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Preference heterogeneity and congestion pricing: The two route case revisited

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ABSTRACT

This paper studies first-best and second-best congestion pricing in the presence of unobserved and observed preference heterogeneity using a stylised stochastic user equilibrium choice model. Travellers choose between multiple alternatives, have heterogeneous values of travel times, and may differ in their valuation of variety. We derive first-best and second-best tolls taking into account how the overall network demand responds to expected generalized prices, including tolls. For second-best pricing, we show that with homogeneous values of times the welfare losses of second-best pricing are smaller when route choice is probabilistic than when route choice is deterministic. Furthermore, we find that with heterogeneous values of times and benefits of variety, uniform second-best tolls and group-differentiated tolls can be very close, implying potentially low welfare losses from the inability to differentiate tolls. Finally, we show that there are cases where all groups benefit from second-best congestion pricing, but that these cases are likely to be politically unacceptable because tolls are then higher for low income groups.

1. Introduction

The clustering of human activities in time and space results in substantial social costs of congestion. For the year 2050, it is expected that 66 percent of the world population will live in urban areas (United Nations, 2014), and with this ongoing increase of urbanization, levels of congestion are expected to increase as well. Nash (2003) estimates congestion costs for European countries at about 1% of GDP, meaning that potential welfare improvements from the regulation of congestion externalities can be substantial. Since the seminal work of Pigou (1920) economists have argued that the price of travellers' trips does not correspond to the marginal social costs because a driver does not take into account that (s)he raises the travel time costs of other travellers' on the road (see Walters (1961) for an early contribution). Therefore congestion pricing has long been advocated as a viable solution, but political and societal opposition has limited its implementation.

Unlike what is assumed in the earliest contributions to the road pricing literature, researchers cannot observe all determinants of choice. Stochastic User Equilibrium (SUE) models are therefore widely employed, for example to study pricing and location decisions of firms (Anderson et al., 1992), households' location choices (Bayer and Timmins, 2007), and route

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choices of travellers (Daganzo and Sheffi, 1977). Instead of considering purely deterministic trade-offs, the utility of alternatives is assumed to depend on a deterministic part and an unobserved part, that might vary over individuals as well as over choice occasions. Individuals' unobserved preferences for routes or modes result in "benefits of variety": an increased number of routes or modes will raise the expected utility of travelling because different alternatives may be appealing to different subsets of consumers. The variety benefits can be included in the welfare function using an entropy term. For example, Erlander (1977), Fisk (1980), Miyagi (1986) and Anderson et al. (1988) showed the connection between the logit model of discrete choices and the benefits of variety: when alternatives have exactly the same deterministic utility (in equilibrium), and hence the same choice probabilities, the benefit of variety is maximized. This corresponds to the intuitive notion that additional alternatives that are (almost) unused in equilibrium hardly increase variety benefits.

1.1. Contribution

This paper shows analytically and numerically how observed and unobserved preference heterogeneity in SUE impacts first-best and second-best congestion pricing policies. We include both heterogeneity in the deterministic part of utility, for example caused by the fact that travellers value travel time differently (Small, 2012), and in the unobserved part of utility by allowing for group specific substitution parameters. Because congestion taxes may impact the benefits of variety and the deterministic part of utility of different groups differently, including preference heterogeneity is of key importance to provide policy makers information about the distributional impacts of congestion pricing. Furthermore, the welfare benefits of congestion pricing may be higher when differentiation of congestion taxes between groups is feasible. The main body of this paper looks at a stylised two-route case to enhance economic interpretation of first-best and second-best congestion tolling with choices governed by random utility maximization. It extends the two-route deterministic user equilibrium (DUE) models of Verhoef et al. (1996) and Small and Yan (2001) to account for the valuation of route variety and an arbitrary number of groups with distinct preferences. Our stylised analytical approach can also be applied in the analysis of taxation of other externalities in the presence of variety benefits and heterogeneous preferences. Extensions to an arbitrary number of alternatives are provided in the appendices.

Several earlier studies have studied congestion tolling in SUE network models (see Yang, 1999; Yang and Huang, 2004; Maher et al., 2005; Huang and Li, 2007) and have analysed congestion pricing with heterogeneous preferences (Arnott et al., 1994; Verhoef et al., 1995; Small and Yan, 2001; Verhoef and Small, 2004; Mahmassani et al., 2005; Lu et al., 2006; Zhang et al., 2008; Clark et al., 2009; Jiang et al., 2011; Sumalee and Xu, 2011; van den Berg and Verhoef, 2011a; 2011b; 2013). However, the most likely realistic combination of price-sensitivity of demand, heterogeneity in valuations of travel time, and benefits of variety has not been studied in a stylised network before. As we accommodate several sources of preference heterogeneity in a fairly general way, it can inspire future analytical research on taxation of externalities in networks in transportation and beyond.

1.2. Structure of the paper and main findings

After introducing the behavioural model in Section 2, Section 3 introduces first-best congestion pricing using a probabilistic SUE model. First, we derive analytical expressions for first-best congestion tolling with homogeneous values of travel time (VOT) and valuation of variety (see Section 3.1). We show that probabilistic choice has no impact on the first-best toll rules, when compared with the Pigouvian toll rules of the Deterministic User Equilibrium (DUE) model. However, for asymmetric route costs, the *levels* of these first-best tolls may still differ for SUE and DUE, despite the equality of the toll rule, because SUE and DUE equilibrium flows are different and therefore so are the marginal external costs. These results also hold for an arbitrary number of alternatives.

Second, we derive first-best congestion tolls in the presence of heterogeneous values of time and benefits of variety (see Section 3.2). Our model thus allows for scale heterogeneity, meaning that the benefits of variety may differ between groups. The DUE model with two groups of Small and Yan (2001) is a limiting case of our model. We assume a finite number of groups, with each group having a different valuation of travel time, and valuation of route variety.[1] When first-best congestion tolls are group-specific, the SUE tolls have the same analytical form as the DUE tolls. The marginal expressions do depend on the group-specific valuations of travel times, but are independent of the benefits of variety. But again, the SUE toll levels may be different when route costs are asymmetric, because equilibrium aggregate usage levels are. The uniform first-best toll we find is equal to the group-specific first-best toll, because we assume that each traveller raises congestion by the same amount. This result also holds for an arbitrary number of alternatives as shown in Appendix A.

Section 4 studies second-best congestion pricing using a SUE modelling framework. First, we derive a second-best toll with homogeneous VOTs and benefits of variety, which has the deterministic second-best toll of Verhoef et al. (1996) as a limiting case when benefits of variety vanish (see Section 4.1). Here we find that the toll rule of the DUE model and the SUE model diverge. This is because the second-best toll corrects for the spillovers on the untolled route. The substitution

[1] Although a continuous distribution may be even more realistic, compared to the case with homogeneous preferences, a discrete distribution of VOTs and scale parameters strongly increases the empirical plausibility of the model and can be connected to empirical applications that seek to estimate preference heterogeneity. For example, it is well known that VOTs of travellers may be different because of variations in job and other characteristics (see Small (2012) for a recent review on heterogeneity in VOTs).