Transportation Research Part E 68 (2014) 138–154

Contents lists available at ScienceDirect

Transportation Research Part E

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

# Tradable credit scheme for mobility management considering travelers' loss aversion

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ARTICLE INFO

*Article history:*
Received 14 September 2013
Received in revised form 7 May 2014
Accepted 9 May 2014

*Keywords:*
Mobility management
Traffic equilibrium
Tradable credit
Loss aversion
Transaction cost

ABSTRACT

Under a given tradable credit scheme, travelers' loss aversion behavior for credit charging during the route choice process is studied. A disutility function of loss aversion is applied to approach travelers' different attitudes towards credit loss and gain, and the transaction costs of buying and selling credits are also incorporated in the function. The user equilibrium (UE) and market equilibrium (ME) conditions considering loss aversion effects are formulated into a variational inequality (VI) problem. Analyses demonstrate that the system optimum (SO) credit scheme does not always exist. A proposition is further presented to guarantee its existence.



## 1. Introduction

Road transport has an overriding role in economic activity and growth. However, road traffic congestion has a range of undesirable consequences, including increasing impacts on travelers, negative economic impacts resulting from the inefficient and unreliable distribution and delivery of goods, services and resources, lost productivity, increased vehicle operating costs, and environmental pollution. Essentially, road transport is a public good that suffers from over consumption due to lack of clear property rights, results in traffic congestion.

To alleviate traffic congestion, different instruments have been proposed. Generally, these instruments used to address congestion fall into five groups (SPECTRUM, 2005; Santos et al., 2010; Grant-Muller and Xu, 2014): infrastructure, public transport, physical restrictions on vehicle use, technology instruments, and economic instruments. Economic instruments to address road traffic congestion can be further categorized as command and control and incentive-based measures. The former are widely used and involve government regulations to compel consumers and producers to change behavior. Incentive-based measures can be separated into two main approaches: fiscal instrument and quantity control. Fiscal instrument is widely used in road transport, for example, taxes, charges (e.g., the London Congestion Charging Scheme, May, 2005), subsidies, etc. Road congestion charge measure has been regarded as an efficient strategy to alleviate congestion and has been applied in some cities. However, it may cause inequity and be perceived as another flat tax and often be objected by the public (Yang and Huang, 2005). Quantity control combines economic incentives and regulation by quantity. It includes number plate rationing measure, tradable credit schemes, etc. However, the number plate rationing measure has only short-term

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http://dx.doi.org/10.1016/j.tre.2014.05.007
1366-5545/

effectiveness. In the long run, this instrument just leads to an increase of the total amount of vehicles, specially, for old, cheap and polluting vehicles (Davis, 2008; Mahendra, 2008).

Using tradable credit schemes for road transport congestion management has received much attention in recent years. Although tradable credit schemes are not new measures and have been used in the environmental field, particularly in relation to pollution control where they are used in practice, they are new for traffic congestion management. It appears that researchers in transport economics view the potential of tradable credit schemes in road traffic congestion management rather favorably. Yang and Wang (2011) introduced a tradable credit scheme to manage road mobility problem. Under this scheme, the government will initially distribute credits freely to all eligible travelers and travelers must pay different amount of credits for their trips based on different choices of routes. Travelers therefore can buy or sell credits in a free market according to their travel demands. Compared with the conventional road pricing, Yang and Wang (2011) pointed out that the tradable credit scheme is revenue neutral and more fair. Recent studies on tradable credit schemes on road transport also include Wang et al. (2012), Nie (2012), Chen and Yang (2012), Wu et al. (2012), Wang and Yang (2012), Xiao et al. (2013), Tian et al. (2013), Nie and Yin (2013), Wang et al. (2014a), Wang et al. (2014b,c), He et al. (2013), Zhu et al. (2014) etc. Fan and Jiang (2013) compared and contrasted the various tradable permit schemes proposed in the literature as an innovative way of allocating roadway capacity. A detailed review of the tradable credit schemes and their roles in road traffic congestion management is given by Grant-Muller and Xu (2014).

According to Yang and Wang (2011), the route choice criterion of travelers under a given tradable credit scheme can be considered as to minimize the generalized travel cost. The generalized travel cost consists of two parts: (1) the usual travel time cost; (2) the credit cost. The credit cost of a route is given by the number of consumed credits multiplied by the unit credit price. In this case, travelers' generalized travel cost is independent of the initial credit distribution among them. However, individual travelers' total demand for credits may be either higher or lower than their initial allocation. Depending on their route choice, they may either sell extra credits to earn monetary reward or buy additional credits at their own cost to fulfill their travel plan. This is fundamentally different from a road pricing scheme under which travelers will always have to pay for their routes with toll charge. Due to their different attitudes towards monetary gain and loss under a tradable credit scheme, travelers may exhibit different route choice behaviors. Inspired by this consideration, this paper aims to considering travelers' loss aversion behavior for credit charge in their route choice under a given tradable credit scheme.

Loss aversion is a basic preference property, which reflects the phenomenon that people treat losses and gains asymmetrically. It plays an important role in decision-making (Kahneman et al., 1986). Most application of loss aversion in the transport field is the cumulative prospect theory (CPT, Tversky and Kahneman, 1992) based models under risk or uncertainty (e.g. Avineri, 2004; Avineri and Prashker, 2003; Fujii and Kitamura, 2004; Avineri and Prashker, 2004; Jou et al., 2008). Avineri (2006) considered the prospect value of travel time as travelers' route choice criterion in a stochastic case. Connors and Sumalee (2009) presented the generalized prospect-based user equilibrium for travel time and formulated a variational inequality problem. Xu et al. (2010) studied the endogenous reference points of the travel time in prospect-based user equilibrium.

Besides the application in prospect theory, loss aversion is also an important part in riskless choice. Tversky and Kahneman (1991) investigated loss aversion in riskless choice and presented a reference-dependent model. The reference-dependent model is characterized by n attributes whose outcomes are certain while the CPT model is characterized by a prospect value which depends on attributes whose outcomes are uncertain. De Borger and Fosgerau (2008) and Hess et al. (2008) formulated reference-dependent route choice models following the framework proposed by Tversky and Kahneman (1991). Delle Site and Filippi (2011) incorporated a reference-dependent route choice model within the stochastic user equilibrium (SUE) and the value-of-time (VOT) analysis. Latter, Delle Site and Filippi (2012) provided a new SUE model with reference-dependent route choice, where the reference points are determined consistently with the equilibrium flows and travel times.

In this paper, we discuss travelers' loss aversion for credit charge in their riskless route choice behavior under a given tradable credit scheme and formulate a new reference-dependent user equilibrium model. Given a tradable credit scheme, travelers are assumed to know exactly about the amount of credits charged by different routes, and therefore their choices are riskless. Travelers must buy extra credits from the market if the amount of credits they consumed exceeds their initial endowment, which means a loss to them; on the other side, they can sell their extra credits, which means a gain to them. From psychological analysis of choice, loss looms larger than gain, therefore it is not sufficient to consider the related credit cost in travelers' route choice as the used amount of credits multiplied by the unit credit price.

We shall apply the value function proposed in Tversky and Kahneman, 1991Tversky and Kahneman's prospect theory (1991) to deal with riskless choice, which, as already mentioned above, has been adopted in many studies (Camerer et al., 2004; Delle Site and Filippi, 2011; Delle Site and Filippi, 2012). Compared with the routes with less credit charge, the cost of the routes with more credit charge will be multiplied by an additional parameter, termed as the loss aversion coefficient. The loss aversion coefficient is a constant greater than or equal to 1, its exact value depends on travelers' degree of loss aversion. In this way, travelers attach more weight to loss (the routes charge more credits than the reference credits), thereby adding realism to the corresponding traffic assignment results.

Apart from consideration of travelers' loss aversion, the transaction cost of a given credit market cannot be ignored, as showed in Nie (2012) and He et al. (2013). We therefore incorporate the transaction cost of buying and selling credits in travelers' disutility function. It is noted that the transaction cost is defined as per unit of trading credit and is independent of the credit price (Nie, 2012). However, the transaction costs of buying and selling credits may be different in the credit market,