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Pre-trip information and route-choice decisions with stochastic travel conditions: Theory

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ABSTRACT

This paper studies the effects of pre-trip information on route-choice decisions when travel conditions are congested and stochastic. We adopt a model based on the classical two-route network in which free-flow travel times and/or capacities on each route vary unpredictably due to such shocks as bad weather, accidents, and special events. We show that the benefits of information depend on differences between routes in free-flow costs, the shape of the travel cost functions, the severity of congestion and capacity shocks, and the degree of correlation between routes in travel conditions. Information is more likely to be welfare-reducing when free-flow travel costs differ appreciably, travel cost functions are convex, shocks are similar in size on the routes, and route conditions are strongly and positively correlated.

1. Introduction

Traffic congestion imposes a high cost. In its 2012 Annual Urban Mobility Report, the Texas Transportation Institute estimates that in 2011 congestion in US urban areas imposed on motorists approximately 5.5 billion hours of travel delay and 2.9 billion gallons of extra fuel consumption with an estimated total cost of $121 billion (Schrank et al., 2012). Much of this congestion delay is due to unpredictable events such as bad weather, incidents, unannounced road work, malfunctioning traffic control devices, and special events. By one estimate, incidents (i.e., vehicle collisions and breakdowns) alone contribute some 52–58% of total delay in US urban areas (Schrank et al., 2011, Appendix B, p. B-27). Using Dutch data, Adler et al. (2013) show that the costs of incidents increase steeply with their duration, and they are particularly high at locations with high levels of recurrent congestion.

One way to mitigate the costs of nonrecurring congestion is to provide motorists with information about travel conditions. For decades, travel information has been available from newspapers, radio, television, and variable message signs. More recently, these media have been supplemented by Advanced Traveler Information Systems (ATIS) that compile information from various sources and convey it via traffic websites (e.g., waze.com), GPS devices, e-mail, mobile phones, 511 phone systems (in the US), and Personal Intelligent Travel Assistants. Motorists can use this information to adjust their trip

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Notational glossary

a_{is}	free-flow travel cost on route i in state s
b_{is}	congestion coefficient on route i in state s
β_i	constant in travel cost function
B	bad state
$C_{is}(N_{is})$	private travel cost on route i in state s
d	power coefficient
$E[\,]$	expectations operator
ε_{is}	elasticity of travel cost with respect to usage on route i in state s
F	full-information regime
G	good state
G^{ZF}	expected welfare gain from shifting from zero information to full information
G_s^{ZF}	welfare gain from shifting from zero information to full information in state s
i	index of route
k_{is}	capacity of route i in state s
MSC	marginal social cost of trip
N	total number of users
N_i	number of users on route i
N_{is}	number of users on route $_i$ in state s
N_{is}^*	system-optimal number of users on route i in state s
r	index of information regime
ρ	index of correlation between route conditions
s	state
S	set of states
Z	zero-information regime

destinations, departure times, route choices, parking locations, and other choices. The focus of this paper will be on the effects of information on route choice given a fixed number of vehicle trips.

The fact that substantial resources are devoted to collecting, processing, and communicating traffic information suggests that it is of private value to motorists. But because individual motorists do not internalize the costs of congestion delay and other external costs they impose on other motorists, the private cost of a trip that they face is less than the social cost. The world of second best applies and it is not a priori clear that more, or more precise, information is socially valuable. As a consequence, both the policy determination and management of traffic systems depend on better understanding of the relationship between the availability of travel information and congestion.

The effects of information on travel-related decisions have been examined in many analytical and simulation studies; see Chorus et al. (2006) and de Palma et al. (2012) for reviews. A majority conclude that information is likely to be socially beneficial, although some studies identify conditions under which adverse responses occur. In theory, information can adversely affect route choice, departure time, and other decisions in three ways: concentration, overreaction, and oversaturation. *Concentration* occurs when many travelers make similar choices that exacerbate congestion. Concentration is an equilibrium phenomenon in the sense that individual travelers do not regret the choices they make. *Overreaction* occurs when travelers fail to anticipate how other travelers will react, and collectively respond too much to new information; see Mahmassani and Jayakrishnan (1991) and Emmerink et al. (1995). Overreaction is out-of-equilibrium behavior since those who respond end up worse off. *Oversaturation* occurs if drivers are faced with too much information, and either fail to use it effectively or become overwhelmed and resort to heuristic decision rules (Ben-Akiva et al., 1991).

A number of economic studies have explored the conditions under which more extensive, or more accurate, information can be detrimental. Arnott et al. (1996) show that when the number of trips is determined endogenously, and demand and capacity are stochastic, information can be welfare-reducing if the travel demand and cost functions have certain shapes. Arnott et al. (1991, 1999) show that with endogenous departure times, providing imperfect information can be welfare-reducing relative to no information. Other studies have looked at the effects of information on route choice as we do here. One recurrent finding is that welfare is maximized when only a fraction of drivers are informed. For example, Mahmassani and Jayakrishnan (1991) and Emmerink et al. (1995) conclude that beyond a penetration rate of about 20%, information has negative effects due to concentration and overreaction. The critical penetration rate can depend on the type of information provided, and the degree of inertia in driver response; see Emmerink et al. (1994) for a review.

In this paper, we conduct a detailed investigation of the effects of pre-trip information on route-choice decisions and system efficiency. We use deterministic user equilibrium as the solution concept and therefore focus on the possible adverse effects of concentration rather than overreaction or oversaturation. We study the classical “two-route network” whose origins trace back to Pigou (1920) and Knight (1924). We take as a starting point studies by de Palma and Lindsey (1994), Verhoef et al. (1996), and Emmerink et al. (1998), who analyze two-route networks with linear link travel cost functions