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Coarse tolling with heterogeneous preferences

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ABSTRACT

This paper analyses optimal coarse tolling of congestion under heterogeneous preferences, and in particular its welfare and distributional effects. With coarse tolling, the toll equals a fixed value during the centre of the peak, whereas outside this period it is zero. This paper separately investigates three dimensions of heterogeneity. With the first, all values of time and schedule delay vary in fixed proportions, and this heterogeneity may stem from income differences. The second has differences in the flexibility of users in when to arrive. The third captures differences in willingness to arrive before or after the preferred arrival time. The paper uses three models of coarse tolling: the 'Laih', 'ADL' and 'Braking' model.

All three dimensions affect the welfare gain of coarse tolling. In the Laih model, the generalised price with coarse tolling is always in between the no-toll and first-best prices. In the other models, this is not the case, and the distributional effects of coarse tolling may be non-monotonic and very different from the distributional effects with first-best tolling. In the Braking model, the bottleneck capacity goes unused for some time during the tolled period. Compared to in the Laih model, this raises the total cost, and it is most harmful for users with low values of time and schedule delay and for users with a relatively high value of schedule delay late: these users could, for instance, be low-income users with a strict work start time or travelling to a doctor's appointment.

1. Introduction

This paper studies step tolling in the bottleneck model with heterogeneous preferences and especially the distributional effects. There is a large literature on fully time-variant tolling, but in practice tolls are either constant over the day (e.g. London) or at most have a few steps in them (e.g. Singapore, Stockholm, the SR91 and the Bay Bridge in California, and the SR520 and SR16 bridges in Washington State). We focus on optimal single-step 'coarse tolling' under three dimensions of preference heterogeneity, where we analyse each dimension separately. We only consider heterogeneity in values of time (α), schedule delay early (β) and/or schedule delay late (γ). All other user characteristics are homogeneous and demand is fixed.

Preference heterogeneity is certainly present in reality (e.g. Small et al., 2005), and it affects the welfare gain of tolling and leads to distributional effects (e.g. Arnott et al., 1988, 1994). This paper finds that heterogeneity can greatly influence the welfare effects of coarse tolling and the relative performance of tolling schemes. Moreover, the distributional effects of coarse tolling may differ substantially from those of first-best tolling. Distributional effects are important. They are a major reason for resistance against congestion pricing. Moreover, if one would like to compensate those who lose due to congestion tolling, one needs to know which types of users lose and by how much.

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'Proportional heterogeneity' was introduced by Vickrey (1973). Under his definition, all three values of time and schedule delay vary proportionally: $\alpha_i = \mu \cdot \beta_i$ and $\gamma_i = \eta \cdot \beta_i$, where μ and η are homogeneous ratios. Proportional heterogeneity could stem from income differences, where a higher income increases all values proportionally: all three values depend on the inverse of the marginal utility of income, which decreases with income. As Van den Berg and Verhoef (2011a) show, with only proportional heterogeneity, first-best (FB) tolling reduces the 'generalised price' (i.e. toll plus travel costs, and henceforth referred to as 'price' for brevity) for all users, except for those with the very lowest values, who are unaffected. This also means that the gain of first-best tolling increases with the degree of proportional heterogeneity.

Our second form of preference heterogeneity measures differences in the importance of travel time versus schedule delays, or, alternatively, it measures how flexible users are in when to arrive. We denote such heterogeneity as 'α heterogeneity' since the value of time (α) varies relative to the values of schedule delay. This heterogeneity could, for instance, result from differences in type of job, family status or trip purpose. Due to self-selection by users, an increase in the degree of α heterogeneity reduces travel time costs. Consequently, the gain of first-best tolling decreases with the degree of α heterogeneity because this gain equals the travel time savings under this form of heterogeneity. Hence, with α heterogeneity, all users—except for those with the highest value—lose due to first-best tolling (Van den Berg and Verhoef, 2011b). Arnott et al. (1988, 1994) and Lindsey (2004a) used this heterogeneity, among others.

Our final form of heterogeneity captures differences in the willingness to arrive after the preferred arrival time. It could, for example, stem from differences in job or trip type. We refer to it as 'γ heterogeneity' as the value of schedule delay late (γ) varies relative to the value of schedule delay early. Arnott et al. (1988, 1994) find that, both without tolling and with first-best tolling, the low-γ users arrive after the preferred arrival time, and a user arrives later the lower their γ is. This self-selection lowers the gain from first-best tolling but leads to no distributional effects from it.

We consider three behavioural models of coarse tolling that differ in how the price is equalised before and after the toll is turned off. The 'Laih model' of Laih (1994, 2004) has separate queues for tolled users and untolled users who arrive after the toll is lifted. The 'ADL model' of Arnott et al. (1990, 1993) has a mass departure just after the toll is turned off. The 'Braking model' of Lindsey et al. (2012) and Xiao et al. (2012) takes into account that users who would pass the tolling point just before the toll is lifted have an incentive to 'brake' and delay passage until the toll is turned off. The braking means that capacity goes unused for some time during the peak period, and this raises costs and lowers the gain of tolling.

While first-best tolling has monotonic distributional effects, with coarse tolling this is not always so and the effects can be very different from those of first-best tolling. Table 1 summarises the distributional effects under the nine regimes. We find that, with proportional heterogeneity in the Braking model, coarse tolling raises the price most for users with intermediate values $\{\alpha_i, \beta_i, \gamma_i\}$, where these intermediate users are indifferent between the tolled and untolled periods. Here, untolled users are better off, the lower their three values are; tolled users are better offthe higher their three values are; the users with the higher values $\{\alpha_i, \beta_i, \gamma_i\}$ may gain. Xiao et al. (2011) study coarse tolling in the ADL model under proportional heterogeneity. They find that coarse tolling lowers the price for all and more so the higher a user's values are. We find that, with γ heterogeneity, coarse tolling leads to very different distributional effects in the three coarse-toll models. With γ heterogeneity and the Laih model, coarse tolling has no effect on prices; in the Braking model, prices increase; finally, in the ADL model, coarse tolling lowers all prices, but it does so most for mass users and especially for those with an intermediate γ. With α heterogeneity, the higher a user's value of time is, the more coarse tolling raises the price: the Laih model has price increases due to coarse tolling that are exactly half that of those of first-best tolling, the Braking model has higher price increases, and the ADL model has lower increases.

Table 2 summarises the welfare effect (from the no-toll case) and relative efficiency of coarse tolling under the nine regimes. The relative efficiency is the total cost reduction of a policy from the no-toll (NT) case divided by the FB reduction. The gain from tolling decreases with the degree of α and γ heterogeneity. Proportional heterogeneity raises the welfare gain from tolling and tends to make the coarse tolling fare better compared to first-best (FB) tolling. In the ADL model, the welfare gain is higher than in the Laih model; in the Braking model, it is lower. Still, both differences decrease with the degree of proportional heterogeneity. With all three dimensions of heterogeneity it is the case that, as the degree of heterogeneity increases, the welfare gain from coarse tolling in the ADL model approaches that in the Laih model.

Table 1
Distributional effects in the three models and three forms of heterogeneity (in the numerical models).

	Laih model	ADL model	Braking model
Proportional heterogeneity	Low-$\{\alpha,\beta,\gamma\}$ users are unaffected High-$\{\alpha,\beta,\gamma\}$ users gain	All types gain and more so the higher the values $\{\alpha,\beta,\gamma\}$ are	Low-to-intermediate $\{\alpha,\beta,\gamma\}$ types lose High values types gain
α Heterogeneity	All types lose and more so the higher the α	Most types lose but less than in the Laih model The highest-α types gain	All types lose and more than in the Laih model
γ Heterogeneity	Prices are unchanged	All prices decrease but most for intermediately low values of γ	All prices increase For untolled types, more so the lower the γ