Transportation Research Part A 118 (2018) 430–443

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Private road supply in networks with heterogeneous users

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ARTICLE INFO

JEL classification:
R41
R42
R48

Keywords:
Congestion pricing
Bottleneck model
Heterogeneity
Private supply
Distributional effects

ABSTRACT

We study different mixes of private and public supply of roads in a network with bottleneck congestion and heterogeneous users. There are two parallel links for one origin and destination pair and two groups of travellers, where the group with the higher value of time also has higher schedule delay values. Previous scholars argued that as users become more heterogeneous, they benefit more from product differentiation, making private supply of roads more efficient. However, we find that local monopoly power might also increase if there is a 'separating equilibrium', which is an equilibrium where at least one group only uses one private road due to the different combinations of toll and congestion of the two roads. The private road can thus increase its toll without worrying about the competition from the other road for this group: it has a local monopoly over them. This lowers the efficiency of private supply. The problem is especially severe with flat tolls, which are constant over the peak. With fine tolls – which vary continuously over the day – there tends to be a pooling equilibrium – where both types use both roads – and competition remains intense. Flat tolling is also worse for users than fine tolling, as it has higher generalized prices.

1. Introduction

Interest in traffic congestion management, including road pricing, is increasing with fast urbanization (Hensher and Puckett, 2007), and private supply of roads is considered by many scholars as a viable complement to the public supply of roads. Often mentioned considerations include shortages of public funds and higher operational efficiency of private sector firms. However, the possibility of excessive pricing under market power calls for caution. Winston (2013) argued that the under-performing US road system needs either massive improved public provision or an expansion of the role of the private sector. However, massive US public investment seems problematic at the moment.

The trade-off between public and private supply is complicated by user heterogeneity, where some people prefer a lower level of congestion at the cost of a higher toll, while others prefer a lower toll accepting a higher level of congestion. When preferences become more heterogeneous, on the one hand, product differentiation offered by different road providers can be expected to make travellers better off; on the other hand, different products become less close substitutes, and the increasing local monopoly market power of the operator may make travellers worse off. We study the impact of such trade-offs in various private, public and mixed regimes, using the bottleneck congestion model.

We develop a model that is as simple as possible, but not any simpler than that, to study the impacts of heterogeneity on the efficiency impacts of private road supply with parallel routes, with the objective to generate insights of a general nature; but not any

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https://doi.org/10.1016/j.tra.2018.09.025
Received 12 December 2017; Received in revised form 24 July 2018; Accepted 24 September 2018

larger networks, which would make generalization more difficult. Yet, as Verhoef (2002) and Yang and Meng (2002) found for static networks, the insights obtained for such simple settings will often carry over to more complicated settings, where otherwise interpretation of results would be impossible. The problems studied seem highly relevant for contemporary transport policies. There is a growing interest in private supply of roads throughout the world. At the same time, only few would advocate a full privatization of roads, if only to limit undesirable concentration of market power. Competition with unpriced public roads will therefore be the rule rather than the exception. Once tolling has been introduced in a network it may be a more feasible option to consider public pricing instead of free supply of public infrastructure. Our paper gives insights that should help making this choice on a more informed basis.[1,2]

The key assumption of the bottleneck model is that congestion cost comes from time wasted waiting in traffic jams and from schedule delays (i.e., the inconvenience of arriving at the destination earlier or later than desired). People in general differ in their values of time and schedule delay. As we will see this has important impacts. Wo consider two groups of commuters, and use 'proportional heterogeneity', as in Vickrey (1973) and Van den Berg and Verhoef (2011), where the values of time and schedule delay vary in a fixed proportion. This heterogeneity could stem from differences in income for otherwise identical preferences. The value of time is the ratio of the marginal utility of travel time to the marginal utility of income, and similarly for the values of schedule delay. A higher income decreases the marginal utility of income, thereby increasing all values by the same percentage. How people's preferences trade-off travel time and schedule delay probably depends more on the type of trip (e.g. shopping vs doctors visit), family status, gender and job type.[3]

We examine two kinds of tolls: flat tolls that are constant over the peak, and fine tolls that vary continuously over the peak period so as to eliminate queueing. We find two types of equilibria: pooling and separating equilibria. In a pooling equilibrium, both types of users travel on both roads, as for both types the generalized price is the same on both roads. In a separating equilibrium, at least one type travels exclusively on one road.

As users become more heterogeneous, a separating equilibrium means that it becomes ever more unlikely that someone will switch to a different road if its type only travels on one road. As a result, for competing suppliers on parallel links, local monopoly power increases with user heterogeneity: these users will not want to switch to the other road, so in effect there is no competition for this type of user as long as the toll does not get too high. This local monopoly power lowers social welfare. On the other hand, with fine tolls, welfare and profit maximisation both result in a pooling equilibrium. Such a market structure means that both roads compete intensely for both types even if user heterogeneity increases. Accordingly, welfare increases with the degree of heterogeneity. The fine toll equilibrium often also gives a private supplier a higher profit than a flat toll equilibrium, as the time-varying part of the fine toll gives toll revenues without raising the generalized price of users by removing all queuing.

Our paper is related to three strands of literature. The first is the large literature on bottleneck congestion and user heterogeneity. Vickrey (1973) was the first, and studied proportional heterogeneity just as we do. Arnott et al. (1992) considered proportional heterogeneity and 'ratio/flexibility', heterogeneity, where the ratios of the value of time and values of schedule delay varies over users. With flat tolling, separation was found to be socially optimal if the degree of 'ratio/flexibility' heterogeneity is not too large compared to the degree of proportional heterogeneity. Separation is always optimal if the high-values type is also more inflexible.[4] Yang and Meng (1998) developed socially optimal variable tolls for a network with heterogeneous users. Van den Berg and Verhoef (2011) assumed continuous heterogeneity both in values of time and schedule delay, and studied the welfare and distributional effects of fine tolls. Cantos-Sánchez et al. (2011) examined the viability of a new road into Madrid city centre with heterogeneous users. General heterogeneity has been studied by, for example, Newell (1987), Lindsey (2004), Wu and Huang (2015), Liu et al. (2015) and Takayama and Kuwahara (2017).

The second strand is on private roads with bottleneck congestion and homogeneous users. Arnott et al. (1992) and de Palma and Lindsey (2002) demonstrated that private supply of roads generally enhances social welfare when congestion is severe. The efficiency is higher when both routes have fine tolls, as these eliminate queueing. Our study shows, in addition, that with heterogeneity, a fine toll is more likely than a flat toll to generate a pooling equilibrium and thereby promotes competition. With homogeneous preferences, de Palma and Lindsey (2002) also considered if a private supplier will choose to set a fine toll or a flat toll, whereas a public operator will always prefer to set a fine toll.

The final strand of literature is on static congestion and heterogeneous users. Edelson (1971) considered a monopolist private road with heterogeneous users, concluding that it may set a toll that is *lower* than socially optimal. Yang et al. (2002) considered a private monopolist operator in a network. Small and Yan (2001) and Verhoef and Small (2004) found that heterogeneity improves the performance of second-best and private regimes, as product differentiation better caters for the specific preferences of each group.

[1] In countries such a France and Spain, it is mandatory that there is an untolled public route parallel to tolled motorways. In the USA, on single motorways, it is common to see tolled pay-lanes and untolled free-lanes. So competition between (semi-) private and untolled roads is already uncommon.

[2] We investigate two objectives: pure welfare maximisation and pure profit maximisation. Firms may also care about consumers or the environment. In Public-Private Partnership (PPP) projects or with governmentally owned private firms the objective may be a mixture of welfare and profit. Finally, government or private employees maximise their own well-being instead of societal welfare or profit.

[3] A surgeon or person in high finance often have strict work start times, while professors often do not. A shop-salesperson may have strict starting times, but a food deliverer or an (independent) plumber much less. Even in the centre peak, a large fraction of trips is for other activities such as trips shopping, visits and leisure – which all have flexible timings – or doctor and hospital appointments – which have very inflexible timings.

[4] The terms proportional and ratio heterogeneity were later introduced by Van den Berg and Verhoef (2011) and Hall (2013) introduced the term flexibility heterogeneity to mean the same as ratio heterogeneity.