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Rationing and pricing strategies for congestion mitigation: Behavioral theory, econometric model, and application in Beijing ☆

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ABSTRACT

Some travel demand management policies such as road pricing have been widely studied in literature. Rationing policies, including vehicle ownership quota and vehicle usage restrictions, have been implemented in several megaregions to address congestion and other negative transportation externalities, but not well explored in literature. Other strategies such as Vehicle Mileage Fee have not been well accepted by policy makers, but attract growing research interest. As policy makers face an increasing number of policy tools, a theoretical framework is needed to analyze these policies and provide a direct comparison of their welfare implications such as efficiency and equity. However, such a comprehensive framework does not exist in literature. To bridge this gap, this study develops an analytical framework for analyzing and comparing travel demand management policies, which consists of a mathematical model of joint household vehicle ownership and usage decisions and welfare analysis methods based on compensating variation and consumer surplus. Under the assumptions of homogenous users and single time period, this study finds that vehicle usage rationing performs better when relatively small percentages of users (i.e. low rationing ratio) are rationed off the roads and when induced demand elasticity resulting from congestion mitigation is low. When the amount of induced demand exceeds a certain level, it is shown analytically that vehicle usage restrictions will always cause welfare losses. When the policy goal is to reduce vehicle travel by a fixed portion, road pricing provides a larger welfare gain. The performance of different policies is influenced by network congestion and congestibility. This paper further generalizes the model to consider heterogenous users and demonstrates how it can be applied for policy analysis on a real network after careful calibration.

1. Introduction

Policy makers and researchers have proposed various policy tools to mitigate ever-growing congestion by allocating scarce road space more efficiently. Road pricing, the probably most well-known travel demand management policy, has been extensively studied in literature (e.g., Mohring and Harwitz, 1962; Arnott and Small, 1994; Verhoef, 2002; Zhang and Ge, 2004; Brownstone and Small, 2005 among others). The first-best pricing, when achievable, is an efficiency way to mitigate

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negative externality generated by traffic. However, road pricing has been controversial among the public because of its (1) similarity to another tax; (2) hefty transaction cost; (3) concerns on welfare distributional effects (Giuliano, 1994; Harrington et al., 2001; Yang et al., 2004; Zhang et al., 2008); (4) and privacy concerns due to certain fare collection technology. Several variants of the conventional road pricing scheme, including tradable credits (Yang and Wang, 2011; Nie and Yin, 2013), congestion pricing combined with revenue refunding (Guo and Yang, 2010), and tradable parking permit (Zhang et al., 2011), have recently been investigated in literature to address some of these concerns. In contrast, rationing as a policy tool does not involve any fee transaction and has been regarded as more equitable in resource allocation by some researchers in other industries (e.g. Evans, 1983). In general, rationing, or quantity control, does not achieve the first-best situation. But they could become very useful when we are dealing with basic life necessity (e.g. water in Renwick and Archibald, 1998), or when the price elasticity is too small (Guesnerie and Roberts, 1984). However, its role as a policy tool to address congestion problem has barely been studied in literature. Several studies focused on early experience in Singapore (Koh and Lee, 1994; Toh and Phang, 1997; Smith and Chin, 1997; Koh, 2003). A few existing studies in other regions include (Daganzo, 1995; Eskeland and Feyzioglu, 1997; Davis, 2008; Nakamura and Kockelman, 2002). The authors pointed out several limitations in current studies and recommended further research in this field. Wang et al. (2010) introduced a more comprehensive framework and considered the possibility of purchasing a second car under rationing policies. However, it did not consider the vehicle ownership rationing policy, and the vehicle usage (vehicle mileage of travel) was not related to the ownership decision.

While the effects of rationing in transportation have not been well understood, it has been implemented in several metropolitan areas. For example, Singapore started the Vehicle Quota System (VQS) in 1990 (Barter, 2005), which only releases a limited number of vehicle purchase permits each month through auctions. A similar quota system was adopted in Shanghai, China in 2001. A more drastic vehicle ownership rationing scheme, where residents can only acquire the vehicle purchase permits through monthly lottery, was recently implemented in Beijing, China (Lim, Accessed on Arpil 8, 2011). Rationing policies can be applied not only to vehicle ownership, but also to vehicle usage. For example, several Latin American countries introduced vehicle usage restriction measures due to emissions and air quality concerns in metropolitan area. Mexico City administration imposed a regulation banning each car from driving on a specific day of the week according to their license plate number in 1989 (dubbed as "Day without a Car"). Similarly regulation has been adopted by Sao Paulo, Brazil, Bogotá, Columbia, Quito, Ecuador, and Santiago, Chile (Davis, 2008). As congestion and air pollution problems deteriorate, vehicle usage restriction has been extended to some smaller cities, such as Medellín and Cali, with less than two million residents each. Outside Latin America, vehicle usage restriction is also seen in Beijing, China, Manila, Philippines, Lagos, Nigeria (Thomson, 1998), Athens, Greece (Kambezidis et al., 1995), as well as Guangzhou, China during the 2010 Asian Games (Hao et al., 2010).

As new technologies such as hybrid and electric vehicles emerge, some researchers propose policies such as Vehicle Mileage Fee that could serve both as solutions to decreasing gas tax (ironically due to the increased fuel efficiency) and travel demand management tools. As policy makers face an increasing number of policy tools, a theory is needed to analyze different pricing and rationing policies under an integrated framework and provide a direct comparison of their welfare implications such as efficiency and equity. However, such a theoretical framework does not exist in literature. To bridge this theoretical gap, this study develops an analytical framework for analyzing transportation pricing and rationing policies, which consists of a mathematical model of joint household vehicle ownership and usage decisions and welfare analysis methods based on compensating variation and consumer surplus. This integrated theoretical model also supports a direct comparison between rationing policies and pricing policy, and to illustrate their difference under various conditions.

2. Theoretical framework

For a traveler who is facing various travel demand management policies, the decision of owning a vehicle and the decision of using a vehicle are interrelated. Previous studies usually treat road pricing and vehicle ownership decisions separately, which prevents policy makers from analyzing pricing and rationing policies under an integrated framework. To correctly capture these behavioral dynamics in reaction to price changes and rationing policies, the proposed framework must be able to jointly model vehicle ownership and usage decisions. This study follows the indirect utility approach initiated by Dubin and McFadden (1984) in their study about residential electric appliance holdings and consumption because of its solid foundation in consumer behavior theory. Hausman (1985) developed similar framework in his work on wages and labor force participation. This approach was first introduced to the field of transportation by Mannering and Winston (1985) (an early version was presented at the 1982 Winter Meeting of the Econometric Society) in their seminal work on household vehicle ownership and utilization. They also extended this approach from static to dynamic models and addressed several econometric issues in model estimation. Train (1985) provided another early application on car ownership study. Following these early works, many researchers, including Winston and Mannering (1984); Hensher et al. (1992); De Jong (1990); Goldberg (1998), and West (2004) have further extended and applied this indirect utility approach in various context (De Jong et al. (2004) provided a review).

In this study, we consider a household who seeks to maximize its utility under a budget constraint. We consider two goods: vehicle usage (A) and all other goods (X). The household faces a discrete choice of owning vehicles and a continuous choice of vehicle usage conditional on the ownership choice. This joint decision gives the consumption of vehicle usage and