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The time dimension of parking economics

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A model of demand for parking, evolving over time, is proposed. The model features both extensive (whether to park) and intensive (for how long to park) margins of parking demand, allows multidimensional heterogeneity of parkers, and evolution of demand throughout the day. I show that the optimal price for parking is proportional to the rate of arrival of new parkers and is inversely related to the square of the occupancy rate, which is different from previously discussed pricing methods. I show that the primary purpose of pricing is to regulate departures, rather than arrivals, of parkers. I also find that asymmetric information about parkers' characteristics does not prevent the parking authority from achieving the social optimum. A numerical example compares the optimal policy against the alternatives.

1. Introduction

Starting from Vickrey (1954), economic theory in general, and multiple studies in particular, prescribe to tackle the problem of curbside parking congestion with price regulation. How exactly pricing affects parking, however, remains an open question. Most existing research asserts that a higher parking price either reduces the number of motorists traveling to the area in question (Ahmadi Azari et al., 2013; Arnott and Inci, 2006; van Ommeren and Russo, 2014), or affects the location of parking (Anderson and de Palma, 2004; Qian et al., 2012), or both (Arnott, 2014; Arnott and Rowse, 1999; Li et al., 2007; Madsen et al., 2013). In this paper, I highlight another channel through which parking prices reduce congestion, namely the duration of parking period, or the *intensive margin* of parking demand. The importance of this channel of parking regulation has been highlighted in popular writings on the topic. For example, Shoup(2005, p. 363) argues that higher parking rates, by reducing the duration of parking (intensive margin), may increase availability of parking to the point that the number of travelers (extensive margin) actually increases. This paper develops a model of parking demand in which both the arrival of would-be parkers and the duration of parking endogenously respond to the parking rates. The model features time-varying intensity of arrival of the motorists, and calculates the socially optimal parking price schedule.

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In a world where parking rates not only deter entry of new motorists, but also expedite exit of those already parked, the philosophy of optimal parking rates is different. The existing research on optimal parking rates, focused on the extensive margin of parking demand, views parking pricing as analogous to that of road congestion pricing: wherever a road usage is below its capacity, motorists have no externality on each other and should travel for free; when full capacity is reached, a negative externality of vehicle use arises, and a toll should be optimally imposed. The existing research on parking (e.g., Shoup, 2005) is very similar as it prescribes to target a specific usage/occupancy rate. The only difference is that the recommended occupancy target is less than 100% (the most popular figure is 85%), so that few spaces are left open for newly arriving parkers. Arnott (2014), in a model with exogenous parking duration, shows that the optimal occupancy may vary over time, with (extensive margin of) demand for parking.

I argue that parking congestion should *not* be viewed as analogous to road congestion. A hundred of motorists on the same road create congestion and reduce each other's welfare; a hundred of motorists already parked do *not* reduce each other's welfare. More generally, *the motorists already parked do not compete with each other for space. The only conflict of interest out there is between a motorist already parked and a motorist still searching for a place to park.*[2] Therefore, the right parking price, that aims to expedite or delay the departure of already parked vehicles, should explicitly take into account not only the occupancy rate (how many are parked) but also the rate of new arrivals (how many are looking for parking). At the same occupancy rate, a higher arrival (=turnover) rate implies a greater negative externality of already parked vehicles, thus should imply a higher price for parking.

Despite the simplicity of this argument, it has been surprisingly overlooked by policy makers. For example, the federally funded SFpark project of San Francisco, considered to have employed the state-of-the art parking pricing policy, does not even keep the data on the frequency of new arrivals despite an infinitesimal additional cost of doing so,[3] and bases its prices solely on the occupancy data.

Many aspects of the economics of urban parking have been analyzed. Glazer and Niskanen (1992), the only known existing model of the intensive margin of parking demand, points out that a higher parking price per unit of time, by increasing turnover of parkers, may increase traffic. Zou et al. (2015) use the mechanism design approach to optimally allocate heterogenous parking spots to heterogenous motorists prior to their arrival, using modern communication technology. Boyles et al. (2015) explicitly models the geography of the search for a parking spot. Fosgerau and de Palma (2013) study how parking fees may substitute tolls on congested roads; in their model however parking space *per se* is unlimited, so there is no search for parking. Inci (2014) contains the most recent review of the parking literature.

A large strand of literature has analyzed the phenomenon known as "cruising for parking", essentially a negative externality of those who search for parking on through traffic. Arnott and Inci (2006) is an early theoretical contribution, while Shoup (2006) provides empirical estimates of the scale of the problem. More recently, Geroliminis (2015), Cao and Menendez (2015), Zheng and Geroliminis (2016) provide further theoretical elaborations on the topic. The current paper, however, does not address the problem of cruising for parking, because this problem is likely to exist only in case of suboptimal (too low) price for parking. When pricing is optimal, the calibration exercise of this paper shows that, during the peak arrivals period, the average duration of search for a parking spot is only 29 s, which essentially eliminates the cruising problem. Outside of the rush hour, the search time may be longer, but the number of vehicles searching is small, so the aggregate negative externality of the searchers is small.

2. Model

Consider the world with continuous time and a continuum of motorists. The length of a day is T units of time, and all days are identical. That is, the equilibrium value of a model parameter at time t is equal to that of time $t+T$. Motorists differ by their type $v \in \mathcal{V}$, which may have one or more dimensions. Motorists of different types have different demand for parking, detailed below. The motorists appear in the model exogenously; the rate of appearance of a type-v motorist at time t is $A(t, v)$. Immediately after appearance, a motorist decides whether to start searching for parking, or to quit the model permanently.[4] Those who quit enjoy the outside utility of $U_0(v)$. Those who start searching are referred to as *searchers*. Search is a Poisson process in which exogenously supplied parking sites are randomly sampled at rate r. At each instance of sampling, a searcher randomly selects a parking site from the mass N of all existing sites. If the site is vacant, the searcher occupies it, the search is over, and the parking period begins. Otherwise, the search continues. The cost of search is c per

[2] One may argue that two motorists simultaneously searching for parking also have an externality on each other. Such externality, however, is only *prospective*: the negative impact that searcher A has on searcher B is conditional on the fact that A finds a spot before B, becoming a parker, and that B stumbles upon the site occupied by A before finding his own vacant site. An optimal policy need not account for this prospective externality if the immediate externality of parkers on searchers is properly addressed.

[3] The installed hardware does measure the precise time and location of arrivals, but the program operators choose not to keep this data, in order do save few hundred megabytes of computer memory per year.

[4] Thus, the model is missing one more margin of demand for parking: the decision when to start searching for parking. Introducing such margin would somewhat smooth the extensive margin (number of arrivals) over time, but I believe it would not change the main results qualitatively. Fosgerau and de Palma (2013) model this margin of demand explicitly.