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Comparing Competition and Regulated Monopoly in a Railway Market: An Agent-Based Modeling Approach

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Abstract

This paper introduces an agent-based model of a passenger railway line. The model is used for comparing the welfare of the railway market under unregulated duopoly and monopoly with maximum-price regulation. In the model, the railway operators gradually adjust passenger fares and eliminate train departures until the market reaches steady state. The paper analyses the steady-state data generated using two sets of parameter values. It finds that for most maximum-price levels, including the price that would be chosen by an unregulated monopoly, the total welfare in the monopolistic market is significantly lower compared to the duopoly market. However, there are some levels of maximum price which produce similar or even higher welfare than the duopoly market. The paper suggests that if correctly implemented, a simple maximum-price regulation may generate welfare outcomes comparable to competition.

Keywords: open access; regulation; railway; welfare

JEL Classification: L11, L92, C63

1. Introduction

The main component of the European railway reform is the separation of infrastructure and transport services, which opens the possibility of competition in the market. Two common competitive regimes are open access and franchising. Under open access, more train companies may operate in the market. While open access is an option in the markets which are not under public obligation (approximately 10% of European markets), it is used significantly less frequently. Under franchising, the market with specified terms of service is usually auctioned to a single operator. Franchising is used particularly for subsidized markets, but it can be implemented also in profitable routes. [4]

The goal of the paper is to discuss the welfare effects of monopoly with specified maximum permitted fare (franchising) as compared to an unregulated duopoly (open access). For this purpose, the paper introduces an agent-based model of a railway line. The construction of the model is similar to the model presented in [2] and [3]. The model contains one or two operators each with more trains departing every day. In sequential steps, the firms adjust prices and departure times of their trains until they reach steady state. Finally, the steady-state outcomes are used for comparing the monopolistic and duopolistic market structures.

Even though the agent technology is used in transport logistics, especially in scheduling, dispatching, optimization of train coupling and sharing systems, or allocation of railroad tracks (see [1] for a survey), the presented model uses a specific market-based approach which determines not only the optimal timetable, but also prices and welfare outcomes. Moreover, the paper addresses the topic of regulation of a monopolistic railway operator. There are several empirical studies dealing with the problem of franchising regulation (see [5] or [6]). But to our knowledge, there are no papers using agent-based simulation for comparing the welfare under competition and franchise contract with the maximum price regulation.

The paper has the following structure. Section 2 introduces the agent-based model of a passenger railway line. Section 3 presents the data generated by the model and the empirical methodology. Section 4 shows the results of the analysis. And Section 5 concludes.

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2. Model

This section presents an agent-based model of a passenger railway line. The model is implemented in the modeling environment Netlogo 5.0.1. In the model, agents behave according to specific rules in a given order. In this section, I describe the model in the same order used in the simulations. In each simulation, the model is first initialized and then runs for T periods.

In the initialization phase, the model creates the landscape, passengers and sets initial train departure times. The landscape is a horizontal line of 240 patches (in Netlogo, a patch is a square field whose side can be used as a measure of distance). The line represents 24 hours at a railway station in the departure city. As the total length of the line is 240 patches, a patch represents 6 minutes.

In the landscape, the model locates 1,000 passengers which may differ in two respects. First, in their reservation price p_r which is the maximum price they are willing to pay for a train ticket to the destination city. The reservation price of a passenger is drawn from a uniform distribution between the minimum and maximum reservation price. Second, they differ in their location on the horizontal line. The location represents the time at which passengers arrive at the station in the departure city, or alternatively the arrival time that would suit them best. For instance, a passenger located at 125 arrives, or would like to arrive at the station at 12.30 p.m. In order to approximate a realistic time pattern, I draw the location of a half of passengers from normal distribution with the mean of 70 and standard deviation of 30 (morning rush hours) and of another half of passengers with the mean of 160 and standard deviation of 30 (evening rush hours). If the drawn location is higher than 240 or lower than 0, the passenger is placed randomly between 0 and 240.

Suppose that there are either one or two train operators in the market. During the initialization, the model creates as many train departures as possible, sets the initial fare to 0, and determines the departure times. Let us assume the smallest technologically feasible difference between the departure times of trains is 10 minutes (for instance because all the trains on the connection depart from the same platform). Hence, the model creates 144 trains departing every 10 minutes from 0.00 to 23.50 if there is only one operator. In a duopoly, operator A has 72 trains leaving every 20 minutes from 0.00 to 23.40 and operator B 72 trains departing every 20 minutes from 0.10 to 23.50.

After the initialization phase, the model evolves in periods. Each period has three or four phases: 1) passengers choose their departure times, 2) the operators calculate profits or losses of the individual trains, 3) in certain periods, the operators may eliminate one train, and 4) the operators adjust prices.

1) Choice of a train – The variables relevant for the optimal choice of passenger j are her reservation price p_{rj}, the price of train i at time t p_{it}, the waiting time in hours h_{ijt} and the per hour weighting cost $w > 0$. Passenger j chooses the train with the lowest $p_{it} + wh_{ijt}$ if $p_{rj} > p_{it} + wh_{ijt}$ and no train otherwise. The choice of no train means that the passenger uses a different mode of transport (bus, airplane, car), or that she does not travel at all. Therefore her reservation price is likely to depend on the availability of alternative transport modes and her preference for train transport.

2) Profit calculation – The profit of train i in period t equals to $\pi_{it} = p_{it}q_{it} - F$, where q_{it} is the number of passengers on the train and F are fixed and quasi-fixed costs.

3) Exit – In certain periods, called *exit periods*, each operator considers eliminating the train with the lowest profit. If the profit of the operator without the train is higher than with the train given the prices of all other trains, the train is eliminated. Otherwise, the train remains in operation. If the exit of the least profitable train does not increase the operator's profit, it closes the second least profitable train in the next exit period. This continues until the operator considers closing each of less profitable half of all its trains. Then again, it starts from the least profitable train.

4) Adjusting prices – The prices of each train may increase or decrease by $\varepsilon > 0$, or remain constant. There are two possible pricing strategies: uniform and local pricing. In this paper, I assume that firms use uniform pricing, which means that all trains of one operator charge the

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same price. Hence in period t, each operator chooses the price $p_{it} + \varepsilon$, $p_{it} - \varepsilon$ or p_{it} that maximizes its profit (given the price of the other operator if there are two operators in the market).

Each simulation lasts for T periods and has two phases: For the first T_A periods, firms adjust prices given no trains exit the market. Then for the remaining T_C periods, firms consider eliminating trains and at the same time adjust prices. The exit period is every c^{th} period in the second phase. If there is only one train operator, it considers eliminating a train every c^{th} period. If there are two operators, operators may eliminate one train every c^{th} period in turns. That is, each operator can change its timetable every $2c^{th}$ period. The second phase has to be long enough so that the actual prices and the timetable are relatively stable in the last T_E periods. However, the variables may vary slightly even in these periods, or some variables may evolve in cycles. Therefore, the model reports averages of the key variables over the last T_E periods.

3. Data and methodology

In this section, I describe the data generated by the model and discuss the empirical strategy used for analyzing the data. The data is generated using the function Behavior space in Netlogo 5.0.1. I consider data generated in two scenarios with the following common parameter values: The fixed cost is $F = 1000$, the waiting cost $w = 100$, pricing step $\varepsilon = 2$, and the exit period occurs every $c = 4$ periods. The total number of periods in each run is $T = 1{,}000$. The price is adjusted for the first $T_A = 200$ periods and the variables are measured for the last $T_E = 100$ periods. In scenario 1, the reservation price ranges from 100 to 200 and in scenario 2, the reservation price ranges from 100 to 400.

In each scenario, I compare the setting with two firms to the setting with 1 firm using maximum prices $p_c = \{10, 20, 30, \ldots, p_m\}$, where the price p_m is higher than the price that would be chosen by an unregulated monopoly. For each setting, I run 10 random initializations of the model with random seeds 1 to 10 using random-seed function in Netlogo 5.0.1.

Each simulation generates the following variables:

- Quantity Q is the number of passengers who bought a ticket (called *customers*) averaged over the last $T_E = 100$ periods.
- Price P is the average price paid by customers averaged over the last $T_E = 100$ periods.
- Number of trains M is the total number of trains departing from the railway station averaged over the last $T_E = 100$ periods.
- The waiting cost C is the sum of the weighting costs of customers averaged over the last $T_E = 100$ periods.
- Total profit Π is the sum of the profits of individual trains π_{it} averaged over the last $T_E = 100$ periods.
- Consumers' surplus CS is sum of individual surpluses of customers calculated as $p_{rj} - p_{it} - wh_{ijt}$ averaged over the last $T_E = 100$ periods.
- Total welfare W is the sum of total profit Π and consumers' surplus CS.

Each monopoly parameterization is compared to a situation in which the price is found by the duopoly market in the following way. I run the following simple OLS regression:

$$X = \alpha_0 + \alpha_1 NO\_FIRMS, \qquad (1)$$

where X may be one of the variables presented in the previous paragraph and *NO_FIRMS* is a dummy variable that is equal to 0 if there are two firms in the market, and to 1 in the case of monopoly. In the following subsection, I report coefficients α_1 and heteroskedasticity-consistent standard errors (hc1 in R). These numbers show the direction and size of the effect and indicate whether the effect is statistically significant.

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4. Results

This section compares the welfare effects of a monopoly with price regulation and two-firm competition using the data described in the previous section. The data is analyzed in the software environment R. The Table 1 compares the situation under regulated monopoly and duopoly in scenario 1 with the reservation price ranging from 100 to 200. The second row shows the means and standard errors of the total welfare W, number of firms M, number of customers Q, and the waiting cost C. The rest of the table presents the change in number of trains ΔM, number of customers ΔQ, total waiting costs ΔC, and total welfare ΔW due to the shift from duopoly to monopoly in scenario 1. The rows show different maximum prices p_c. While the mean of the average price P under duopoly is 80, the price charged by an unregulated monopoly is approximately 99. Therefore the maximum price is always binding except for the situation with the maximum price $p_c = 100$.

In the first column, we can see that the total welfare is statistically significantly lower for all maximum prices except for p_c = 60, 70, and 80. The change in total welfare can be decomposed in three parts. First, total welfare is higher due to the lower number of trains (i.e. due to the lower total fixed costs) under regulated monopoly – the change in the number of trains ΔM is significantly negative and increasing in the maximum price p_c. Second, since the train departures are less frequent, the waiting costs are so high for some passengers that they stop using trains. Table 1 shows that the change in the number of customers ΔQ is significantly negative for all relevant prices. With increasing maximum price p_c, ΔQ first increases thanks to the increasing number of trains, and then decreases because of the increasing train fares. Each lost customer reduces the total welfare in the market by her reservation price which ranges from 100 to 200. And finally, the lower number of departures increases the total waiting cost of the remaining customers. The change in waiting cost ΔC is significantly positive and decreasing in p_c because of the increasing number of trains M.

Table 1. The effect of monopoly with regulated price – scenario 1

Duopoly	mean W (s.e.)	mean M (s.e.)	mean Q (s.e.)	mean C (s.e.)
	95.337 (2.378)	35.8 (2.25)	950 (23.5)	13,054 (1,034)
Maximum price	ΔW (s.e.)	ΔM (s.e.)	ΔQ (s.e.)	ΔC (s.e.)
$p_c = 10$	-38,768 (2,720))	-31.3 (0.76)	-274 (30.1)	33,004 (588)
$p_c = 20$	-21,278 (1,152)	-28.9 (0.73)	-124 (12.3)	33,004 (588)
$p_c = 30$	-9,703 (1,210)	-26.7 (0.73)	-61 (9.4)	27,935 (742)
$p_c = 40$	-6,607 (1,308)	-25.6 (0.74)	-55 (9.0)	24,117 (545)
$p_c = 50$	-2,931 (922)	-24.0 (0.74)	-55 (9.0)	20,040 (534)
$p_c = 60$	-1,516 (1,156)	-22.7 (0.81)	-65 (10.7)	16,089 (575)
$p_c = 70$	101 (1,179)	-20.3 (0.91)	-70 (10.9)	11,719 (487)
$p_c = 80$	400 (902)	-17.8 (0.88)	-82 (9.3)	7,661 (483)
$p_c = 90$	-2,237 (932)	-15.5 (0.83)	-116 (8.9)	4,182 (395)
$p_c = 100$	-7,616 (1,112)	-14.5 (0.81)	-172 (9.7)	1,861 (361)

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Table 2 compares the market situations under duopoly and regulated monopoly in scenario 2 in which the reservation prices range from 100 to 400. Table 2 has the same structure as Table 1. The first row presents means and standard errors of total welfare W, number of trains M, total sales Q, and waiting costs C under duopoly. Compared to scenario 1, higher reservation prices lead to significantly higher total welfare, number of consumers, and waiting costs. The remaining rows show coefficients and standard errors of regression equation (1). In Table 2, I present only a part of the relevant range of prices. For the maximum prices p_c = {10, 20, 30, …, 170}, the changes in total welfare ΔW, the number of firms ΔM and customers ΔQ are significantly negative and increasing in the maximum price p_c. The change in the waiting cost ΔC is significantly positive and decreasing in p_c. The table presents more interesting price range from p_c = 180 to 300. The signs and trends of the coefficients are similar to scenario 1. What is important, the change in total welfare is significantly negative or not statistically significant for all maximum prices p_c with one exception. The change in total welfare is significantly positive for the maximum price p_c = 260.

Table 2. The effect of monopoly with regulated price – scenario 2

Duopoly	mean W (s.e.)	mean M (s.e.)	mean Q (s.e.)	mean C (s.e.)
	297,550 (2,982)	33.7 (0.08)	996 (4.7)	17,870 (1,550)
Maximum price	ΔW (s.e.)	ΔM (s.e.)	ΔQ (s.e.)	ΔC (s.e.)
p_c = 180	−11,138 (1,576)	−23.0 (0.99)	−4.25 (1.81)	32,784 (1,498)
p_c = 190	−8,404 (1,945)	−22.3 (1.00)	−4.95 (2.09)	29,128 (1,718)
p_c = 200	−6,560 (1,545)	−21.8 (0.98)	−7.05 (1.81)	26,099 (1,374)
p_c = 210	−5,160 (1,473)	−20.9 (0.96)	−6.05 (2.15)	24,176 (1,066)
p_c = 220	−4,060 (1,493)	−20.1 (0.99)	−7.25 (2.15)	21,893 (1,248)
p_c = 230	−1,408 (1,131)	−18.3 (1.00)	−11.2 (1.82)	16,174 (940)
p_c = 240	−389 (1,413)	−16.7 (1.00)	−14.1 (3.25)	12,683 (688)
p_c = 250	1,522 (1,176)	−14.6 (0.97)	−13.3 (2.52)	8,916 (583)
p_c = 260	2,550 (1,001)	−10.9 (1.10)	−12.2 (1.81)	4,575 (646)
p_c = 270	−114 (1,029)	−7.9 (1.09)	−21.5 (2.68)	1,347 (539)
p_c = 280	−3,606 (1,258)	−3.8 (1.08)	−28.5 (3.02)	−1,387 (546)
p_c = 290	−8,093 (1,375)	−0.62 (1.50)	−38.5 (2.56)	−3,214 (670)
p_c = 300	−9,237 (1,626)	−0.52 (1.39)	−42.3 (3.83)	−3,338 (696)

In both scenarios, the market situation under the maximum price that generates the highest total welfare under monopoly is characterized by a lower number of trains compared to the duopoly market. This increases total welfare because the total fixed costs are lower compared to the competitive situation. On the other hand, it leads to higher waiting costs and lower number of customers in the market.

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5. Conclusion

The goal of the paper is to compare welfare outcomes under regulated monopoly and duopoly. In the model, operators adjust their prices and timetables in order to maximize profits. The findings therefore apply especially to unsubsidized markets and long-distance services, where net-cost contracts are preferred and the timetabling might be done by the operator. Using the model, the paper generates data for two different parameter combinations. The data suggest that for most levels of the maximum price, including the price of unregulated monopoly, total welfare under regulated monopoly will be significantly lower compared to the welfare under duopoly. At the same time, the data suggest that for a relatively narrow range of maximum prices, total welfare under monopoly may be comparable, or even higher than the welfare under competition. In this range of maximum prices, the number of train connections and the number of passengers using the monopolistic railway service is lower compared to the duopolistic market. Therefore, the paper suggests open-access policy might be preferable to competitive franchising with price regulation thanks to the effect of competition on the frequency of service, especially if the policy objective is not only to maximize welfare but also to increase the market share of railway passenger transport.

There are many opportunities for further research in this area. In order to get more reliable results, it would be useful to run simulations for more sets of parameter values. Furthermore, it would be beneficial to test the sensitivity of the results to changes in model assumptions. Most importantly, it would be interesting to test whether the findings of the model hold if the timetable is found using an entry algorithm instead of the exit algorithm used here. Furthermore, the paper presents only one of many possible application of the model. Most importantly, the model can be used for testing different types of monopoly regulations, or for evaluating specific franchise contracts.

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