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The Impact of Market Competition on High-Speed Rail Service Quality: Does Monopoly Slow Down a Bullet Train?*

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Abstract

When Japan National Railways (JNR) was privatized into six regionally monopolistic railway corporations in 1987, there emerged exceptional areas where the industrial structure of railway transportation happened to be duopolistic due to an operational reason. Leveraging on this natural experimental setting arising from the privatization of JNR, we estimate the impact of market competition on the service quality i.e., speed and scheduling of a high-speed rail (HSR) run by an oligopolistic service provider. The paper shows that the change in time costs is significantly lower in those segments where HSR is competing with a conventional rail, and that such effect is larger for the shorter-distance markets where the competition is presumably more intensive.

JEL codes: R41, R48

Keywords: High-speed rail, Market competition, Travel time, Difference in differences

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1 Introduction

Japan National Railways (JNR) –a state-owned public corporation that provided railway services nation-wide– was dismantled into six regional railway companies in 1987. As a result of dismantling of JNR, each of six railway companies is in charge of both the Shinkansen high-speed rail (HSR) and a conventional rail in its respective region. There emerged, however, a limited number of areas with an increased level of market competition, where HSR and conventional rail are operated by two separate companies due to an operational reason. By utilizing this exogenous variation in the competitive pressure from a conventional rail, this paper measures the impact of market competition on supply behaviors of an oligopolistic HSR transport service provider. Specifically, we obtain from published timetables the change in time costs namely the in-vehicle time and schedule delay of traveling on a HSR before and after the JNR's privatization. The paper has found that the change in users' time costs of using HSR are significantly higher in the area where railway service is monopolized relative to the area where it is duopolized. We have also found that such effect is larger for the trip distance of 30-40km reflecting that the conventional rail acts as a closer competitor to HSR in shorter-distance markets.

As its start of privatization process in 1987, JNR was geographically divided into six Japan Railway (JR) companies. In principle, each of them is in charge of both HSR and parallelly running conventional rail in the designated region. Exception to this principle is greater-Tokyo and greater-Osaka areas, where they are operated by two separate JR companies. While JR Central operates the HSR all the way from Tokyo to Osaka, conventional rail services are provided by JR East and JR West in the vicinity of Tokyo and Osaka terminals. This created a difference in the intensity of market competition where HSR and conventional rail services are either monopolized or duopolized after the privatization. This conforms the design of the current research that measures the difference in the impact of duopoly and monopoly before and after the privatization of railway services.

Shinkansen, as known as a "bullet train", started running in 1964. The zero series, a bullet-shaped train car designed exclusively for Shinkansen ran on the newly developed track of 552.6-km length between Tokyo and Osaka at the maximum operational speed of 210 km/h. It connected these two largest cities of Japan in 3 hours and 10 minutes, which is less than a half of the fastest conventional express trains' at that time. As a result, there are two parallel rail tracks that connect major cities between Tokyo and Osaka, namely, Shinkansen HSR and the conventional rail. Table 1 summarizes the differences between these two modes of rail transport along this largest trunk route in Japan.

On April 1st, 1987, Japan National Railways (JNR) was divided geographically into six Japan

Table 1: Characteristics of Shinkansen and conventional rail in 1965.

	Shinkansen (HSR)	Conventional Rail
Maximum speed	210 km/h[1]	110 km/h
Average speed[2]	171.8 km/h[1]	86.0 km/h
Minimum travel time[2]	3 hrs 10 mins[1]	6 hrs 30 mins
Gauge	1,435 mm	1,067 mm
Minimum curve radius[2]	2,500 m	400 m
Total length of tunnels[2]	68.0 km	27.0 km
Road crossings	none	about 1,100
Length of a train car	25.0 m	20.5 m
Width of a train car	3.38 m	2.95 m

Notes: [1]These values are after the one-year initial inauguration period of Shinkansen HSR. [2]These values are between Tokyo and Osaka. Data source is Japan National Railways.

Table 2: Operators of railways between Tokyo and Osaka after dissolution of JNR.

	Segment		
Type of Service	Tokyo-Atami	Atami-Maibara	Maibara-Osaka
High Speed Rail	JR Central	JR Central	JR Central
Conventional Rail	JR East	JR Central	JR West
Distance	104.6 km	341.3 km	106.7 km

Railway (JR) companies as shown in Figure 1.[1] In principle, each of six JR companies provides both the HSR and conventional rail services in the designated region.[2] For example, JR East is in charge of the area east of Atami city including greater Tokyo, and JR West is covering western part of mainland Japan beyond Maibara city including greater Osaka. One of the exceptions to this principle is HSR service between Tokyo and Osaka. While the provision of conventional rail services between Tokyo and Osaka is divided into three companies at Atami and Maibara as mentioned above, HSR is operated throughout by one single company, namely JR Central for practicality of operation. This situation is summarized in Table 2.

When these six JR companies were founded, they were regarded as special corporations because JNR Settlement Corporation –a public entity to settle the huge debt that JNR left– still owned the entire share. JNR was badly in red. Its huge debt was not only due to investment, but rather by cumulated operational losses over the years. JR companies took over about a third of JNR's debt of 37.1 trillion yen back then, while the two thirds were supposed to be repaid by selling their shares in the stock market later on. Though they were publicly owned, the new JR companies were expected

[1]They are JR Hokkaido, JR East, JR Central, JR West, JR Shikoku, and JR Kyushu. Another company in charge of cargo, Japan Freight Railway Company, was also established.

[2]There is no HSR in JR Shikoku area.

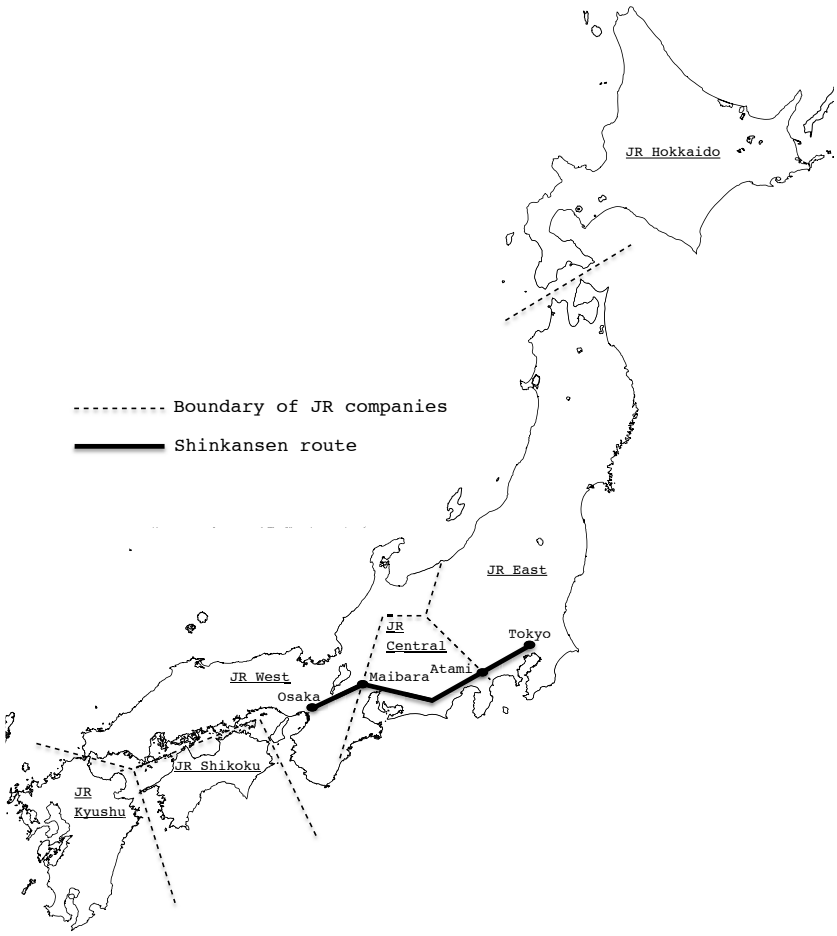


Figure 1. Geographical locations of JR companies and Shinkansen route between Tokyo and Osaka.

to make as much profit as possible and pay back the debt as soon as possible. JR companies who inherited a large, if not excessive, number of employees and unprofitable routes in rural areas, had to improve their operational efficiency greatly in order to be profitable.

Three JR companies in mainland Japan, namely JR East, JR Central, and JR West did well by exploiting the market power as regional monopoly. Price back then was set by the government based on their cost with a fixed markup. Their high cost implied high price set by the government. This high price enabled them to cash in their market power as they improved their operational efficiency. JR East was listed on Tokyo Stock Exchange in 1993 and JR West was in 1996, followed by JR Central in 1997. By April 2006, all three companies' stocks were sold entirely to private share holders.

Until they were excluded in 2001, these three JR companies were regulated by JR Corporation Law.[3] Under the law, price change required government's approval. Indeed, price has not been changed since 1987 until January 1996, when three JR companies outside of mainland Japan for the first time requested system-wide price change and were granted approval. However, JR East, JR Central, and JR West did not change their prices even then, and in fact not ever since the start of JNR's privatization process until now.[4] We therefore measure the treatment effect of the market competition on time costs in the current paper. We focus on two time points when three mainland JR companies started and completed public listing, namely 1996 and 2006. These two years are compared to 1986, the year before the start of their privatization process.

Market competition is the most classic, if not the most important issue in Economics (cf. Chamberlin, 1933). In fact, there exists a vast theoretical literature on the role and impact of market competition (e.g. Abbott, 1955). Theory tells that competition increases quality when prices are regulated. However, when firms set both price and quality, the impact of competition is ambiguous (e.g., Spence, 1975). Some models predict competition increases quality (Tirole, 1988; and Pepall et al., 2005).[5] In contrast to the theoretical literature, empirical literature on causal inference of competition impact is limited.[6] Masta (2011) examines the effect of competition in the US supermarket industry utilizing Walmart store openings as an exogenous shock to local markets. Busso and Galiani (2015),

[3]Other three, JR Hokkaido, JR Shikoku, and JR Kyushu are still currently regulated under the law.

[4]This is mostly due to political pressure that privatization cannot be associated with price increase. However, ever since JR companies are established Japanese economy has been facing continuous deflation, that effectively increased the relative price. There is common political sentiment, or phobia, among formerly state-owned and then privatized regional monopolies such as highway, electricity, and railway companies, regarding discussing about prices, especially when they are being profitable.

[5]See appendix for the theoretical illustration in our context.

[6]There exist several papers attempting to identify the impact of market competition. For instance, Domberger and Sherr (1989) is on the market for conveyancing legal services in England and Wales; Hoxby (2000) on school education in the US; Mazzeo (2003) on the US airline industry; Amiti & Khandelwal (2013) on the manufacturing industry. l Some of them exploit quasi/natural experimental settings to isolate the impact of competitive environment, such as the timing of a policy implementation and geographical features. However, none of these studies controls unit-intrinsic heterogeneity mainly because they rely on cross-sectional variations in the degree of competition.

which is the first and sole experimental study in the literature, explores the impact of competition among grocery stores on prices and quality of goods in the Dominican Republic, randomizing the entry of new grocery stores in a conditional cash transfer program. Background of this limited empirical literature is a lack of "good" exogenous variation, while experiment is almost impossible. This is largely due to the fact that the intensity of market competition is typically time-invariant, and therefore only cross-sectional data are available. As a result, in many studies heterogeneity between units in treatment and control is seriously large, which leads to confounding say, by self selection. Reverse causality is also likely to bias the result if a company with high product quality kicks out others and thus reduces competition. This paper adds to a few empirical studies that measures the impact of competition by using exogenous variation arising from a natural experimental setting along with unit-of-observation fixed effects.

In the next section we explain our data and empirical strategy in detail. Section 3 presents the results. Section 4 concludes the paper.

2 Sample Design and Identification Strategy

As can be seen in Table 1, those segments, Tokyo-Atami and Maibara-Osaka are duopolized after privatization, while Atami-Maibara segment remained as monopoly. Our unit of analysis is a directional pair of Shinkansen stations, one being the origin and another being the destination, which we refer to as an OD pair. We group OD pairs into two; one with those OD pairs such that the entire journey is contained in the duopolized area, and another with those such that both their origin and destination stations are in the monopolized area. We refer to the former as the treatment group and the latter as the control group. At the time of privatization, there were two intermediate stations between Tokyo and Atami; six were between Atami and Maibara; and there was one between Maibara and Osaka.[7] Therefore the number of directional OD pairs is 18 in the treatment area and it is 56 in the control area.

Our outcome variable is users' time cost. User's time cost of a trip between an OD pair is a sum of in-vehicle time and schedule delay. Schedule delay is the time difference between the train arrival and the passenger's target arrival time. In-vehicle time and schedule delay on three time points before and after the privatization of JNR corporation in 1987 is collected, namely for years 1986, 1996 and 2006 from published timetables. Base year in our data is 1986, the year before the start of privatization process. Treatment year is as mentioned above, either 1996 or 2006. Duopoly dummy takes the value

[7] Shinkansen stations then are, from east to west, Tokyo, Yokohama, Odawara, Atami, Mishima, Shizuoka, Hamamatsu, Toyohashi, Nagoya, Gifu, Maibara, Kyoto, and Osaka.

Table 3: Key characteristics of OD pairs.

	Average	*Standard Deviation*	*Minimum*	*Maximum*
1. Distance (km)				
in monopoly area	155.8	92.4	16.1	341.3
in duopoly area	64.7	29.9	20.7	106.7
2. Values in 1986:				
In-vehicle time	54.1	36.1	10.0	140.2
Schedule delay	17.2	2.92	9.1	25.7
Travel Time	71.3	37.1	25.3	160.1
3. Values in 1996:				
In-vehicle time	58.8	42.1	8.0	158.9
Schedule delay	17.1	2.42	9.0	23.2
Travel Time	75.9	43.0	23.5	180.2
4. Values in 2006:				
In-vehicle time	54.8	40.0	7.1	151.3
Schedule delay	16.6	3.82	5.7	27.7
Travel Time	71.5	41.3	20.3	170.8

Notes: The number of OD pairs is 56 in monopoly area and 18 in duopoly area. The number of observations is 74 for all years. Distances are in kilometers. In-vehicle time, schedule delay, and travel time are in minutes.

of one in the treatment year if the OD pair is in the duopolized area, and zero otherwise.

In order to measure the time cost of an OD pair, we generate 50 hypothetical target arrival times from a uniform distribution between 6:00AM and 12:00 midnight. This reflects the fact that Shinkansen provides HSR service for inter-city travel that do not exhibit obvious peak hours, and also that by regulation the operation of Shinkansen is restricted from 6:00AM up to midnight. For each of these 50 target arrival times a train that minimizes the user cost is picked, and both time and monetary costs are recorded for all OD pairs. We assume that late arrivals are not allowed.[8] Then the average of these time values is computed to yield the in-vehicle time and schedule-delay data for each OD pair. This procedure is repeated for three years, 1986, 1996 and 2006.

Table 3 summarizes the data. Table 4 presents the balance checks of baseline characteristics between OD pairs in monopoly and duopoly areas.

3 Effects of Railway Market Competition on HSR

Table 5 shows the average travel time of OD pairs in each area, as well as their differences and changes. Columns (i) and (ii) show the data of the OD pairs in monopoly and duopoly areas respectively. Column (iii) gives the difference between the two, i.e., duopoly minus monopoly. Panel 1 gives the average

[8] We drop the target arrival time when it is not possible to leave on the same day as the target arrival time is early in the morning.

Table 4: Balancing test of baseline characteristics

	Control (monopoly)		Treatment (duopoly)		(2)-(4)
	Obs.	Mean (Std.Dev.)	Obs.	Mean (Std.Dev.)	Diff. [Std.Err.]
Time cost per distance (min./km.)	(1)	(2)	(3)	(4)	(5)
Time spent in-vehicle / dist.	56	0.484	18	0.493	-0.009
		(0.116)		(0.089)	[0.030]
Schedule delay / dist.	56	0.145	18	0.183	-0.038
		(0.140)		(0.122)	[0.037]
Total time cost / dist.	56	0.629	18	0.675	-0.046
		(0.186)		(0.186)	[0.050]

Notes: Standard deviations and standard errors are given in parentheses and square brackets, respectively.

Table 5: Average travel time before and after the privatization of JNR and their differences.

	OD pairs by Area		
	Monopoly (i)	Duopoly (ii)	Difference, Duopoly-Monopoly (iii)
1. Values in the base year			
Average travel time in 1986	79.81	44.72	-35.09***
	(38.16)	(14.64)	[6.15]
2. Values in 1996 in comparison to the base year			
Average travel time in 1996	86.86	41.77	-45.09***
	(43.49)	(13.77)	[6.66]
Average change: 1986-1996	7.06	-2.95	-10.01***
	(6.48)	(2.85)	[1.09]
3. Values in 2006 in comparison to the base year			
Average travel time in 2006	81.85	39.12	-42.73***
	(41.83)	(13.98)	[6.49]
Average change: 1986-2006	2.04	-5.60	-7.64***
	(5.49)	(3.09)	[1.03]

Notes: Standard deviations are given in parenthesis. Robust standard errors are in square brackets. The sample consists of 56 OD pairs in monopoly area and 18 OD pairs in duopoly area for each of years 1986, 1996, and 2006. All values are measured in minutes. Significance at 0.1% is indicated by ***; 1% is by **; 5% is by *; and 10% is by +.

Table 6: Reduced form regressions for natural log of time costs.

	(a) *1996 as treatment year*			(b) *2006 as treatment year*		
	(1)	(2)	(3)	(4)	(5)	(6)
Duopoly dummy	-0.138***	-0.147***	0.155	-0.150***	-0.207**	1.755***
	(0.018)	(0.036)	(0.504)	(0.026)	(0.069)	(0.468)
Distance×Duopoly dummy		0.015	-2.281		0.089	-14.89***
		(0.044)	(4.327)		(0.078)	(4.108)
Distance^2×Duopoly dummy			5.830			37.37**
			(12.51)			(11.78)
Distance^3×Duopoly dummy			-6.128			-37.85**
			(14.59)			(13.51)
Distance^4×Duopoly dummy			2.287			13.47*
			(5.868)			(5.344)
Adj. R^2	0.971	0.970	0.970	0.899	0.901	0.918

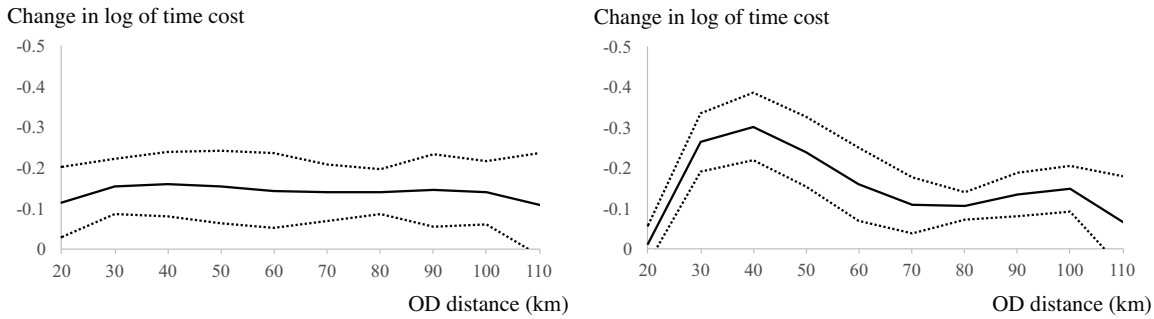
Notes: Robust standard errors are given in parentheses. The sample consists of 148 observations, and the base year is 1986 for both treatment years of 1996 and 2006. Distance is measured in 100 kilometers. All models include year and OD fixed effects. Significance at 0.1% is indicated by ***; 1% is by **; and 5% is by *.

travel time in monopoly and duopoly areas and their differences before the privatization of JNR in 1986. Panel 2 gives the average travel time in 1996 for both areas and their difference, as well as their changes between 1986 and 1996. Panel 3 gives those in 2006 as well as their changes between 1986 and 2006.

Average travel time is relatively longer in the monopoly area than in the duopoly area due to the longer average distance as shown in Table 2. The change in the travel time is also larger for the OD pairs in monopoly area. The average treatment effect of duopoly on travel time reduction since 1986 measured as the difference in differences is about 10 minutes in 1996, and 7.6 minutes in 2006.

In order to account for the difference in distance of OD pairs in two areas, in the next section we analyze the the reduced form models. In our estimation we take natural logarithm of the travel time. We regress this log of travel time against Duopoly dummy and its interaction terms with polynomials of distance, along with year and OD fixed effects. We look for a heterogeneous impact of market competition with respect to distance, as conventional rail is a closer substitute for those OD pairs with shorter distances. It is thus expected that the effect of market competition is augmented in these short-distance markets. Besides, scatter plot of the travel time over distance shows their relation has two humps. Given this, polynomials of distance up to the forth order are incorporated in the form of cross terms to the duopoly dummy.

Table 6 presents the reduced form regression results. Among them, the results in columns (1) and



(a) Treatment effect by distance over the period of 1986-1996 (b) Treatment effect by distance over the period of 1986-2006

Notes: Dotted line shows the 95% confidence interval of the treatment effect at each distance. Values are computed based on the estimates of the model with interaction terms of duopoly dummy and forth-order polynomials of distance.

Figure 2. Treatment effects as the change in log of time costs by OD distance.

(4) show that the travel time became significantly lower by about 14% by 1996 and 15% by 2006 in those segments in duopoly area where HSR is competing with conventional rail, relative to those segments in monopoly area. This tells us that the bullet train slowed down significantly in monopoly area, relative to duopoly area, after the privatization.

Interaction terms of the duopoly dummy with polynomials of distance seems to be insignificant for the treatment year of 1996 as shown in Panel 1. However, by looking at each distance, treatment effect is significant over the range of relevant OD distances in duopoly area. Figure 2 presents the treatment effect as the change in log of travel time by relevant OD distance in duopoly area, based on the estimates of the interaction terms of the duopoly dummy and the forth order polynomials of distance in Column (5) of Table 6. The figure shows that the treatment effect is significant for the period of 1986 to 1996 over the distance between 20 to 100 km, which is the range of OD distance in duopoly areas. The effect in the duopoly area is about 10% reduction in travel time, and it is consistent over the range of distance. For the longer period of 1986 to 2006, treatment effect is more prominent in shorter distances of 30 to 50 km. The magnitude of travel time reduction in duopoly area is larger and is over 20% for these distances. This indicates that the competition against the conventional rail is more intense in these markets.

4 Conclusion

This paper investigated the impact of market competition on the service quality of intercity high-speed rail (HSR) transport by an oligopolistic service provider. When Japan National Railways (JNR) was privatized into six regionally monopolistic railway corporations in 1987, there emerged areas where the

industrial structure of railway transportation happened to be duopolistic due to an operational reason. Leveraging on this natural experimental setting arising from the privatization of JNR, we conducted a difference-in-difference analysis to estimate whether the change in speed and scheduling of HSR has made users worse off in the segment where railway service provision is monopolized, relative to other segments where HSR and conventional rail are competing each other, after the privatization of Japan National Railways. The paper showed that the change in time cost is significantly lower in those segments where HSR is competing with conventional rail, and that such effect is larger for the trip distance of 30 to 40km where the competition is presumably more intensive.

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Appendix: Market Structure and Travel Time of Parallel Railways

We here illustrate a situation where monopoly increases the users' time cost under a plausible setting. Let us suppose there are two types of train services in parallel denoted by $i = 1, 2$. Demand of type i train service is a function of its own price as well as that of another:

$$Q_i = Q_i(P_i, P_j)$$

for $i \neq j \in \{1, 2\}$, where Q_i is the demand and P_i is the price of the type i train. Here, $Q_{ii} = \partial Q_i / \partial P_i < 0$ and since railways are substitutive $Q_{ij} = \partial Q_i / \partial P_j > 0$. For simplicity we assume $Q_{iij} = 0$. Price is consisted of two parts, namely, ticket price say f_i and user's time cost t_i hence

$$P_i = f_i + t_i$$

for $i = 1, 2$. Time cost t_i of the type i train determines the amount of required investment $K_i(t_i)$. We assume $K_i > 0$, $K_i' < 0$ and K_i'' is positive and monotonic.

Duopoly owns either type while monopoly owns both types of train services. Then duopolist's problem is to maximize its profit with respect to ticket price f_i and time cost t_i which can be written as

$$\begin{aligned} \max_{f_i, t_i} \pi_i &= f_i Q_i(P_i, P_j) - K_i(t_i) \\ s.t. \quad & P_i = t_i + f_i \end{aligned}$$

given P_j for $i \neq j \in \{1, 2\}$. The first-order conditions are

$$\begin{aligned} Q_i + f_i Q_{ii} &= 0 \\ f_i Q_{ii} - K_i'(t_i) &= 0 \end{aligned}$$

where we define $Q_{ii} = \partial Q_i / \partial P_i < 0$. Let t_i^D and f_i^D be the solution to the above, and let $P_i^D = t_i^D + f_i^D$.

Monopolist's problem in turn becomes

$$\max_{f_1, f_2, t_1, t_2} \pi_1 + \pi_2$$

and the corresponding first-order conditions are

$$\begin{aligned} Q_i + f_i Q_{ii} + f_j Q_{ji} &= 0 \\ f_i Q_{ii} + f_j Q_{ji} - K_i'(t_i) &= 0 \end{aligned}$$

for $i \neq j \in \{1, 2\}$. Let t_i^M and f_i^M be the solution to the above, and let $P_i^M = t_i^M + f_i^M$. We can rewrite these first-order conditions by using a parameter $\delta \in \{0, 1\}$:

$$\begin{aligned} Q_i &= -K_i'(t_i) \\ f_i D_i^i + \delta f_j D_i^j &= K_i'(t_i) \end{aligned} \tag{1}$$

as $\delta = 0$ corresponds to duopoly and $\delta = 1$ to monopoly.

Travel time under price regulation

Suppose for now that the fare is effectively restricted as in our context. Then duopolist's profit-maximization problem becomes

$$\begin{aligned} \max_{t_i} \pi_i &= f_i Q_i(P_i, P_j) - K_i(t_i) \\ s.t. \quad & P_i = t_i + f_i \end{aligned}$$

which further yields the first-order condition as

$$f_i Q_{ii} = K_i'\left(t_i^D\right)$$

for $i = 1, 2$. We assume that the second-oder condition is globally satisfied implying that $f_i Q_{iii} < K_i''$.[9] In turn, monopolist's problem is now simply

$$\max_{t_1, t_2} \pi_1 + \pi_2$$

and the corresponding first-order conditions are

$$f_i Q_{ii} + f_j Q_{ji} = K_i'\left(t_i^M\right)$$

[9]Here we denote by $Q_{iii} = \partial Q_{ii} / \partial t_i$.

for $i \neq j \in \{1,2\}$. The fact that $f_j Q_{ji} > 0$ and $f_i Q_{iii} < K_i''$, along with $K_i' < 0$ yields that $t^M > t^D$.

A case of symmetric parallel railways

Here, we consider a situation where both price and the speed of railways –i.e. the time cost– are endogenously determined. For analytical tractability we specify the demand and investment functions assuming symmetry between the two parallel railways as follows:

$$Q_i = a_0 - a_1 P_i + a_2 P_j$$

$$K_i = k_0 - k_1 t_i + \frac{1}{2} k_2 t_i^2$$

for $i \neq j \in \{1,2\}$, with all parameters being positive, and $a_1 > a_2$. Then the first order conditions (1) imply

$$\begin{aligned} a_0 + (a_2 - a_1)(t + f) &= k_1 - k_2 t \\ (a_1 - \delta a_2) f &= k_1 - k_2 t \end{aligned}$$

where, by symmetry we let $t = t_i$ and $f = f_i$ for both $i = 1, 2$. Solving these gives the time cost t as a continuous function of δ

$$t(\delta) = \frac{(k_1 - a_0)(a_1 - \delta a_2) + (a_1 - a_2) k_1}{(k_2 - a_1 + a_2)(a_1 - \delta a_2) + (a_1 - a_2) k_2}.$$

This generates $t^M = t(1)$ and $t^D = t(0)$ and hence

$$t^M - t^D = t(1) - t(0).$$

Using continuity of $t(\delta)$ with respect to δ rewrites the above as

$$t^M - t^D = \int_0^1 t'(\delta)\, d\delta$$

where

$$t'(\delta) \quad = \quad [a_2 (a_1 - a_2)(a_0 k_2 - (a_1 - a_2) k_1)] g^{-2}$$

and $g = (k_2 - a_1 + a_2)(a_1 - \delta a_2) + (a_1 - a_2) k_2$. Now, $K_i'(t_i) < 0$ implies $t < k_1/k_2$ which further implies that

$$a_0 k_2 - (a_1 - a_2) k_1 \quad > \quad 0$$

This, together with $a_1 > a_2 > 0$, yields that $t^M > t^D$.