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Urban Vehicle Congestion Pricing: A Review

Richard C. Larson[1*], Katsunobu Sasanuma[2]

[1]Engineering Systems Division, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139 USA
rclarson@mit.edu

[2]Heinz College, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213 USA

ABSTRACT

Drivers in urban neighborhoods who cruise streets, seeking inexpensive on-street parking create a significant fraction of measured traffic congestion. The solution to this problem is to reduce the total traffic volume including cruising traffic by implementing a congestion pricing scheme: the imposition of a usage fee on a limited-capacity resource during times of high demand. We review the history of two alternatives for implementing congestion pricing scheme: **road pricing** (RP), which involves cordoning off a section of the center city and imposing a fee on all vehicles that enter it; and **parking pricing** (PP), which increases the costs of on-street and perhaps off-street parking. PP is needed in many environments where a significant fraction of drivers are simply cruising, looking for inexpensive on-street parking. In this paper, we propose a simple method to estimate the number of cruising drivers and the optimal parking price. Our survey in Boston shows that the number of cruising vehicles reaches 10-20% of the total number of parking spaces during peak hours and the required congestion charge (CC) for on-street parking is at least about $1/ hour.

1. INTRODUCTION

Consider a typical recent study of street traffic congestion in urban America. This report[1] is from the Park Slope section of Brooklyn, New York, a thriving commercial and residential zone. The purpose was "…to ascertain the extent of the neighborhood's ever-worsening traffic and parking problems and to propose solutions to both." Based on data collected in 2007, "…the study reveals an overwhelming amount of traffic is simply circling the block 'cruising' for parking, while the curbside itself is nearly 100% filled with parked vehicles." The researchers found that 45% of total traffic and 64% of local traffic is cruising for a parking space. And the average curb occupancy rate is 94%, with "…nearly 100% occupancy at metered spaces during peak periods."

Urban traffic congestion is a challenge within a transportation system that requires the simultaneous consideration of many options. The solution chosen often combines several initiatives, with a small but growing number of cities utilizing or at least considering the congestion pricing (CP) schemes described in this paper. CP, perhaps used with companion incentives, can motivate citizens to substitute public transportation (PT), bicycles, or walking for personal motorized vehicles. CP can

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* Corresponding Author

1 Transportation Alternatives (February 27, 2007) 'No Vacancy: Park Slope's Parking Problem And How to Fix It'. http://www.transalt.org/campaigns/reclaiming/novacancy.pdf

be implemented via road pricing (RP) by imposing fees on drivers crossing cordoned lines, and/or via parking pricing (PP) by imposing fees on drivers who park within designated areas.

PP offers two practical benefits: (a) cost effectiveness: PP does not necessarily require an additional toll-collection organization, making it cost-effective for medium- and small-scale cities for which RP may not be affordable, and (b) scalability: PP can be extended as its affected area expands without costly additional infrastructure or the risk of increasing the fraction of exempted residents, which could significantly reduce the effectiveness of RP. As discussed later, good examples of the efficacy of PP can be found in Japan.[1]

In this paper we review the arguments for CP in cities, the need to consider PP in addition to RP, the experiences of several cities in implementing or trying to implement CP, and realities of implementation going forward. In a companion paper, *Congestion Pricing: A Parking Queue Model* (R. C. Larson and K. Sasanuma, 2010), we develop a new queueing model depicting driver behavior while cruising for on-street parking. The model is linked to economic incentives and demonstrates how cruising for on-street parking should diminish according to appropriate changes in parameters. We conducted a simple survey in Boston and estimated the necessary congestion charge (CC).

2. TRAFFIC CONGESTION

2.1 Cost of Congestion[2,3]

As countries develop and the number of cars increases, traffic congestion can impede their cities' development. In the United States, the Texas Transportation Institute (TTI) estimated[4] the annual delay per peak-period traveler in large urban areas with populations of more than 3 million to be 61 hours for the year 2003, which is much larger than 13 hours in small metropolitan areas with populations less than 0.5 million. The average annual delay for all cities has grown from 16 hours to 47 hours since 1982. According to TTI's estimate, urban traffic congestion costs Americans $63.1 billion a year, based only on time and fuel wasted. However, the total cost of congestion would include at least the following four categories: (1) waste of time: total delays reached 3.7 billion hours in 2003, according to TTI, (2) waste of resources: engines idling in congested traffic wasted 2.3 billion gallons of fuel in 2003, according to TTI, (3) loss of environmental quality, and (4) loss of business. We will discuss (4) in the later section.

2.2 Congestion Problem as "the Tragedy of the Commons[5]"

The *tragedy of the commons* has become a now-standard allegory for a situation in which a free public good is available to the public, each person's private utility function is optimized by continually incrementally increasing his/her use of that good, and eventually the good become

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1 See Section 3.1.4, 'Tokyo, Japan (PP)' of this article for more information and sources regarding these examples.

2 Downs, A. (2004) *Still Stuck in Traffic: Coping with Peak Hour Traffic Congestion,* Brookings Institution Press, Washington, D.C.

3 May, A.D. (2004) 'Transport and Land Use Instruments for A Better Environment', Chapter 4 in World Conference on Transport Research Society, *Urban Transport and the Environment: An International Perspective,* Elsevier, New York.

4 Schrank, D., and Lomax, T. (2005) *The 2005 Urban Mobility Report,* Texas Transportation Institute, College Station, TX. http://www.apta.com/research/info/online/documents/urban_mobility.pdf

5 Hardin, G., (December 13, 1968) *The Tragedy of the Commons*. http://www.sciencemag.org/cgi/content/full/162/3859/1243

saturated and of limited or no value to anyone. Personal, utility-optimizing decisions are at odds with global societal optima.

To visualize the allegory, consider the Boston Common, where – until the year 1830 -- residents of Boston were allowed to graze their cows. This setting could provide an example of the *tragedy of the commons,* if each owner of cows had been persuaded by self-interest to add 'one more of his cows' to the Common, each ignoring the deleterious effects of one more cow, until there was no more grass to craze and then no cows could be supported there[1]. This allegory applies to urban street traffic, where the streets of the city correspond to the Commons and cars correspond to grazing cows.

More generally, the Tragedy of the Commons arises if the following three conditions are satisfied: (1) the resource is limited, (2) the resource is shared and open to everyone (i.e., a *common-pool resource*), and (3) a negative externality exists associated with the usage of the resource. (A negative externality is a broader social cost arising from individual decisions, and the individual decision maker does not bear the costs associated with his decision.) Like the Boston Commons, the road resource satisfies all these conditions. In such a case, a "free rider" problem occurs: a driver has little incentive to limit the use of his car because he bears only the fuel and time cost spent on congested roads, and he does not need to bear the external cost, such as the cost of pollution or extra congestion caused by his entrance. Because of the drivers' free-riding behaviors, the road resource is overused and congestion becomes heavy, which increases the environmental externalities and makes the society worse off collectively.

One way to solve the congestion problem is to increase the supply if demand is too strong, e.g., add "acreage to the Commons." This is the strategy that some cities have taken, that is to increase the supply of roads. However, for large cities, adding new roads is difficult because of limited land resources. Even if creating more roads is possible for some cities, it may not solve the problem because more roads attract more traffic in the city, which causes traffic congestion again sooner or later, again with large negative externalities to the city. In most instances, we cannot solve the "the tragedy of the commons" by just increasing the size of the "commons".

Now, continuing the allegory, consider a situation in which we charge each farmer with the true total cost of adding his next cow to the Commons. Eventually, this cost becomes so large that the myopic utility maximizing behavior of the farmer changes so he no longer chooses to add more cows to the Common. The same logic can apply to urban car drivers. An economically efficient level of congestion is realized if the negative marginal external cost is imposed to each driver. This can be done by means of either fuel tax or CP schemes. A fuel tax is not as effective as CP because it reduces car usage uniformly rather than coping with local and time-specific forms of congestion. In contrast, CP (which can be implemented by RP or PP) can be applied effectively to specific areas and also made time-dependent if the extra fee, or congestion charge (CC), is adjusted locally and dynamically in accordance with traffic situations. However, the most commonly-used CP scheme, cordoned-area RP, cannot control trips taken within cordoned areas effectively since road users are charged only once per day and residents in cordoned areas are often exempted from paying full CC. Full-scale RP,[1] which essentially prices every road in a city, can control traffic level locally and dynamically, but associated administrative costs are large, making it difficult for medium and small-scale cities to implement full-scale RP. Singapore's RP, with many gantries installed over the

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[1] For historical accuracy, cows became forbidden in Boston Common in 1830 not due to *a tragedy of the commons*, but because of increased human population in Boston, the need to use the space for purely human activities and to respond to the complaints of ladies who were bothered by the cows.

city center, is currently the system closest to full-scale RP. Hong Kong tested a large-scale, peak-hour pricing system for six months but rejected it because of privacy concerns. A GPS-based system might be a viable solution to address Hong Kong's concerns. One such system has been tried in Gothenburg, Germany, but many technical problems remain before a GPS-based system can be fully implemented.

PP has the ability to control the driving behavior in the congested area effectively using the price differentials between on-street parking and off-street parking. PP can be applied locally and dynamically, applied to disconnected, congested areas since parking lots are distributed throughout cities, and adjusted smoothly as congested areas expand or contract without significant investment. The biggest problem with PP is when through traffic is responsible for much of the congestion, since PP cannot impose a CC on each driver if he does not park. In practice, an extensive network of highways serves most large cities, and in most cases, drivers with remote destinations rarely enter local congested roads. A mathematical model of driving behavior under PP is examined in a companion paper, *Congestion Pricing: A Parking Queue Model*.

Incentives to use cars

The problem of "the tragedy of the commons" becomes even worse if there exist various incentives to use cars, such incentives having unintended negative consequences in urban congestion.

One incentive is caused by a large fixed cost for the purchase and maintenance of cars paid in advance and a relatively small usage cost associated with the actual driving. Once they own their cars, car owners want to use cars as often as possible to justify their purchase. To reduce this incentive, one needs to charge more for the usage of cars or to give cash or some other benefit for not using cars. CP is an attractive option because it increases the usage cost when cars are used in a congested area. Another example is pay-as-you-drive (PAYD) car insurance. Insurance is often a larger expense than gasoline and oil expenses for small and intermediate vehicles mostly used for commuting. By changing the insurance system from term-based to distance-based, a fixed cost is decreased and a usage cost is increased, which reduces the incentive to use cars.

A parking benefit offered to commuters by some employers creates another incentive. This benefit is typically free parking at parking garages near their places of work. Employees need to drive to gain the benefit. American firms currently provide 84.8 million free parking spaces to their employees (Downs, 2004), and some are in the center of large cities. Considering the cost of parking in the centers of the large cities, the benefit of free parking can far exceed daily marginal expenses associated with driving. Census data for the year 2000 show that 35% of government workers in Manhattan drive to work mainly because they have *free parking*.[1] This problem could be solved by employers giving employees the cash equivalent of parking fees to spend on using an alternate mode of transportation. Donald C. Shoup examined eight case studies conducted from 1993 through 1995 on the effect of a "cash-out" scheme in the Los Angeles region.[2] A cash-out scheme gives employees a choice between free parking and its cash equivalent, introducing the market mechanism to companys' free parking. This scheme does not remove a benefit from employees since they can either continue driving to work or receive a cash benefit by using PT. The results in Los Angeles were remarkable: after a cash-out scheme was introduced, the number of solo drivers fell 17% while the number of carpoolers rose 64%, and public transit ridership increased

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[1] Neuman, W. (January 12, 2007) 'Cars Clogging New York? Most Are From the City', *New York Times*

[2] Shoup, D. (October 1997) 'Evaluating the Effects of Cashing Out Employer-Paid Parking: Eight Case Studies', *Transport Policy*, **4**, pp. 201-216.

50%. The number of miles traveled by private vehicles declined 12%. This program has reduced the number of cars used to commute without sacrificing the number of persons commuting, and according to surveys taken, has increased both employers' and employees' satisfaction. In California, a law was passed in 1992 (although it has not been enforced) requiring all employers to make such cash-out options available to employees (Downs, 2004).

If the current PT is poor, the incentive to use cars in commuting inevitably remains high. The quality of a PT system includes its vehicles' speed, punctuality, accessibility, network coverage, cleanliness and safety. For example, before implementing RP, London introduced about 300 additional buses,[1] set new bus routes, and increased the frequencies of bus operation. London also has enforced traffic rules strictly with police cooperation. London currently has 130 km of priority bus lanes, and bus service 24 h/day. Tokyo, too, is famous for its high-quality PT system. To compensate for its less than punctual bus system, a GPS bus-locator system has become common in Japan so users can check buses' current location by Internet or cell phone.[2]Trains in Japan are reliable and their network is extensive. In contrast, Edinburgh's citizens were generally dissatisfied with their city's PT, and as a result, roundly rejected the prospect of RP when that was raised. One important difference between London/Tokyo and U.S. cities should be noted: U.S. cities are less densely populated; therefore, providing extensive PT in the U.S. is more costly. A park-and-ride system can therefore be especially important in the U.S.

Finally, there is the incentive of inexpensive on-street parking. Two observations[3] in New York City have especially interested us: (1) a recent survey conducted by Bruce Schaller, principal of Schaller Consulting, showed that 28% of drivers in the SoHo district in Manhattan were searching for on-street parking, and (2) as cited in this paper's Introduction, a second survey, by Transportation Alternatives, showed 45% of drivers were searching for on-street parking in the Park Slope neighborhood in Brooklyn.[4] This, of course, is not always the case, but often is during busy times in city centers, where most drivers try to find a place to park. Historical data on the percentage of traffic cruising shows that between 8% and 74% of traffic may be cruising in search of available street parking in major US cities (Shoup, 2005), with an average time required to find a vacant spot ranging from 3.5 to 14 minutes.[5]

The underlying problem is inappropriate PP when on-street parking capacity cannot accommodate all who wish to park. For example, in Manhattan, off-street parking (averaging US$24.42 per person per day) costs 14 times more than on-street parking (which averages US$1.73 per person per day).[6] If prices for on-street parking are much lower than those charged by off-street parking lots, drivers have a strong incentive to search for parking on the street, creating extra traffic and congestion. When congestion is expected, street parking should be eliminated or its price level increased towards that of nearby off-street parking.

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1 http://news.bbc.co.uk/2/hi/uk_news/england/2774271.stm

2 One example of Japanese bus locator Internet sites is: http://info.entetsu.co.jp/navi/pc/location.aspx

3 Shoup, D. (March 29, 2007) 'Gone Parkin', *New York Times* Op-Ed. http://www.nytimes.com/2007/03/29/opinion/29shoup.html?ex=1332820800&en=cdabf3ece6c4a862&ei=5088&partner=rssnyt&emc=rss

4 Transportation Alternatives (February 27, 2007) 'No Vacancy: Park Slope's Parking Problem And How to Fix It'. http://www.transalt.org/campaigns/reclaiming/novacancy.pdf

5 Shoup, D.C. (2006) 'Cruising for parking', *Transport Policy* **13**, pp. 479-486.

6 Schaller Consulting (March 1, 2007) *Free Parking, Congested Streets*. http://www.transalt.org/campaigns/reclaiming/freeparking_traffictrouble.pdf

3. IMPLEMENTATION

3.1. Examples of RP and PP Implementations Around the World

3.1.1. London, England[1] (RP)

RP went into effect in London on February 17, 2003, at an initial charge of 5 UK pounds (approximately US$10) per vehicle per day. Drivers paid the charge if their vehicles entered a congestion-charging zone anytime between 7 a.m. and 6:30 p.m. weekdays. Six hundred eighty-eight cameras in 203 locations within an 8-square-mile (21-square-km) area captured the license plate numbers of about 250,000 vehicles daily. The number of vehicles entering central London during charging hours declined about 25% the day RP were introduced. Since then, vehicle delays due to traffic congestion have dropped about 30% and carbon dioxide emissions have decreased more than 15%. In 2005-06, London's RP scheme cost 230 million UK pounds (about US$460 million) to implement, while its annual operating costs were around 88 million UK pounds (about US$176 million). Its net revenue was 122 million UK pounds (about US$244 million) [2], most of which was spent improving bus services, as London put 300 additional buses into service before introducing RP. Bus passengers entering the charging zone during morning rush hour during the first year increased 37%.[3]

Because of such successes as well as a need to reduce traffic further, the City of London raised its CC to 8 pounds (US$16) per vehicle per business day in July 2005. Since February 2007, the congestion-charging zone has extended westward. Residents in the zone can apply for a 90% discount price of 4 pounds (US$8) per business week.

The success of London's RP is usually explained as follows: First, the center city had been heavily congested, and the citizens and mayor recognized that a RP scheme should be implemented. Second, the technology for gantries to automatically read license plates was provided by the city, so citizens would not need to bear any related monetary burden such as for the in-vehicle units (IVUs) that are required in Singapore's case. Third, even before implementation of RP in London, 85% of commuters used PT, more than one million riders per day. Hence, the additional expenses required to reinforce the PT system in preparation for RP were minimal, and most of the commuting public favored RP, expecting that it would improve PT.

3.1.2. Singapore[4] (RP)

RP was first adopted by the city of Singapore in 1975, using a paper license scheme for want of a more reliable technology. The planners understood the scheme's limited effectiveness. Every vehicle containing three or fewer people was charged Singapore$3 (about US$2) per business day on any given weekday upon initial entry to the 2.3-square-mile central area of the city between 7:30 a.m. and 10:15 a.m. This scheme reduced the total peak-period traffic each business day by 45%. An electronic toll collection system (Electronic RP, or ERP) using IVUs replaced paper licenses in April 1998 to better control traffic. IVUs simplified the task of varying tolls by time of day or location. Singapore initially did not change toll levels, hours, or boundaries to minimize controversy

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1 *Still Stuck in Traffic* (See References)

2 European Local Transport Information Service website. http://www.eltis.org/study_sheet.phtml?study_id=140

3 Ibid

4 A Deloitte Research Public Sector Study (2003) *Combating Gridlock: How Pricing Road Use Can Ease Congestion,* Deloitte Consulting. http://www.deloitte.com/dtt/cda/doc/content/DTT_DR_Gridlock_110303.pdf

over the charges, but gradually did start to vary tolls according to time and place. Signs on gantries now inform motorists of the toll in effect. Currently Singapore's RP scheme is closer than any other city's to the ideal dynamic RP since the CC level changes with time and location, using an ERP system.

3.1.3. Stockholm, Sweden[1] (RP)

An RP scheme was applied in Stockholm on January 3, 2006. The system was scheduled to run for seven months, then a vote on whether to continue was held on September 17, 2006. In that referendum, the citizens of Stockholm voted for a congestion-charging scheme: 51.7% in favor, 45.6% against. All parties in the city council promised to abide by the results. A fee of 10 to 60 kronor (approximately US$1.4 to US$8.5) was charged to vehicles entering the inner city on weekdays between 6:30 a.m. and 6:30 p.m., payable by direct debit. Traffic volumes were reduced 25%, and the number of vehicles during peak hours fell by 100,000. At the same time, public transit rides increased by 40,000 per day. Retail sales in central Stockholm shops also rose after the congestion-pricing scheme was introduced, as people bought more locally rather than drive to suburban stores. The system used cameras, but drivers were also encouraged to install radio-frequency identification (RFID) transponders in their cars. The permanent RP phase started in Stockholm on August 1, 2007, employing the same system used during the 7-month trial RP in 2006.

3.1.4. Tokyo, Japan (PP)

The city of Tokyo has been investigating RP schemes since 1999, when the current governor of the Tokyo District, Shintaro Ishihara, was first elected. One challenge has been that Tokyo is so large and congested everywhere. Many roads are congested not because of a large inflow from the suburbs but because of numerous intracity trips: according to one estimate made by the Tokyo Metropolitan Government, 50.5% (40.7%) of total trips in Tokyo are intracity trips on weekdays (weekend).[2] Therefore, RP would not be effective if cordon-tolls similar to London's RP were implemented. PP would be more appropriate in Tokyo than a simple cordon-line RP because PP can vary charges as needed to regulate intracity trips.

Although on-street parking officially has not been allowed on most roads in Japan, until recently drivers parked almost anywhere because the number of police was insufficient to check for violators. Too, officers permitted a grace period of 15 minutes or more before issuing tickets. Since June 1, 2006, however, Japan has enforced a strict parking regulation in Tokyo, Osaka, and other cities, and this has proved equivalent to eliminating much "free" on-street parking. In particular, a June 1, 2006 revision of the Road Traffic Law has enabled private vendors to enforce parking regulations by issuing tickets immediately after identifying violators, without any grace period. With no grace period and improved enforcement, the 15 minutes or more of "free" parking that had been granted drivers on most roads as a grace period has risen to an expensive on-street parking which costs 10,000 yen (US$108) as a penalty fee for parkers. Three months after the June 1, 2006, implementation, the National Police Agency reported[3] a 27.2% decrease in the average duration of traffic jams and a 9.5% decrease in average travel time on the main streets of Tokyo, comparable to results achieved with London's RP scheme. The agency estimated economic benefits of this policy

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1 Victoria Transport Policy Institute (2006) 'Road Pricing: Congestion Pricing, Value Pricing, Toll Roads and HOT Lanes' http://www.vtpi.org/tdm/tdm35.htm

2 http://www2.kankyo.metro.tokyo.jp/jidousya/kotsuryo-taisaku/s4.html

3 http://www.npa.go.jp/koutsuu/shidou30/20060915.pdf (in Japanese)

to be 181 billion yen (US$2 billion) and the reduction in CO_2 emissions to be 15.2 thousand tons/yr. In addition, a modal shift from cars to PT was observed. In fact, such improvements were observed in not only Tokyo but also in medium-sized cities throughout Japan where strict parking regulations were enforced. Tokyo's example thus demonstrates that PP can be as effective as RP, and a cost-effective alternative for cities of all sizes.

3.2. Examples of Rejected RP

Some cities have experienced difficulties introducing an RP scheme, or at least have required much time to consider doing so.

3.2.1. Edinburgh, Scotland (RP)

In February 2005, about 290,000 voters in and around the city of Edinburgh were asked whether the city should implement an RP scheme similar to London's. The plan proposed was to charge 2 UK pounds (US$4) to enter the cordoned area and 60 UK pounds (US$120) for violations—amounts much lower than those in London's scheme. More than 74% of those queried rejected the scheme.[1] Here are typical reasons that Edinburgh citizens gave for rejecting it[2]:

(1) Distrust of local government: Citizens regarded the RP scheme as a mere tool for raising revenue rather than reducing congestion. Many thought alternative ways to reduce congestion should be sought before additionally burdening citizens.

(2) Currently inadequate PT: Edinburgh has a poor public transport system. Citizens described it as expensive, dirty, and unreliable: an inadequate transport framework in which to implement the RP scheme.

(3) Two cordons: Because the Edinburgh proposal recommended two cordoned areas, the number of people impacted was greater than would have been the case with a simpler one-cordon plan. Even though computer simulation showed the increased congestion at two cordon lines would be minimal, people distrusted the results, worrying especially about traffic increases in residential areas and around schools between the two cordon lines.[3]

3.2.2. New York City, USA[4] (RP)

A proposal for road pricing in New York City backed by Mayor Michael Bloomberg, which would have been the first city to introduce the scheme in the U.S., was rejected in 2008 because of the strong opposition from various parties even though Bloomberg's RP plan received strong support [5] from Governor Eliot Spitzer and the Bush administration. The mayor's plan was to charge US$8 for cars and US$21 for commercial trucks entering Manhattan below 86th street between 6 a.m. and 6 p.m. on weekdays, or US$4 for all drivers within the congestion zone. The rejection was caused by various concerns:

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1 http://news.bbc.co.uk/2/hi/uk_news/scotland/4287145.stm

2 http://news.bbc.co.uk/2/hi/uk_news/scotland/4286791.stm

3 http://news.bbc.co.uk/2/hi/uk_news/scotland/4216347.stm

4 http://cityroom.blogs.nytimes.com/2008/04/07/congestion-pricing-plan-is-dead-assembly-speaker-says/?hp

5 Hakim, D. and Rivera, R. (June 7, 2007) 'City Traffic Pricing Wins U.S. and Spitzer's Favor', *New York Times.*

(1) New York might be hurt economically.[1] A report by the Queens Chamber of Commerce [2] released in February 2006 estimated that a US$14 congestion charge similar to London's would reduce by 40,000 the number of people entering Manhattan's central business district each weekday, causing a loss of US$2.7 billion in economic output per year.

(2) There could be equity issues. Low-income drivers often lack flexibility to change a given traffic pattern because they generally have fixed work schedules and consequently difficult-to-change travel patterns. If they must drive to their required destinations, they may have no option other than to pay any CC that is imposed.

3.3 Obstacles to RP and PP

We have argued that pricing initiatives such as RP and PP are often appropriate for solving road traffic congestion problems in cities. Although most large cities suffer from congestion, today only a handful of cities are successfully implementing RP. For other cities to implement these schemes successfully, we believe that certain obstacles and potential stumbling blocks must be addressed in the planning process, and that RP and PP should be considered in an integrated manner.

i) Fairness issues

There are numerous stakeholders involved with urban transportation. Any change that is viewed as adding costs to transportation will be viewed by some as punitive and unfair, and these groups may then appear as vigorous opponents to any plan that raises prices.

An example is the set of suburbanites who commute to work and who often live where PT is inconvenient. They have to bear the full cost of CC since they have no alternative means to commute. On the other hand, urbanites who live near PT have an alternative option to commute, so they do not bear the full cost of CC. Hence, suburbanites often regard CP as a measure that is unfair to them. In order to reduce this sense of unfairness, planners can focus on the following: (1) raising the effectiveness of reducing congestion, (2) using the revenue of CP for PT improvement, and (3) offering suburbanites alternative means of commuting (e.g., share a ride, perhaps with a waiver of the CC).

To raise the effectiveness of reducing congestion, it is important to show that the city is also planning to implement various supplemental measures (such as strict parking regulations, strict traffic rule enforcement, synchronized traffic lights, road repairs/extensions) other than RP to solve the congestion problem at the same time. It is also important to raise the CC sufficiently high and limit the affected time/district in order to guarantee the effectiveness of the scheme and give options for drivers to shift commuting time or detour around the area.

Revenue of CP should be clearly earmarked for the improvement of PT. In addition, it is also important that the current PT uses the revenue efficiently. If the public perceives that the current revenue is not well spent, then they are likely to regard CP as compensation for inefficient use of funds allocated to the current PT. In such a case, people will not support CP.

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[1] Report Shows Congestion Tax Would Hurt New York Business' (April 6, 2006) theNewspaper.com, http://www.thenewspaper.com/news/10/1056.asp

[2] http://www.queenschamber.org/

For an alternative commuting method, a bus network system is generally recommended, except for U.S. cities. In Asia or in Europe, the bus is a usual transportation means for many people. Extension of a bus network is a relatively inexpensive, but an effective measure to improve public transit accessibility for suburbanites. For example, in London, the current revenue from CP is mostly used for the improvement of bus transportation. In contrast, in the U.S., since suburban areas are much wider compared to those in Asia and Europe, providing park-and-ride facilities with inexpensive shuttle bus/commuter train services is more appropriate. The revenue of CP can be used to build those facilities to give some of the benefit of CP to suburbanites.

ii) Equity issues

If citizens perceive CP as a discriminatory policy against the poor or the elderly or other disadvantaged groups, then the public -- including PT commuters -- may reject the scheme. Hence, it is advisable to conduct a survey to learn of the proportion of low- and moderate-income people who use cars to commute. The results of such a survey will provide guidance to planners on fine-tuning of the CP plan. Often, the great majority of low-income commuters use PT, so the initial concerns about equity can be alleviated by the survey results. For example, a survey conducted [1] in 2003 by Schaller Consulting for Transportation Alternatives and the NYPIRG Straphangers Campaign showed that most people who drive into Manhattan are relatively wealthy. Specifically, Schaller Consulting conducted a survey regarding the East River bridges connecting Manhattan with other parts of the city. The East River bridges are inexpensive or even free, and therefore heavily congested. In order to estimate the effect of CC to drivers crossing the bridges, Schaller Consulting investigated the equity issue and found that lower-income people are far more likely to take public transit than to drive themselves across the bridges. Since drivers crossing the bridges tend to be in the upper income ranges, Schaller concluded that a toll would have little impact on lower-income drivers.[2]

iii) Concerns for business

Retail businesses and restaurants may be negatively affected if the improvement of traffic conditions leads to a net reduction in the number of people entering the city. If retail/restaurant business owners believe this is a risk, then they will form a strong and influential opposition to CP and try to achieve the political decision to reject CP. Their concern might be legitimate. For example, the London Chamber of Commerce reported in its retail survey published in 2005 that the RP scheme in London was negatively affecting retail business. According to their report,[3] 79% of Central London retailers had experienced a fall in receipts and over half (56%) had seen a drop in number of customers. Forty-two percent of respondents indicated they felt the CP scheme was all or mostly to blame.

Whether this result in London is a permanent condition is still unknown. At the extreme, there are numerous examples of cities removing vehicular traffic totally from designated “walking mall”

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[1] Schaller Consulting (September 29, 2003) ‘East River Bridge Tolls: Revenue, Traffic, Mobility and Equity Impacts’, report prepared for Transportation Alternatives and NYPIRG Straphangers Campaign: http://www.straphangers.org/tollreport/tollreport.pdf

[2] The researchers also found that many drivers use free bridges to avoid tolls; free bridges are extremely congested as a result. The congestion mechanism triggered by the price differential resembles the PP problem we are considering here.

[3] Campaigns Team, London Chamber of Commerce and Industry (January, 2005) ‘The Third Retail Survey: The Impact of Congestion Charging on the Central London Retail Sector – Eighteen Months On’. http://www.londonchamber.co.uk/docimages/260.pdf

areas that then become revitalized with many prosperous shops and restaurants. The absence of congestion, noise and street chaos should make an urban neighborhood more attractive to shoppers and other visitors. The key is to include in any master plan alternative means for such visitors to easily travel to these formerly congested areas. In the case of vehicle–free walking malls, installation of inexpensive off-street parking perhaps with shuttle bus service is an example of a transport alternative. This is an illustration of an instance in which innovative PP results in new lower costs for parking than previously experienced, with elimination of on-street parking and subsidized inexpensive off-street parking. As in most complex systems, the key is to listen and learn from all stakeholders and to then design a system that is responsive to their major concerns.

4. EVALUATION OF CRUISING TRAFFIC

Despite the fact that parking pricing has many practical benefits, on-street parking spaces in many locations have still remained unmanaged without being recognized as a potential cause of congestion. Part of the reason is that vehicles cruising for a spot are not clearly visible by observation. In this section, we propose a simple method to evaluate cruising traffic including estimates of the probability that a driver can find a vacant on-street parking spot and the total number of cruising vehicles. The analyses can be made with simple observations of driving behaviors without the necessity of conducting a large intercept survey of visitors.

We now describe our Boston-area application of the suggested method. Sample size was small, and any survey having significant policy implications would require a larger sample size. Interviews were conducted on Saturday noon at Boston's Newbury Street and at the Boston Common, where on-street parking demand is large. We asked questions of those who had just entered a vacant on-street parking spot during most congested peak hours. Questions included cruising time, reneging time, and parking time. Using the collected data, we were able to evaluate performance indices proposed in our paper, *Congestion Pricing: A Parking Queue Model*. Here is a summary of the indices we evaluated:

Table 1 Performance Indices when Parking System is Saturated

Performance index	**Analytical Expression**
Expected number of cruising vehicles per on-street parking space	$\frac{L_q}{S} = \frac{\lambda - S\mu}{S\gamma} = \frac{\mu W_q}{1-\gamma W_q}$
Expected cruising time	$W_q = \frac{L_q}{\lambda} = \frac{\lambda - S\mu}{\gamma\lambda}$
Probability that a random arrival obtains a parking space	$\frac{S\mu}{\lambda} = \frac{S\mu W_q}{L_q} = 1-\gamma W_q < 1$
Congestion Charge	$MC_e = \frac{S\mu}{\lambda}\frac{c}{\gamma} = (1-\gamma W_q)\frac{c}{\gamma}$

λ = arrival rate of would-be parkers,
μ = departure rate from each on-street parking spot.
γ = reneging rate from the parking queue.
S = total number of on-street parking spots.
c = cost of delay per driver.
L_q = expected number of cruising drivers.
W_q = expected delay (cruising) time.

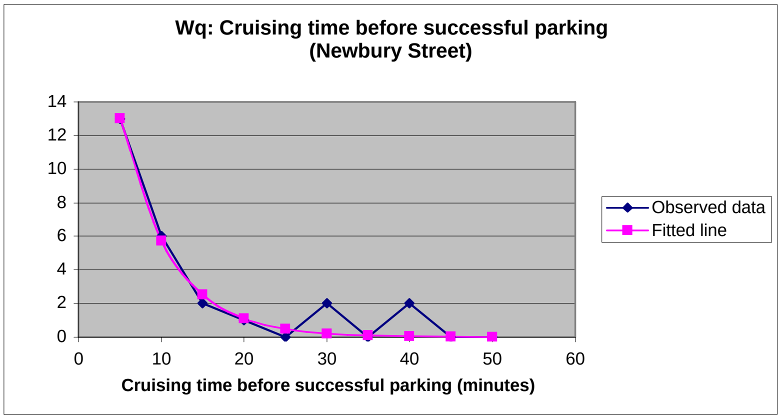
i) Mean parking time $1/\mu$

Although the parking time limit for on-street parking is two hours for both locations, the result of the survey shows that the averages are 120 minutes at Newbury Street and 158 minutes at Boston

Common, from which we obtain μ = 0.5 /hour and 0.38 /hour for Newbury Street and Boston Common, respectively.

ii) Mean cruising time W_q

The cruising time distribution for successful parkers follows a negative exponential distribution. The mean cruising time for successful parkers W_q is obtained by fitting negative exponential curve by least squares. We obtained $1/W_q$ = 9.8 /hour and 6.7 /hour for Newbury Street and Boston Common, respectively. We used STATA for non-linear statistical analysis. We obtained adjusted R^2 as 0.9563 for Newbury Street data and 0.9621 for Boston Common data, respectively.



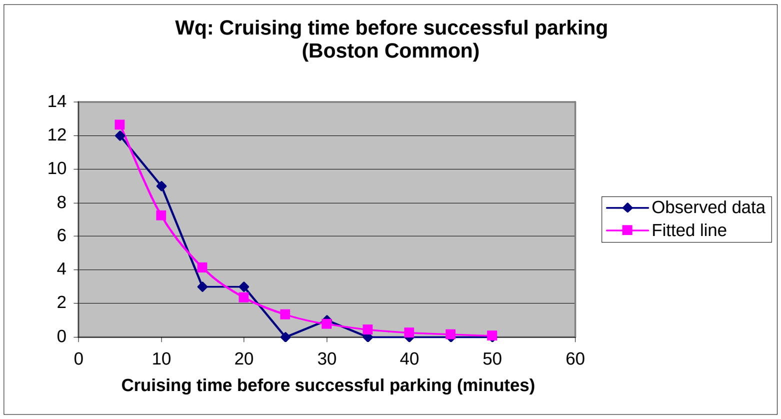


Figure 1 Cruising Time Distributions for Successful Parkers

We observed some discrepancies from the negative exponential distributions above. These irregularities may be caused by the preference of drivers to answer in round numbers, such as 10, 20, 30, and 40 minutes.

iii) Poisson reneging rate γ

We asked drivers who had just found an on-street parking space how long they initially planned to cruise (We call it maximum cruising time). The distribution of the maximum cruising time for successful parkers follows an atypical distribution.

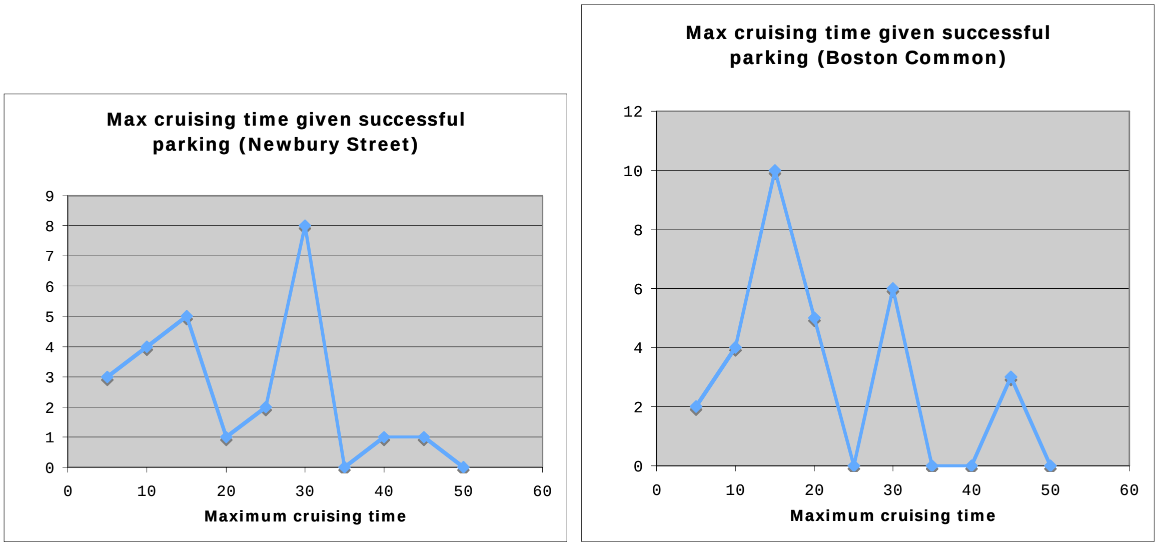


Figure 2 Maximum Cruising Time Distributions for Successful Parkers

We can obtain the remaining time until reneging by subtracting their actual cruising time from above. The results are as follows:

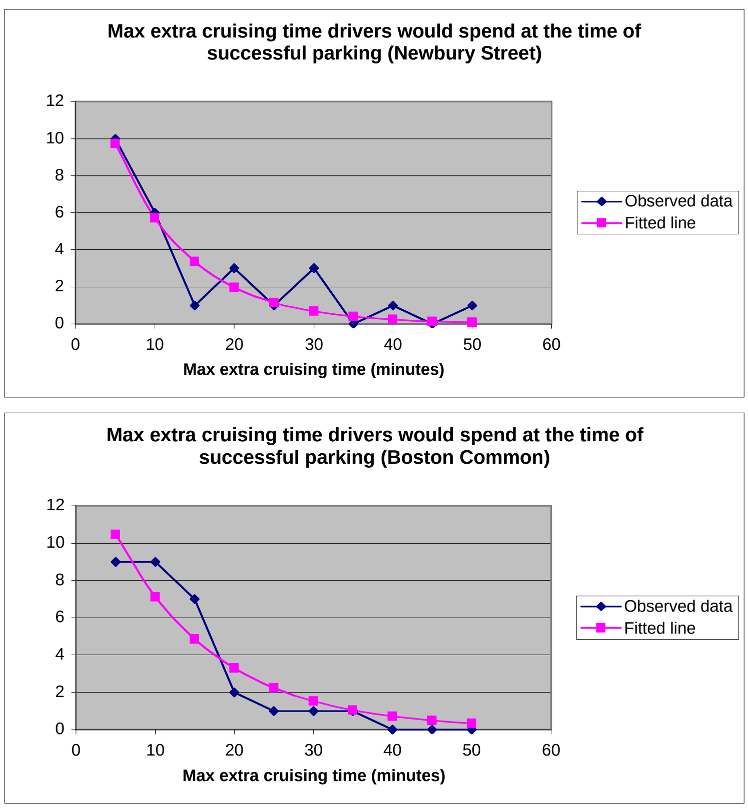


Figure 3 Reneging Time Distributions for Successful Parkers

We found that this reneging time roughly follows a negative exponential distribution. The Poisson reneging rate γ is obtained by fitting negative exponential curve by least squares. Again using STATA, we obtained γ = 6.4 /hour and 4.6 /hour for Newbury Street and Boston Common, respectively. The results of non-linear analysis are that adjusted R^2 is 0.8910 for Newbury Street data and is 0.9159 for Boston Common data, respectively. We believe that the results obtained here are sufficiently good to estimate γ.

iii) Cruising rate L_q/S and Congestion Charge (CC) MC_e

Using estimated parameters above, we found that the success rate of finding an on-street parking space is higher in Newbury Street (35%) compared to Boston Common (31%). The number of cruising vehicles per space, L_q/S, is higher in Boston Common (18%) than Newbury Street (14%).

Assuming the cost of time is $20 /hour, CC is calculated as about $1 /hour for the cruising drivers. Note that this CC only considers the cost for cruising drivers. If we take into account environmental and health concerns when evaluating the cost of congestion, the overall marginal external cost becomes larger.

5. POLICY RECOMMENDATIONS

The "Parking Queue" model gives us an insight into the cause of heavy cruising traffic: The reasons for heavy cruising traffic are low departure rate, low reneging rate, and high arrival rate. In the following, we discuss possible measures to reduce cruising traffic.

i) Increasing departure rate

To increase the departure rate μ, we can simply increase price of parking. An alternative is to punish longer-time on-street parkers and prioritize shorter-time parkers. This can be achieved by a progressive pricing scheme. For example, progressive on-street parking pricing is implemented in Manhattan: fees are $2 for the first hour, $3 for the second hour, and $4 for the third hour.

The reduction of parking time limits increases departure rate μ and thus reduces the parking queue. We can dynamically change parking time limits or set peak-time/off-peak-time parking time limits. Any time limit measures should be accompanied by strict enforcement in order to prevent drivers from parking longer than time limit by adding extra coins. Displaying signage indicating penalty fees explicitly would also discourage overtime parkers who do not realize the cost of parking violations.

ii) Increasing reneging rate

The reneging rate plays an important role in cruising traffic. To increase the reneging rate, off-street parking pricing structure should be fair and attractive to shorter-time parkers. However, we often observe the opposite parking pricing policy in a city. Examples of undesirable, aggressive fee structures for garage parking can be seen in many cities: for example, the parking fee in private parking garages quickly reaches its daily maximum after two or three hours of parking. This fee structure especially punishes shorter-time parkers and gives a disincentive for cruising drivers to "renege" to garage parking. In Japan, a free first thirty-minute parking scheme is implemented in about 30 public parking lots in Tokyo.[1] The purpose is to encourage the use of garage parking.

[1] http://www.tmpc.or.jp/contents/parking/30.html

Garage parking capacity is not be affected heavily by this policy because each free parking time is short. This free parking policy is socially desirable, although some subsidy may be required for private garage parking owners. The parking information system can also increase the reneging rate, and is one of the least expensive measures that we can take. According to our survey, many drivers are optimistic about finding an on-street parking spot. We also observed many cruising drivers who did not know the location/price/availability information about parking garages nearby.[1] Off-street parking information could change decisions to use cars for those who do not wish to try their luck.

iii) Reducing the arrival rate

Undoubtedly, people would drive into downtown less frequently if they had alternative options. The provision of alternatives contributes to a reduction in arrival rate and hence, to a reduction of cruising queue length. Extensive public transit or convenient park-and-ride systems are important in this regard. Imposition of a congestion charge MC_e on drivers through RP and PP is also very effective in reducing arrival rates. A congestion charge does not have to be a monetary charge. The high cost of cruising is equivalent to congestion charge for many drivers. This cost can be made higher by banning double parking and eliminating efficient cruising paths.

5. CONCLUSION

Traffic congestion is a problem of *the tragedy of the commons*. We can ameliorate the problem by charging for the usage of cars by various means such as road pricing (RP) and parking pricing (PP) schemes, cashing-out free parking schemes, and pay-as-you-go insurance. These measures are effective not only in realizing short-term reduced levels of congestion, but often also in promoting a shift from road "commons" to public transportation (PT) "commons", thereby leading to a more sustainable long-term solution. To implement successfully RP/PP schemes, it is important to recognize issues of fairness and equity, and to give the public alternative, less expensive transportation options such as PT.

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