ARTICLE IN PRESS

Economics of Transportation (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Economics of Transportation

journal homepage: www.elsevier.com/locate/ecotra

On the potential remedies for license plate rationing

Yu (Marco) Nie*

Department of Civil and Environmental EngineeringNorthwestern University 2145 Sheridan Road, Evanston, IL 60208, USA

ARTICLE INFO

Keywords:
License plate rationing
Travel demand management
Permit trading
User heterogeneity
New vehicle quota

ABSTRACT

This paper analyzes three travel demand management policies designed to correct the shortcomings of license plate rationing (LPR). The first policy couples LPR with a new vehicle quota scheme that directly controls auto ownership. The other two policies turn the driving permit into a tradable commodity. They differ, however, in that one policy ties the permit to the license plate while the other bestows all travelers with equal driving permits. All new policies may be viewed as "derivatives" of LPR because they share some key features: simplicity and revenue neutrality. Using a conceptual model that considers two modes (transit and driving) and user heterogeneity, we analyze user equilibrium solutions under each new policy, and for policies based on permit trading, introduce and characterize a function that links individuals' trading behavior to their value of time. Our analysis and numerical experiments show that giving tradable permits to all travelers is more efficient than the other alternatives. Under this policy, travelers who decide to own automobiles will acquire enough permits from those who do not so that the former can drive without any restriction. Consequently, the permit each traveler should receive can be easily determined from the ratio between a desired highway flow level and the total demand. Importantly, when the desired flow level equals the system optimal flow, the policy is revenue-neutral and first-best under idealized conditions.

1. Introduction

Travel demand management (TDM) policies have been a recurrent theme in transportation systems analysis (e.g. Beckmann et al., 1956; Ferguson, 2000; Gärling et al., 2002; Small and Verhoef, 2007). These policies are widely considered useful tools for solving the chronic traffic congestion problem in big cities, arguably the "Holy Grail" of the field. They also increasingly appear in the discussions of sustainable cites since traffic congestion contributes to excessive energy consumption and emissions of green house gas and air pollutants (Schrank et al., 2012; DOE, 2014).

Managing travel demand always involves, in one way or another, inducing or forcing behavioral/attitudinal changes regarding an essential public good, i.e., roads. Not surprisingly, the public often meets any proposals of TDM policies with suspicion and hesitation, if not outright rejection. Congestion pricing, for example, has only been successfully implemented in a handful of cities in limited forms (Lindsey et al., 2012), despite transportation economists had appraised and advocated the policy passionately for decades, supported by convincing theoretical arguments (Vickrey, 1969; Hau, 1992; Yang and Huang, 2004; Tsekeris and Vos, 2009; de Palma and Lindsey, 2011). High profile failures such as Hong Kong in 1987 (Hau, 1990), Edinburgh in 2006[1] and New York in 2007,[2] serve as vivid reminders of the extraordinary challenge to win public support for the policy.

Interestingly, a seemingly more intrusive TDM policy, known as *license plate rationing* (LPR), has begun to gain popularity in recent years, mostly in developing countries. The first large scale LPR was implemented by the Mexico City in 1989 (Eskeland and Feyzioglu, 1997; CA, 2007), which bans each car from being driven on a specific day of the week, based on the last digit of its license plate number, hence the name. Since then, at least seven cities have implemented similar policies: Manila, Philippines (1996, see GUETA and GUETA, 2013), Sao Paulo, Brazil (1997, see CA, 2007), Bogota, Columbia (2000, see CA, 2007), and four Chinese cities (Beijing, Chengdu, Tianjin, Hangzhou, all adopted the policy since 2011, see Nie, 2016). However, the long-term effectiveness and efficiency of LPR policies have been repeatedly challenged in the literature, empirically and theoretically. Eskeland and Feyzioglu (1997) observed that the policy failed to reduce driving in the Mexico City. GUETA and GUETA (2013) made a similar observation for the city of Manila. Later, Davis (2008) found no evidence that the policy improved air quality in the Mexico City, a promise based on which the policy was sold to the residents. For

* Corresponding author.
E-mail address: y-nie@northwestern.edu.

[1] http://news.bbc.co.uk/2/hi/uk_news/scotland/4287145.stm, last visited on 6/21/2015.
[2] http://www.nytimes.com/2007/07/17/nyregion/17congestion.html?_r=0, last visited on 6/21/2015.

http://dx.doi.org/10.1016/j.ecotra.2017.01.001
Received 3 April 2016; Received in revised form 4 January 2017; Accepted 18 January 2017
2212-0122/

Beijing, a study using data from 2009 to 2014 found that, since LPR went into effect in 2011, traffic conditions have been significantly improved in the restricted time period, with travelers shifting to buses and taxis[3] Yet, Nie (2016) showed that the positive effect of LPR has been more than offset by the steady growth in the auto ownership by the end of 2014. A report published by the Regional Plan Association of New York City (Zupan et al., 2007) compares LPR with congestion pricing, and concludes that LPR is far less effective in generating congestion relief and pollution reduction. The findings of the empirical studies are also echoed by theoretical analysis. Eskeland and Feyzioglu (1997) suggest that LPR may lead to high welfare losses because it could curtail trips with high willingness to pay. Zhu et al. (2013) show that when the induced demand is considered LPR always leads to welfare losses. Wang et al. (2010) characterize equilibrium solutions under LPR, using a general network model that allows travelers to acquire additional vehicles to bypass the restriction. They show that the policy is Pareto-improving if no one-car traveler's average travel time increases after LPR is implemented, a condition not particularly easy to fulfill, especially if many desire to buy the second car. Recently, using a simplified model of Wang et al. (2010), Nie (2016) shows that LPR may impact the ability of other TDM policies to maximize system efficiency, when jointly implemented.

In light of the evidently negative picture, one cannot help but wonder why policy makers seem more willing and able to implement LPR than congestion pricing.[4] While many factors could be at play, two are likely dominating the others. The first has to do with the fact that LPR is relatively easy and cheap to implement and enforce. It does not require dedicated infrastructure and complicated collection/redistribution schemes essential to congestion pricing. Second and perhaps more important, LPR is revenue neutral and hence likely to be perceived fairer by the public, because all travelers, rich or poor, are subject to the same driving restriction. In comparison, congestion pricing is often considered a regressive policy that benefits the rich at the expense of the poor (Evans, 1992; Arnott et al., 1994; Hau, 1998; Taylor and Kalauskas, 2010).

Motivated by the practicality and implementability of LPR, this paper aims to explore potential remedies that would help overcome the known shortcomings of the policy. In seeking alternative policies, the primary criterion is to keep the key features of LPR: simplicity and revenue neutrality. Specifically, the following three policies will be considered:

1. LPR coupled with new vehicle quota (NVQ) (Chin and Smith, 1997).[5] The idea is that coupling LPR with NVQ would help curtail the growth of auto ownership triggered by LPR, hence improve its effectiveness.
2. LPR coupled with trading among auto owners. The promise of trading the "permit" to drive is that for some travelers, desirable access to driving may be achieved at a lower cost by purchasing such permits than the second car.
3. Permit rationing and trading among all travelers. This policy aims to avoid making the right to drive as a de facto "entitlement" of auto owners, which not only is unfair, but could also induce excessive demand for auto ownership.

The above policies will be analyzed using the same model as in Nie and Liu (2010) and Nie (2016), which explicitly considers mode choice and user heterogeneity. The model is derived from that of Wang et al. (2010), but reduces its general network representation to a single road for better analytical tractability.

The idea of allowing all travelers to trade driving permits is inspired by recent studies on tradable credit schemes (TCS) (see e.g. Verhoef et al., 1997; Viegas, 2001; Yang and Wang, 2011; Nie, 2012, 2013; Wang and Yang, 2012; Nie and Yin, 2013; Xiao et al., 2013; Ye and Yang, 2013). One can argue that the second and third policies above may be viewed as variants of TCS that are coarser but are easier to implement and enforce. There are notable differences, however. To the best of our knowledge, credit trading only in a subset of all travelers has not been explored in the literature. A more important distinction of the proposed analysis is the consideration of heterogeneous trading behavior. Specifically, the number of credits bought/sold is assumed to depend on individuals' value of time (modeled as a continuously distributed random variable) through a so-called *trading function*. We shall characterize this trading function and reveal its differences under the two trading policies. Our analytical and numerical results will show that the third policy above is the most promising of the three in terms of alleviating traffic congestion and improving social welfare.

The rest of the paper is organized as follows. Section two briefly reviews the model. Sections three to five analyze the three new LPR-based TDM policies to establish theoretical results that help qualitatively assess their effects. Results of numerical experiments are discussed in Section six. Section seven concludes the study with a summary of findings and future research topics.

2. The model

For completeness, we briefly review the model in this section. The reader is referred to Nie and Liu (2010) and Nie (2016) if more details are desired.

Consider a single origin-destination (O-D) network that has a fixed demand d and is connected by two routes that essentially represent the choice of two modes: riding transit and driving on highway with a private automobile. The travel time on the highway is denoted as $\tau(q)$, which is a strictly increasing and convex function of the highway flow q. The transit travel time γ is assumed to be a constant. c_A and c_T denote the user costs associated with driving on highway and riding transit respectively. Let ϕ be the amortized cost of owning a vehicle, referred to as the *auto capital cost* hereafter. To simplify the analysis, we assume $\gamma > \tau(0)$, $c_A > c_T$ (Nie and Liu, 2010).

Travelers are heterogeneous in the sense that the value of time (VOT, denoted by β) is different. The distribution of β among travelers is denoted as $F(\beta)$, where $F(\beta_0)$ is the total number of travelers whose value of time $\beta \geq \beta_0$. Accordingly, $F(\beta_L) = d$ and $F(\beta_U) = 0$, where β_L and β_U are minimum and maximum VOT among all travelers, and $\beta_L \geq 0$. For simplicity, we shall also assume that $F(\cdot) \in \mathcal{F}$, where $\mathcal{F}$ is a class of *continuous* and *strictly decreasing* function defined on $[\beta_L, \beta_U]$. Thus, any individual can be identified according to β or a ranking in the population $q = F(\beta)$. Conversely, for any given q, $F^{-1}(q)$ identifies a unique β. For homogeneous travelers with the same β, F^{-1} would be a horizontal line between 0 and d with a height of β.

The total *travel cost* of an individual is a combination of the monetary value of travel time, operating cost and auto capital cost (if any). When the highway flow is q, the travel cost of an individual with a VOT β is

$$u_A = \beta\tau(q) + c_A + \phi, \quad \text{and} \tag{1a}$$

$$u_T = \beta\gamma + c_T, \tag{1b}$$

for driving and using transit, respectively. Following the standard assumption in transportation (e.g. Wardrop, 1952), we assume that travelers always choose either of the modes to minimize their own travel cost. Accordingly, the bi-modal network admits a user equili-

[3] Yang, Jun, Fangwen Lu and Ping Qin. 2016. How does a driving restriction affect transportation patterns? The medium-run evidence from Beijing. Environment for Development, Discussion paper 16-10,http://www.rff.org/files/document/file/EfD-DP-16-10.pdf.

[4] In fact, since 2007 congestion pricing has been considered by various Chinese cities (e.g. Shenzhen, Guangzhou, Shanghai and Beijing, see Nie (2016)). Yet, so far not a single one has adopted it. LPR seems to be received much better, however.

[5] The policy had been adopted by several Chinese cities, including Beijing and Shanghai (see Wang, 2010; Nie, 2016).