers ratio(t)													4.382	3.597	−13.289	6.370**	−9.811	6.631
Concrete sleepers ratio(t-17)-Concrete sleepers ratio(t)															5.507	4.284	−20.850	7.604**
Concrete sleepers ratio(t-18)-Concrete sleepers ratio(t)																	13.987	4.572***
Log of passenger kilometers	0.642	0.094***	0.640	0.094***	0.637	0.090***	0.633	0.089***	0.633	0.094***	0.618	0.097***	0.626	0.099***	0.603	0.093***	0.639	0.102***
Log of operating kilometers	0.199	0.131	0.195	0.129	0.201	0.124	0.233	0.127*	0.254	0.134*	0.275	0.139*	0.293	0.150*	0.277	0.150*	0.188	0.153
Constant term	4.165	0.703***	4.202	0.721***	4.235	0.694***	4.182	0.649***	4.127	0.667***	4.191	0.634***	4.086	0.626***	4.332	0.596***	4.282	0.940***
Variance inflation factor of 50kg/m and over rails ratio	1.30		1.31		1.34		1.38		1.42		1.48		1.58		1.90		2.57	
Variance inflation factor of concrete sleepers ratio	1.21		1.23		1.30		1.36		1.47		1.58		1.74		2.20		2.91	
Adjusted R-squared	0.777		0.776		0.785		0.796		0.803		0.818		0.834		0.842		0.878	
Number of companies	39		38		37		36		36		36		35		33		32	
Number of observations	354		315		277		240		204		168		132		97		64	

Notes: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% significance levels, respectively. Standard errors are robust for company-level clustering structure.

cost with respect to concrete sleepers ratio, the estimates of θ^{CS} in the equations (3) and (4). For all models shown in Table 2, the sign of the coefficients of adoption rate of concrete sleepers are negative. The coefficients of concrete sleepers' adoption rate show statistical significance at the 10% significance level in the 11-year and 18-year lag models, 5% significance level in the 12-year, 13-year, 14-year, and 17-year lag models, and 1% significance level in the 15-year and 16-year lag models, respectively.

Furthermore, the coefficients of the adoption rate of 50kg/m and over rails indicate the long-run elasticity of track maintenance cost with respect to 50kg/m and over rails ratio, the estimates of θ^{HR} in the equations (2) and (4). Unlike the coefficients of concrete sleepers' adoption rates, the sign of the coefficients of the adoption rate of 50kg/m and over rails are positive for all models shown in Table 2. The coefficients of 50kg/m and over rails' adoption rate show statistical significance at the 10% significance level in the 14-year lag model, and 5% significance level in the 15-year, 16-year, and 17-year lag models, respectively.

In these models, there are coefficients of the difference in the adoption rates, for example, the coefficients of "the concrete sleeper ratio in $t-10$ year minus that in t year." These are the coefficients of 50kg/m and over rails' adoption rate in $t-s$ year, δ_S^{HR}, and the coefficients of concrete sleepers' adoption rate in $t-s$ year, δ_S^{CS}, in the equations (1), (2), (3), and (4). As shown in the equation (2) and (3) in section 3, θ^{HR} is sum of the δ_S^{HR} from $s=0$ to $s=S$, and θ^{CS} is sum of the δ_S^{CS} from $s=0$ to $s=S$. Some coefficients of the difference show statistical significance at the 10%, 5%, or 1% significance levels, and other coefficients of the difference do not show statistical significance at any conventional significance levels. Note that the estimates of θ^{HR} is the sum of not only the statistically significant estimates of δ_S^{HR} but also the statistically insignificant estimates of δ_S^{HR} for all s. The same applies to θ^{CS}.

The variance inflation factor of 50kg/m and over rails ratio, HR_{it} in the equation (4), and that of the concrete sleepers ratio, CS_{it} in the model (4), range from 1.21 to 2.91 and do not exceed 10 for all models shown in Table 2. This indicates that there is no evidence that the coefficients of these two variables suffer from multicollinearity. There is thus the possibility that the standard errors of long-run elasticity θ^{HR} and θ^{CS} are estimated precisely.

In addition, for all models shown in Table 2, the coefficient of passenger kilometers representing the amount of traffic is statistically significant at the significance levels of 1%, and the sign is positive. This result is consistent with the results of Johansson and Nilsson [2004], Wheat and Smith [2008], Odolinski and Smith [2016], and Odolinski and Nilsson [2017].

Furthermore, the coefficients of operating kilometers representing the size of the network show a positive sign. They show statistical significance at the 10% significance levels in the 13-year, 14-year, 15-year, 16-year, and 17-year lag models.

Depending on the number of the maximum lags of the models, statistical significance of each coefficient changes. However, the sign of the coefficients of the two adoption rates, passenger kilometers, and operating kilometers is the same for all models. The results are thus almost robust for the lag length of the models.

Looking at the goodness of fit of the model with Adjusted R-squared, "Adjusted R-squared" of the model that took up to 18 years lag ($S=18$) was the highest, with a value of 0.878. Therefore, we discuss the 18-year lag model hereafter.

In the 18-year lag model, the sign of the coefficient of adoption rate of concrete sleepers is negative and shows statistical significance at the 10% significance level. Since the coefficient is -0.714, it can be interpreted that if the railroad company increases the concrete sleepers ratio by 1 percentage point every year, the maintenance cost will be reduced by 0.714% in 18 years. Although this is not directly comparable because of the different definitions of track improvements, it is consistent with the results by Johansson and Nilsson [2004] demonstrated in Swedish railways that derived the results that the higher the track quality index, the lower the track maintenance cost. On the other hand, the sign of the coefficient of the adoption rate of 50kg/m and over rails, the long-run elasticity of track maintenance cost with respect to 50kg/m and over rails ratio, is positive and does not show statistical significance at any conventional significance level, which means that the maintenance cost reduction effect due to introducing heavy rails was not detected.

Due to the small number of observations, 64, we need to carefully interpret the results from the 18-year lag model. However, a positive coefficient of the 50kg/m and over rails ratio and negative coefficient of concrete sleepers ratio are obtained in the other models with more observations and a smaller lags (97 observation for 17-lag, 132 observation for 16-lag, among others). Furthermore, the coefficients of the concrete sleepers ratio show statistical significance at the 10%, 5%, or 1% significance level when the lag of the model is 11 or more. Therefore, the results are almost robust as mentioned before.

6. Discussion

1) Interpretation of Estimation Results of Long-run Elasticity

As described in the previous section, as a result of estimating the distribution lag model, we revealed that the track maintenance cost of railroads would be reduced by 0.714% in 18 years if the adoption rate of concrete sleepers increased by 1 percentage point every year. Although these cost savings are small relative to track maintenance costs, it is important to reduce any costs for railroad companies that face severe financial situations.

As opposed to concrete sleepers, since the estimated coefficient of the adoption rate of 50kg/m and over rails, no long-run track maintenance cost reduction effect was observed with respect to introducing heavy rails. The reason for this result is that replacing wooden sleepers with concrete sleepers is a change to a product made from another raw material, while replacing light rails with heavier ones is just a change in the weight of the product made from the same raw material. Therefore, the change in the resistance (strengthening) of the track equipment will be smaller when the weight of the rail is increased compared to when the wooden sleepers are replaced by concrete ones. Hence, by installing concrete sleepers, railroad companies will not only improve safety and prevent derailment accidents caused by track gauge spread, but will also achieve long-run cost reductions and survivability improvements.

2) Robustness Check

As the maximum lag of the distributed lag model increases, the number of railroad companies in the sample decreases gradually, from 45 companies in the models with non-lag to 32 companies in the models with 18-year lags—via 39 companies in the model with 10-year lags. This is because the data are unbalanced panel: some companies entered and exited during the study period as mentioned in section 4. However, there is the possibility that companies' cost structure changes largely in the years when they enter or drop from the market. This subsection examines whether the main results are robust when we use only the 32 companies that existed throughout the 20-year period, the balanced panel data.

Using the 32 companies, we estimated the distributed models, beginning from maximum lag order and then progressively increased value of by

Table 3 Estimation Results of Distributed Lag Models (32 Companies)

	10 lags		11 lags		12 lags		13 lags		14 lags		15 lags		16 lags		17 lags		18 lags	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
50kg/m and over rails ratio	0.298	0.241	0.317	0.246	0.332	0.243	0.380	0.235	0.439	0.240*	0.497	0.231**	0.485	0.221**	0.549	0.239**	0.456	0.273
50kg/m and over rails ratio(t-1)-50kg/m and over rails ratio(t)	−1.084	1.158	−1.231	1.114	−1.022	1.010	−1.789	0.823**	−1.819	0.988*	−1.927	−1.927**	0.387	0.808	−0.803	0.899	0.293	2.046
50kg/m and over rails ratio(t-2)-50kg/m and over rails ratio(t)	0.668	0.643	0.554	1.159	1.527	1.434	2.466	1.221*	2.568	1.741	2.455	1.141**	−1.480	2.104	−0.044	2.686	−13.318	3.536***
50kg/m and over rails ratio(t-3)-50kg/m and over rails ratio(t)	−0.379	0.545	−0.127	0.580	−1.145	1.404	0.306	1.114	−0.289	2.046	−0.434	1.139	3.004	2.827	0.737	4.323	10.895	6.336*
50kg/m and over rails ratio(t-4)-50kg/m and over rails ratio(t)	0.271	0.914	−0.177	0.975	−0.759	0.697	−1.117	1.482	2.927	1.862	2.689	1.130**	1.249	2.924	2.208	4.620	11.110	9.456
50kg/m and over rails ratio(t-5)-50kg/m and over rails ratio(t)	−0.861	0.912	−0.843	0.764	−0.405	0.986	−2.113	0.867**	−5.480	2.307**	−2.645	1.421*	−1.555	2.886	−2.379	4.998	−12.836	7.797
50kg/m and over rails ratio(t-6)-50kg/m and over rails ratio(t)	0.591	0.738	0.396	0.697	−0.127	0.771	−0.242	0.972	−0.551	0.973	−2.730	2.546	0.444	2.408	2.185	4.211	7.487	3.506**
50kg/m and over rails ratio(t-7)-50kg/m and over rails ratio(t)	0.562	1.119	0.546	1.444	0.620	1.219	0.396	1.110	0.228	1.143	−0.377	2.029	−3.065	3.029	−1.300	3.456	0.704	7.775
50kg/m and over rails ratio(t-8)-50kg/m and over rails ratio(t)	−0.585	0.607	−0.253	0.828	−0.394	0.937	−0.549	0.829	−1.108	0.944	−1.227	1.171	−3.690	1.838*	−6.429	3.061**	−6.708	5.005
50kg/m and over rails ratio(t-9)-50kg/m and over rails ratio(t)	−0.907	0.715	−0.804	0.820	−0.411	0.740	−0.615	0.746	−0.686	0.791	−1.076	0.685	0.097	1.331	−0.849	1.514	−2.346	2.677
50kg/m and over rails ratio(t-10)-50kg/m and over rails ratio(t)	1.745	1.009*	0.943	0.938	1.010	0.720	2.404	0.801***	2.904	1.088**	3.452	0.927***	2.831	1.205**	4.003	1.544**	−0.079	2.236
50kg/m and over rails ratio(t-11)-50kg/m and over rails ratio(t)			0.687	1.055	−0.325	1.168	−0.360	0.952	−0.020	1.285	0.077	0.975	−0.701	1.531	−1.582	1.702	2.459	2.042
50kg/m and over rails ratio(t-12)-50kg/m and over rails ratio(t)					1.108	1.146	0.018	2.286	0.458	1.928	1.502	2.370	3.811	2.990	5.056	3.163	5.716	5.553
50kg/m and over rails ratio(t-13)-50kg/m and over rails ratio(t)							0.847	1.748	0.314	2.064	1.651	2.204	−0.106	3.701	−1.026	3.953	3.771	9.760
50kg/m and over rails ratio(t-14)-50kg/m and over rails ratio(t)									0.298	1.944	−3.965	1.898**	−1.660	2.938	−4.574	3.203	−7.253	9.702
50kg/m and over rails ratio(t-15)-50kg/m and over rails ratio(t)											2.070	1.521	−0.206	3.251	3.173	3.757	−5.944	3.682
50kg/m and over rails ratio(t-16)-50kg/m and over rails ratio(t)													1.108	2.041	2.742	3.388	9.715	3.595**
50kg/m and over rails ratio(t-17)-50kg/m and over rails ratio(t)															−1.678	2.167	−7.319	6.950
50kg/m and over rails ratio(t-18)-50kg/m and over rails ratio(t)																	4.409	4.366
Concrete sleepers ratio	−0.407	0.228*	−0.435	0.234*	−0.487	0.240*	−0.560	0.250**	−0.638	0.269**	−0.685	0.265**	−0.746	0.278**	−0.850	0.334**	−0.714	0.386*
Concrete sleepers ratio(t-1)-Concrete sleepers ratio(t)	−1.607	1.867	0.959	1.446	1.029	1.482	1.977	1.614	2.766	1.923	0.308	2.000	−2.136	2.125	3.052	4.200	2.414	5.397
Concrete sleepers ratio(t-2)-Concrete sleepers ratio(t)	0.523	0.667	−1.092	1.351	2.760	1.714	3.640	2.121*	4.868	2.047**	5.312	2.027**	5.404	3.037*	2.105	3.344	−1.169	4.500
Concrete sleepers ratio(t-3)-Concrete sleepers ratio(t)	0.543	0.419	0.494	0.558	−3.536	1.929*	0.028	0.782	0.006	1.444	2.657	1.715	0.584	1.958	1.218	2.190	−4.874	4.583
Concrete sleepers ratio(t-4)-Concrete sleepers ratio(t)	−0.810	0.961	−0.499	1.211	0.683	0.527	−4.605	2.533*	1.728	2.422	1.065	3.087	5.524	3.516	6.844	4.378	18.924	10.288*
Concrete sleepers ratio(t-5)-Concrete sleepers ratio(t)	1.113	0.718	0.982	0.891	−0.014	0.998	1.643	0.770**	−5.176	3.011*	1.249	2.302	−1.596	2.949	2.222	2.591	−7.205	12.350
Concrete sleepers ratio(t-6)-Concrete sleepers ratio(t)	0.605	0.735	0.783	0.704	1.265	0.910	1.009	0.738	1.687	0.813**	−4.439	3.065	3.651	2.357	−3.193	4.463	4.100	7.330
Concrete sleepers ratio(t-7)-Concrete sleepers ratio(t)	−1.350	1.196	−1.174	1.359	−1.219	1.156	−1.127	1.317	−0.958	1.136	−0.547	1.403	−8.286	3.028**	1.245	4.089	−9.094	5.944
Concrete sleepers ratio(t-8)-Concrete sleepers ratio(t)	−0.190	0.463	−0.426	0.740	−0.211	0.864	−0.049	0.674	0.149	0.988	0.566	0.969	2.165	1.478	−5.141	3.936	7.911	5.479
Concrete sleepers ratio(t-9)-Concrete sleepers ratio(t)	0.082	0.689	0.285	0.664	0.019	0.753	0.199	0.815	0.152	1.001	−0.317	0.900	−0.757	1.314	0.592	1.464	−8.066	3.643**
Concrete sleepers ratio(t-10)-Concrete sleepers ratio(t)	−0.286	1.163	−1.905	0.910**	−1.753	0.678**	−2.742	0.775***	−2.757	1.084**	−2.891	0.783***	−2.510	1.293*	−3.585	1.534**	−0.708	2.398
Concrete sleepers ratio(t-11)-Concrete sleepers ratio(t)			1.359	1.017	−1.375	1.364	−0.530	1.729	−1.015	2.014	−1.718	2.481	−1.382	2.642	−2.517	2.963	−7.842	2.660***
Concrete sleepers ratio(t-12)-Concrete sleepers ratio(t)					2.510	1.551	−2.461	2.935	−1.285	2.604	−1.258	2.460	−3.718	3.050	−3.299	3.549	1.642	1.917
Concrete sleepers ratio(t-13)-Concrete sleepers ratio(t)							4.365	1.873**	−0.147	2.473	1.810	2.454	3.446	3.374	4.934	4.456	−0.892	9.252
Concrete sleepers ratio(t-14)-Concrete sleepers ratio(t)									3.362	2.945	1.961	6.320	9.049	6.219	15.467	9.351	20.994	13.199
Concrete sleepers ratio(t-15)-Concrete sleepers ratio(t)											−0.040	4.299	−10.419	5.623*	−6.322	8.234	1.929	12.980
Concrete sleepers ratio(t-16)-Concrete sleepers ratio(t)													3.319	3.900	−11.993	6.729*	−9.811	6.631
Concrete sleepers ratio(t-17)-Concrete sleepers ratio(t)															4.785	4.579	−20.850	7.604**
Concrete sleepers ratio(t-18)-Concrete sleepers ratio(t)																	13.987	4.572***
Log of passenger kilometers	0.634	0.101***	0.633	0.101***	0.630	0.095***	0.623	0.094***	0.610	0.098***	0.590	0.099***	0.595	0.103***	0.592	0.098***	0.639	0.102***
Log of operating kilometers	0.232	0.130*	0.226	0.130*	0.229	0.126*	0.257	0.130*	0.283	0.139*	0.305	0.141**	0.316	0.156*	0.288	0.157*	0.188	0.153
Constant term	4.173	0.782***	4.208	0.792***	4.244	0.744***	4.232	0.694***	4.284	0.692***	4.400	0.634***	4.328	0.623***	4.414	0.611***	4.282	0.940***
Variance inflation factor of 50kg/m and over rails ratio	1.26		1.27		1.29		1.34		1.40		1.44		1.58		1.89		2.57	
Variance inflation factor of concrete sleepers ratio	1.33		1.36		1.43		1.49		1.61		1.71		1.83		2.25		2.91	
Adjusted R-squared	0.767		0.765		0.771		0.782		0.788		0.809		0.830		0.837		0.878	
Number of observations	320		288		256		224		192		160		128		96		64	

Notes: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% significance levels, respectively. Standard errors are robust for company-level clustering structure. The number of companies is 32.

one ($S=1$, $S=2$, and so forth) again. Table 3 shows the results from "the model with 10-year lags" to "the model with 18-year lags."

The 18-year lag model estimated by using the unbalanced panel data shown in Table 2 was estimated by using the 32 companies that existed throughout the 20-year period. So, the results of the 18-year lag model estimated by using the unbalanced panel data shown in Table 2 are the same as those of the 18-year lag model shown in Table 3.

We obtained substantially similar results to those of the unbalanced panel reported in Table 2. For all models shown in Table 3, the sign of the coefficients of adoption rate of concrete sleepers are negative. The coefficients of concrete sleepers' adoption rate show statistical significance at the 10% significance level in the 10-year, 11-year, 12-year, and 18-year lag models, the 5% significance level in the 13-year, 14-year, 15-year, 16-year and 17-year lag models, respectively. The sign of the coefficients of the adoption rate of 50kg/m and over rails are also positive for all models shown in Table 3. The coefficients of 50kg/m and over rails' adoption rate show statistical significance at the 10% significance level in the 14-year lag model, the 5% significance level in the 15-year, 16-year, and 17-year lag models, respectively. Although the statistical significance of the coefficients changed slightly, the sign of coefficients is the same as the results of unbalanced panel data. Furthermore, in the model estimated by using the 32 companies' balanced panel data, the model with the highest Adjusted R-squared was the 18-year lag ($S=18$) model. Therefore, the results are robust for the railroad companies included in the sample.

7. Concluding Remarks

In Japan, regional small and medium-sized passenger railroad companies have faced difficult business conditions, and train derailment accidents have occurred because of track gauge spread resulting from ageing wooden sleepers. It is said that track improvements, such as replacing light rails with heavier ones and replacing wooden sleepers with concrete ones, not only increase the strength of the track facility and improve safety, but also reduce the required track maintenance frequency, which leads to cost reduction. In addition, replacing wooden sleepers with concrete ones might prevent track gauge spread and derailment accidents caused by it. However, a certain period of time is required before the track maintenance cost reduction effect appears after the implementation of track improvements because track maintenance workers need to be skilled. Therefore, this study attempts to clarify how many years it will take for the track maintenance costs to show a reduction after conducting track improvements and to what extent track maintenance costs will be reduced during that period by adopting panel data of small and medium-sized regional passenger railroad companies in Japan.

The empirical results indicate that if the adoption rate of concrete sleepers increased by 1 percentage point every year, track maintenance cost would be reduced by 0.714% in 18 years. However, there was no long-run track maintenance cost reduction effect with regard to introducing heavy rails. This is because replacing wooden sleepers with concrete ones is a change to products made of different raw materials, while replacing light rails with heavier ones is a replacement for products made of the same raw materials, and the change in the tolerance of the track equipment will be smaller when introducing heavy rails than when introducing concrete ones. Track improvements are a large capital investment, and it is difficult for railroad companies to carry them out with their own funds, but national and local governments have provided subsidies for track improvements. Therefore, with the help of public subsidies and by focusing on introducing concrete sleepers, it is possible for railroad companies to achieve a reduction in total cost and improve management performance in the long-run. Apart from these long-term benefits, the immediate benefits would be improved safety and prevention of train derailment accidents caused by track gauge spread.

This study has several limitations. First, although the explained variable of the distributed lag model in this study is defined as the track maintenance cost, the input price is not included in the explanatory variable, which is different from the normal cost function. However, input prices, such as the wages of track maintenance workers and the price of equipment used for maintenance, might have an impact on track maintenance costs. Future studies could control the input prices and derive a more precise measure of the effect of track improvements. Second, we could not determine whether the reduction in track maintenance cost was larger than the investment cost for track improvements because the data on the price of heavy rails and concrete sleepers is not available. This evidence needs to be shown and provided for decision making by railroad companies and governments. Finally, this study did not clarify the considerable differences in the adoption rates of improved tracks, time taken to start upgrading rails and sleepers, or the speed of progress of track improvements among companies because these are beyond the scope of this study. Furthermore, there is a possibility that the technology of track improvements and the material of the track differ depending on the time. Therefore, if railroad companies conduct track improvements early, their track maintenance cost at that time might be high. Future research should explore the companies' decisions on whether and when to improve their tracks. Despite these limitations, we make a meaningful contribution by quantitatively showing that installing concrete sleepers is likely to reduce track maintenance costs in the long run.

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Notes

(1) As for the models that are not shown in Table 2, the number of observations is 785 for the non-lag ($S=0$) model, 740 for the one-year lag ($S=1$) model, 695 for the two-year lag ($S=2$) model, 650 for the three-year lag ($S=3$) model, 605 for the four-year lag ($S=4$) model, 560 for the five-year lag ($S=5$) model, 517 for the six-year lag ($S=6$) model, 474 for the seven-year lag ($S=7$) model, 432 for the eight-year lag ($S=8$) model, and 393 for the nine-year lag ($S=9$) model, respectively. The number of companies is 45 for the non-lag, one-year lag, two-year lag, three-year lag, and four-year lag model, 43 for the five-year lag and the six-year lag model, 42 for the seven-year lag model, 39 for the eight-year lag and nine-year lag model, respectively.

(2) We also tried estimating the models whose dependent variable is logarithm of "the track maintenance cost per operating kilometers" without using logarithm of the operating kilometers as an independent variable. However, the results did not change substantially. This suggests that the lack of variation of the operating kilometers within the companies does not affect the results significantly. Therefore, we mention the estimation results of the equation (4) only.

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