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Impact of hourly parking pricing on travel demand

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Efficient parking management strategies are vital in central business districts of cities where parking is limited and congestion is intense. Hourly parking pricing is a common parking management strategy where vehicles pay based on their parking duration (dwell time). In this paper, we derive comparative static effects for a small network to show that road pricing and hourly parking pricing are structurally different in how they influence the traffic equilibrium with elastic demand. Whereas road pricing strictly reduces demand, hourly parking pricing can reduce or induce demand depending on the parking dwell time elasticity (to the hourly parking price). When dwell time is elastic, demand always increases with parking price. However, when dwell time is inelastic, demand may increase or decrease with the parking price. Hence, hourly parking pricing can actually cause higher congestion and decay social welfare if imposed imprudently. For larger networks, we present a Variational Inequality model that characterizes the emergent equilibrium. Numerical experiments on a large network validate our analytical findings from a smaller and stylized case study. Our results also show a lower standard deviation in the parking search time (i.e., time to find a parking spot) when dwell time is highly elastic to the hourly parking price.

1. Introduction

1.1. Motivation

Efficient parking management strategies are vital in Central Business Districts (CBDs) of cities where parking is limited and congestion is intense. A great deal of parking demand in these regions is generated by travelers who visit their destination for some specified period (called dwell time) before returning to their origin location (Anderson and de Palma, 2007). To find parking for these activities (e.g., shopping activities), travelers incur a cost comprised of traveling to a chosen parking area, searching for a spot, paying the parking price, and walking to the final destination.

In day-to-day equilibrium conditions or in the presence of information systems such as mobile apps, travelers adjust their travel patterns to minimize their experienced costs. This adjustment includes choosing an affordable parking area in the vicinity of the final destination. Parking areas are underground or multi-floor parking garages, surface lots, or a collection of on-street parking spots. They can be public or private and generally require a parking fee with a fixed price (e.g. $3 for entrance) and an hourly price (e.g. $0.5 per hour). The hourly price plays a key role in parking management. Its impact on parking demand is twofold. First, increasing the hourly price of a parking facility increases user costs and explicitly

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Nomenclature

Sets

$G(N, A)$	graph with node set N and arc set A
N	set of nodes
R	set of external nodes
I	set of parking nodes
S	set of internal zones
A	set of arcs
A_d	set of driving arcs
A_w	set of walking arcs
V	set of O-D pairs
$\Omega(r,s)$	parking choice set of O-D pair $(r,s) \in V$ travelers
$\psi(r,s,i)$	set of routes for O-D pair $(r,s) \in V$ travelers who choose parking $i \in \Omega(r,s)$

Constants

w_b	walking time on walking link $b \in A_w$
k_i	capacity of parking $i \in I$
$\Delta_{a,b}$	link-path incidence matrix
σ_i	maintenance cost of one spot at parking zone $i \in I$
l_i	average searching time at parking $i \in I$
μ_i	constant representing how drivers adopt occupancy information at parking $i \in I$
α	marginal cost of each hour of driving time
β	marginal cost of each hour of parking search time
γ	marginal cost of each hour of walking time
θ	dispersion parameter in the parking choice model

Decision variables

x_b	flow on link $b \in A_d$
$\tau_b(x_b)$	travel time on driving link $b \in A_d$
d^i_{rs}	flow of O-D pair $(r,s) \in V$ travelers who choose parking $i \in \Omega(r,s)$
d_{rs}	flow of O-D pair $(r,s) \in V$ travelers
$d^i_{rs,a}$	flow of O-D pair $(r,s) \in V$ who choose parking $i \in \Omega(r,s)$ via route $a \in \psi(r,s,i)$
d^i	flow of travelers into parking $i \in I$
q_i	occupancy of parking $i \in I$
h^i_{rs}	dwell time of O-D pair $(r,s) \in V$ travelers who choose parking $i \in \Omega(r,s)$
π^i_{rs}	probability that an O-D pair (r, s) traveler chooses parking $i \in \Omega(r,s)$
η_{rs}	expected perceived travel cost of O-D pair $(r,s) \in V$ travelers
$D_{rs}(\eta_{rs})$	demand function of O-D pair $(r,s) \in V$ travelers
C^i_{rs}	observed cost of O-D pair (r, s) travelers who choose parking $i \in \Omega(r,s)$
ε^i_{rs}	unobserved cost of O-D pair (r, s) travelers who choose parking $i \in \Omega(r,s)$
p_i	hourly price of parking at zone $i \in I$ measured in dollars per hour
Γ	feasible region of the Variational Inequality program
u^i_{rs}	Lagrange multiplier associated with conservation of flow for O-D pair (r, s) travelers who choose parking $i \in \Omega(r,s)$
λ_{rs}	Lagrange multiplier associated with conservation of flow for O-D pair (r, s)
δ_i	Lagrange multiplier associated with conservation of flow at each parking zone $i \in I$
$\varphi^i_{rs,a}$	Lagrange multiplier associated with conservation of flow for O-D pair (r, s) travelers who choose parking $i \in \Omega(r,s)$ via route $a \in \psi(r,s,i)$

Functions

$H_{rs}(p_i)$	dwell time function for O-D pair (r,s) at parking zone $i \in \Omega(r,s)$
$F_i(q_i)$	searching time at parking $i \in I$
PM	profit maximization function
SS	social surplus function