Pricing and Capacity of a Congestible Highway with an Elastic Demand: Social Optimum, Second best, Privatization, and Vertical Disintegration

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1. Introduction

One of the purposes of this paper is to confirm that the socially optimal policies such as pricing and capacity of a congestible highway remains the same as conventional literature even using a spatial model of one-dimensional city. The paper considers a city with a highway stretching from the CBD into one direction where all residents of the city have to commute to CBD. Hoewever, there are imperfectly substitutive transportation means other than this highway, and thus the demand for the highway services are elastic to the price. Through the theoretical analysis the paper confirms that many of the relevant results are still holding: the optimal toll is equal to the congestion externality at each location; and the optimal capacity is such that the marginal cost and benefit of expanding the highway are equated. The paper then analyzes a case where the highway operation is privatized. The results show that a profit maximizing firm will charge a monopolistic markup in addition to the congestion externality cost, unless it faces a perfect competition. In other words, when the firm faces a perfect competition, it charges the socially optimal levels of toll.

In Japan, highway toll is typically set proportional to the distance of travel. This location-invariant uniform unit-distance toll is clearly sub-optimal. The paper analyzes via simulation this second best under the integrated ownership and operation by a welfare-maximizing public transport authority.

2. Simulation Results

(1) Case 0: The Benchmark Case

Under this benchmark case we set the capacity and pricing at the actual level. That is, the capacity w is set to be 72,000 vehicles/day upto the 9th segment and is 48,000 vehicles/day for segments from 10th to the 20th; and the pricing is 24.6 yen/km or 246yen per one segment. Under this setting, we compute the social welfare without the break-even constraint. S /ocial welfare is computed as 235.0 million yen per day. Marginal external cost (MEC) in the first segment at CBD is as high as 1,011 yen, while that at the end of the highway is just 4 yen, indicating underpricing near CBD and overpricing at the end of the highway. We label this scenario as case 0-1. We compute the welfare where the toll schedule is such that for the first 4 segments it is 29.5 yen/km while for 5th and beyond it is 24.6 yen/km. We call this case 0-2. In case 0-2, social welfare is computed as 236.6 million yen per day, which is slightly higher than case 0-1. This is clearly because that the underpricing near the CBD is alleviated. However, the overpricing is still existent toward the end of the highway in this case as well. In both cases, highway authority will incur slight loss. For case 0-1, the loss is 22 million yen per day and for case 0-2, it is 9 million yen per day.

(2) Case 1: The First Best

We will now turn to the first best in which both the capacity and pricing are optimized to maximize the social welfare. Here we continue to assume that the highway authority does not face the break-even constraint. Social welfare is as much as 309 million yen per day. Optimal capacity in the first segment is 79,507 vehicles/day, which is about 10¥% more than the actual capacity. However, optimal capacity decreases rather rapidly, and for the last segment, it is 15,480 which is less than a third of actual capacity. In this case of the first best, toll is set at MEC. The toll (and hence the MEC) for the first segment is 562 yen, and it monotonically decreases to 92 yen for the last segment. This result that the MEC is lower than that in case 0 in segments near CBD is due to the reduced traffic flow. At the end of the highway the MEC is considerably higher as capacity is reduced significantly and thus congestion is more eminent. Due to increased toll revenue, despite the reduced flow, the highway authority will gain positive profit in the first best. The profit amount is 130 million yen per day.

(3) Case 2: The Second Best

Case 2 analyzes the second-best situation described above. That is, highway authority now faces the uniform-toll constraint, though it does not again face the break-even constraint. The second-best toll is computed as 378 yen. The social welfare is 307.6 million yen, and thus only slightly lower than that in the first best, and substantially larger than in the benchmark cases. Capacity is slightly larger compared to the first best for all segments, yet, it is much smaller than the actual capacity in benchmark cases except for the first few segments. These results tells that the significant part of the welfare gain in the first best from the benchmark case is due to optimizing capacity, rather than pricing. In this second best, the highway authority earns profit of 144 million per day.

(4) Case 3: The Third Best

The third best imposes the break-even constraint to the second best. That is, highway authority faces not only the uniform-toll constraint, but also the break-even constraint. Social welfare for this case is 297.2 million yen. The fact that the second best resulted in budget surplus of 144 million yen, the third-best toll is lower than in the second best, and is 172 yen. With this low price, flow is larger and to accommodate this large flow, capacity is larger near the CBD. MEC is 661 yen for the first segment while it is 87 yen at the end of the highway.

(5) Case 4: Uniform Toll under Actual Capacity without Break-Even Constraint.

The results from cases 1 through 3 compared to the benchmark case of case 0 revealed the importance of capacity optimization (or, in other words, the significant damage of overcapacity toward the end of highway) on the social welfare. In cases 4, 5, and 6 we will set the capacity at the actual level: 72,000 vehicles/day for the first 9 segments and 48,000 vehicles/day for 10th through 20th segments and optimize the pricing only to see this point more clearly. First, the case 4 analyzes a situation where the highway authority optimizes the level of uniform toll given the capacity without a break-even constraint. As a result, welfare is greatly reduced to 236.5 million yen per day, only 1.5 million larger than that in the benchmark case (case 0-1). The optimum toll is 321 yen per segment, which is about 30¥% higher than the actual toll of 246 yen/segment, resulting in a small surplus of 23 million yen/day. This toll level lowers the degree of underpricing near the CBD, however at the same time, widens the extent of overpricing near the end of highway.

(6) Case 5: Uniform Toll under Actual Capacity with Break-Even Constraint.

Unlike the case 4, case 5 imposes the break-even constraint, while other settings are the same as in case 4. The welfare is 236.1 million. This figure is very slightly lower than that in case 4, reflecting the fact that the surplus in case 4 was very small. The optimal toll level is 281 yen/segment, which is close to the actual level, reflecting the fact that this setting of uniform toll with break-even constraint under the actual capacity is the closest scenario to the actual situation. Note that case 0-2 has higher welfare compared to cases 4 and 5, due to its differentiated toll schedule.

(7) Case 6: Location-Varying Toll under Actual Capacity without Break-Even Constraint.

Lastly, we analyze the situation where the highway authority optimizes the toll level at each segment given the actual capacity, without facing the break-even constraint. The resulting toll is 754 yen for the first segment just by the CBD, while it is only 4 yen at the end of highway. Though this pricing schedule encourages travel from the points near the end of highway, suppressed travel demand near the CBD outweighs such increase, resulting in much lower aggregate travel demand measured as the traffic flow at the CBD. Social welfare in this case is only 241 million yen/day. Despite the optimization of toll at each location, the welfare gain was almost negligible. This confirms our previous statement that the welfare gain is largely from the optimization of capacity, rather than the toll level. In this case 6, the highway authority's loss is just 4 million yen per day.

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