The cost of travel time variability: does congestion matter?
Nicolas Coulombel, Yu Xiao, André de Palma

Context
In recent years, the valuation of travel time variability has become a key concern in transport planning and decision making. In cities with relatively mature networks, the prospects of travel time savings, which used to be the primary source of socioeconomic benefits for new transportation projects, have become limited. In parallel, a now vast body of literature has emphasized the importance of travel time reliability for transport users (e.g. Li et al., 2010, for a recent review), to the point that the value of travel time variability (VTTV) is now - along with the value of travel time savings - a typical output of travel demand studies (Carrion and Levinson, 2012). Based on these observations, more and more transport projects focus no longer on improving speed and/or expanding capacity, but on optimizing the use of the transportation system and guaranteeing a certain level of quality of service to users (HOT lanes being a good representative of this trend). Accordingly, an increasing number of national guidelines include or are in the process of including travel time reliability in the economic appraisal of transportation projects.

The social cost of travel time variability is currently assessed as the aggregation of individual costs, which are valued using the VTTV. The VTTV is therefore instrumental in this regard. A series of recent works (Engelson and Fosgerau, 2011; Fosgerau and Engelson, 2011; Fosgerau and Karlström, 2010) has given a sound theoretical basis to this notion by adapting the standard scheduling model to the case of stochastic travel times. In this theoretical framework, the VTTV captures the impact of a marginal change in travel time variability on the individual expected cost of travel. Congestion is represented exogenously: the mean travel time is a fixed function of departure time, independent of travel time variability. This is consistent with the view that the VTTV should solely reflect individual preferences, and not how the whole system reacts to a change in travel time variability. This assumption is challenged when network capacity becomes scarce, however. During the rush hour, car users behave strategically such as leaving earlier or later to avoid congestion, a phenomenon well known since the works of Vickrey (1973, 1969). An improvement in travel time reliability is likely to change the congestion profile as drivers adapt their departure time to the new travel conditions. By failing to capture this equilibrium mechanism, the VTTV could misestimate the cost of travel time variability when recurrent congestion is not negligible. This point might have important consequences on the evaluation of socioeconomic benefits, considering that the (morning and evening) rush hour usually represents a substantial share of daily traffic and is also the period for which reliability issues are the most significant.
Objectives and Methodology

This paper studies the impact of travel time variability on the choice of departure time and the expected cost of travel in the presence of recurrent congestion. We build on the bottleneck model of road congestion (Vickrey, 1973, 1969) and incorporate stochastic travel times. This is achieved by introducing a random delay, in consistency with the standard analytical framework used for the VTTV. Then, we study the impact of travel time variability on the user equilibrium. The marginal social cost of travel time variability (MSCTTV) is simply defined as the derivative of the equilibrium expected cost with respect to the standard deviation of travel time, then compared to the VTTV. This allows us to determine whether the VTTV well captures the cost of travel time variability at peak hour. A previous work by Coulombel and de Palma (2014) studied this issue, but under several restricting assumptions: they only considered \( (\alpha, \beta, \gamma) \) preferences and uniformly distributed random delays. The present paper extends their work by considering general scheduling preferences as well as a general distribution of the random delay.

Preferences are represented using the \((h, w)\) formulation proposed by Tseng and Verhoef (2008), where the function \( h \) is the instantaneous utility (also called marginal utility of time) at home and the function \( w \) is the instantaneous utility at work. As different specifications of scheduling preferences \( (i.e. \text{different} \, (h, w) \, \text{couples}) \) can represent different types of risk-aversion (Engelson, 2011), it is fairly intuitive that the VTTV and the MSCTTV will change accordingly. Considering this point, a side objective of this paper is to shed light on the role of scheduling preferences and investigate whether some specifications have more desirable properties than others for the economic appraisal of transport reliability improvements. We also discuss some policy implications of our results.

Results

After establishing the existence and uniqueness of the Nash equilibrium in departure times in the stochastic case, we start by studying the impact of travel time variability on the timing of the rush hour. When travel time variability increases, the timing of the rush hour is adjusted until the variation of scheduling utility equalizes the variation of utility resulting from poorer travel time reliability, in order to maintain the same utility level between the first and the last traveler. Because the sign of the latter variation is undetermined in the general case, the direction in which the rush hour shifts is not clear. When travelers have \( (\alpha, \beta, \gamma) \) preferences and when the random delay follows an exponential law, the rush hour may for instance shift later for low values of \( \sigma \) (the standard deviation of travel time) then shift earlier and earlier when \( \sigma \) becomes greater.
The ambiguousness is lifted when the instantaneous utility at work $w$ is convex/linear/concave, in which case we show that the rush hour shifts earlier/remains unchanged/shifts later as $\sigma$ increases. This result is consistent with the standard “single traveler case”, in which congestion (if any) is represented exogenously. The rush hour shifts to the same direction as a single traveler would do when facing a change in travel time variability.

Next, we study the relationship between the VTTV (i.e. the marginal cost with exogenous congestion) and the MSCTTV (i.e. the marginal cost with endogenous congestion). Again, we find this relationship to be not trivial in the general case. Notwithstanding, we show that the MSCTTV and the VTTV are equal under linear $(h, w)$ preferences. Furthermore, while we did not manage to prove this point yet, this result seems to hold true when both the function $h$ (instantaneous utility at home) is constant and the function $w$ is either convex or concave, based on numerical simulations. When $h$ strictly decreases, the MSCTTV is strictly larger than the VTTV when the function $w$ is strictly convex or strictly concave. These findings strongly differ from the case of $(\alpha, \beta, \gamma)$ preferences previously considered by Coulombel and de Palma (2014). Indeed, the authors found that the MSCTTV is null (bounded delay) or very small (unbounded delay) for small values of $\sigma$, then progressively converges toward the VTTV as $\sigma$ increases.

All in all, our findings suggest that regular $(h, w)$ preferences are better suited to capture the cost of travel time variability than $(\alpha, \beta, \gamma)$ preferences. Indeed, the latter lead to a MSCTTV that is null over a range of sensible values for $\sigma$, which is quite unlikely. This is due to a property of $(\alpha, \beta, \gamma)$ preferences, which is that individuals departing at times distant from the peak to avoid congestion are risk neutral. Regular $(h, w)$ preferences always include some level of risk aversion, whatever the departure time. Moreover, in the case of linear $(h, w)$ preferences, or of constant $h$ combined with convex/concave $w$, the VTTV and the MSCTTV are equal. This implies that the VTTV can be used indiscriminately for the off peak period or the peak period in order to assess benefits of travel time reliability improvements. Those preferences should therefore be favored over other preferences when possible. Otherwise, calculations of economic benefits should be carried out separately for the off peak and peak periods, the former using the VTTV, and the latter using the MSCTTV.
References


