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Trip mode and travel pattern impacts of a Tradable Credits Scheme: A case study of Beijing

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ABSTRACT

We examine how trip mode and travel pattern of travelers are influenced by a given Tradable Credits Scheme (TCS). An analysis framework is proposed to investigate the effects of a basic TCS. Using a simulation analysis and case study from the Beijing municipality, we demonstrate that a TCS can achieve a target for reducing the expected car kilometers. The research demonstrates that a TCS will have an effect on travelers' mode choice. However, it is likely to have only a minor effect on the overall travel pattern in terms of OD movements.

1. Introduction

Mode choice is a fundamental issue in transport studies and one which has been heavily researched (see, for example, Ben-Akiva and Lerman, 1985; Dijst et al., 2002; Hensher and Rose, 2007; Van Exel and Rietveld, 2009; Ho and Mulley, 2013; Chidambaram et al., 2014; Habib and Weiss, 2014). However, many of these studies are based on a disaggregate approach and have sought to understand how travelers' mode choice behavior is affected by a series of factors, based on analysis of past (or anticipated) travel data. Other studies of transport mode choice have been based on a macroscopic network equilibrium approach, e.g., (Sheffi, 1985; Jara-Dıaz and Videla, 1989; Oppenheim, 1995; Ortuzar et al., 2001; Xu and Gao, 2009; Can, 2013; Zhao et al., 2013).

The notion of the Tradable Credits Scheme (TCS) has evolved over a relatively long period, particularly in relation to pollution control, where it has been well studied and used in practice. In the transport sector, the scheme is a particular case of a wider group of so-called economic instruments that have used pricing or changes to income to influence travel behavior and transport choices. Economic instruments have a strong, direct leverage on both fixed and variable prices related to travel choices. Fixed price schemes include the use of registration fees and car ownership costs, whilst examples of variable pricing includes public transport (PT) fare structuring, variable parking charges and toll fees. Other types of economic instruments include positive 'incentive-based' policies, taxes and subsidies on vehicle purchase, scrappage incentives, taxes on vehicle use, emission taxes, fuel taxes, vehicle kilometer traveled taxes, congestion charges and pay-as-you-drive insurance. See (e.g. Santos et al., 2010; Ben-Elia and Ettema, 2009; 2011a; 2011b; Potter et al., 2006; Beck et al., 2013).

A significant tranche of research has also been carried out on alternative transport management policies, largely to understand the role these policies playing in achieving sustainable development of the transport system. Various travel demand management policies have been proposed and analyzed in the context of mitigating traffic congestion, with examples including the use of reward measures (Verhoef et al., 1997; Bliemer and Van Amelsfort, 2010; Ben-Elia and Ettema, 2011b), tradable driving rights (Akamatsu, 2007; Yang and Wang, 2011), road pricing (Yang and Bell, 1997; Yang and Huang, 2005) and rationing (Zhu et al., 2013). Examples of 'command and control' policies include controls on car ownership (e.g. a quota system for new vehicle plates in Singapore, Chin and Smith, 1997) and a driving ban scheme in Mexico City (Davis, 2008).

Concerning studies of mode choice behavior, the literature reflects areas that have had particular attention. Examples include logit-based mode choice analysis under road pricing (Huang, 2002), which provides some discussion of the classical bottleneck model. Tirachini and Hensher (2011) address policies around multimodal transport pricing. Recently, Wu et al. (2012) present optimization model to design equitable and efficient tradable

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credit schemes for general multimodal transportation networks. Tian, Yang and Huang (2013) examine a two-mode problem (auto and transit modes) under a TCS with a bottleneck modal (Arnott, de Palma and Lindsey, 1993) which a physically separated transit mode is parallel to a highway with a bottleneck, and demonstrated that a TCS which emulates the bottleneck congestion pricing and transit subsidy in a revenue-neutral manner. However, further studies are necessary to identify how a TCS may impact on transport mode choice of travelers.

TCSs cover a variety of instruments that range from the introduction of flexibility into regulation to the organization of competitive markets for credits (Goddard, 1997). Quantified physical constraints are set in the form of credits allocated to groups of agents consuming scarce resources, and permission is granted to transfer these quotas between activities, products or places (offsetting), periods of time (banking) or to other agents (trading, hence "tradable credits"). For travel demand management, a tradable credit scheme can reward travel patterns and provide a continuing incentive for travelers to manage their credits, e.g. reducing credit use by carpooling or using PT. Through the design of credit based measure, it is possible to achieve desirable outcomes of travel demand management.

In comparison to the case of road pricing and some other economic policies for travel demand management, TCS is a relatively new measure both in theory and in practice. The lack of practical application of this economic measure may be attributable to an undeveloped and incomplete theoretical foundation and particular practical issues that are yet to be resolved (Grant-Muller and Xu, 2014). However, the idea of TCS provides a promising policy approach for mobility management and has received increasing attention in recent years. Section 2 presents a literature review of the art-of-state studies of TCS within the transport field, from which it is apparent that most recent studies on TCS have largely focused on macroscopic analysis.

A fundamental question is whether a TCS is likely to affect travelers' mode choice if it were implemented in practice. In the same way that road pricing polices (used in London and Singapore for example) have impacted on demand for private vehicle travel, it is quite possible that a TCS may have a similar effect and reduce the number of vehicle kilometers traveled (VKT). In this study, we examine how travelers' mode choice preferences may be influenced by implementing a TCS in an urban setting. The study supposes that the regional authority is responsible for implementing the TCS, the initial credit allocation is free and individuals receive a number of credits (representing vehicle-kilometers) based on a target of reducing the overall total VKT for the urban area. Individuals, in maximizing their utility, must consider their travel mode choice based on their credit allocation. That is, the individual must consider the permitted number of kilometers, the credit price (p_e) and then determine how many further credits they should purchase if they wish to travel additional kilometers using a private car.

To investigate the influence of a TCS on travel mode choice and different from existing studies i.e. Wu et al. (2012) and Tian et al. (2013), we present a microeconomic quantitative analysis framework to simulate policy scenarios. Travel patterns are compared before and after introduction of a TCS. This study presents a framework which connects a microeconomic analysis (of individual travel mode choice) and a macroscopic network analysis (i.e. the travel pattern for a network) in order to analyze a specific transport demand management policy (i.e. the TCS). Therefore, a TCS based on VKT for travel demand management is outlined and a new travel demand management policy analysis framework based on a neo-classical microeconomic model is presented.

The organization of the paper is as follows. In Section 2, a brief review of TCS and the appropriateness of the Constant Elasticity of Substitution (CES) approach are presented whilst in Section 3, a policy analysis framework for transport mode choice with a TCS is proposed. In Section 4, we develop an estimation model of the individual average vehicle kilometers (based on a neo-classical microeconomic model) with and without a TCS, including the credit equilibrium price and the travel pattern in different zones. In Section 5, the detail of the analysis framework is given, including scenario setting with and without a TCS, input data, and investigation process, based on a small network. We discuss and further compare the effects of a TCS on transport mode choices in Section 6, based on survey data and the presented analysis framework for the case of Beijing municipality. Finally, Section 7 concludes the paper.

2. Problem description and basic considerations

2.1. TCS: a cap-and-trade measure

A TCS usually assumes the form of a cap-and-trade system (Dales, 1968). It often targets a certain level of activity (for example, emissions), assigns credits to match the targeted total quantity and allows consumers, organizations and other entities to trade the credits at an endogenously determined price. To the extent that quantity control instruments involve a trading mechanism, they also provide price incentives to the regulated parties (Hepburn, 2006). Although market efficiency could be satisfied by an auction or other measures and some challenges in policy implication (Sovacool, 2011), the credit allocation mechanism is important. For example in emission control political concerns often favor a proportional allocation based on historical emission records. The credit allocation mechanism has been applied in a variety of different contexts including controlling air pollution, the degradation of wetlands, agricultural pollution, water scarcity and fisheries depletion (OECD, 2004). Examples include an oligopolistic power market model with tradable NO*x* permits (Chen and Hobbs, 2005), biodiversity conservation with tradable credits (Drechsler and Watzold, 2009), Nitrates control in groundwater (Morgan et al. 2000), regulation of an airline duopoly on a congested airport (Verhoef, 2010), emission reduction from air transport (Carlsson and Hammar, 2002; Mendes and Santos, 2008), incorporating the transport sector into a carbon cap-and-trade program (Ellerman et al., 2006; Millard-Ball, 2008; Jochem, 2008), pollution permits to reduce car ownership in the UK (Walton, 1997) and land use management (Henger and Bizer, 2010).

Recent investigations on travel mobility management using tradable credits include a series of studies since the work of Yang and Wang (2011), which has discussed the management of road network mobility with tradable travel credits with a network modeling approach. Continuing this innovative research, there are further series studies on the TCS for travel behavior analysis, see for example, (Wu et al., 2012; Wang and Yang, 2012; Wang et al., 2012; He et al., 2013; Nie and Yin, 2013; Xiao et al., 2013; Tian et al., 2013; Bao et al., 2014; Wang et al., 2014a, 2014b; Zhu et al., 2014; Mamun et al., 2016). Table 1 characterizes existing TCS approaches used in the transport sector for mobility management, along with examples of where such schemes have been adopted. Recent reviews on TCS can refer to Fan and Jiang (2013) and Grant-Muller and Xu (2014), where Fan and Jiang (2013) reviewed a variety of TCSs for roadway capacity allocation focusing on detailed system design and overall functions, and Grant-Muller and Xu (2014) has focused on the TCS roles in road traffic congestion management.

In this paper, we discuss how to use a TCS for mobility management and form a comparison with existing studies of TCSs. Supposing that a government authority needs to control the total VKT by private car in an urban area or region, it will need to