Transportation Research Part D 48 (2016) 248–266

Contents lists available at ScienceDirect

Transportation Research Part D

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

Modeling the effects of vehicle emission taxes on residential location choices of different-income households

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ARTICLE INFO

Article history:

JEL classification:
R14
R48
H21
H23

Keywords:
Vehicle emission taxes
Income class
Residential segregation
Monocentric city

ABSTRACT

Taxing vehicle emissions has been advocated as an effective measure to solve the smog and haze problems in China. This paper investigates the effects of vehicle emission taxes on residential segregation in a model of a monocentric city with two income classes. The proposed model explicitly considers the interactions among three types of stakeholders, namely the authority, property developers and heterogeneous households in terms of income level. The properties of the proposed model are analytically explored and the optimal vehicle emission taxes that maximize the social welfare of the urban system are determined. The conditions under which either the rich or the poor lives in the urban central area while the other class in the suburb are identified. The findings show that (i) a high emission tax can drive the low-income households to migrate from suburbs to urban central areas, and the high-income households to migrate from urban central areas to suburbs; (ii) the implementation of the vehicle emission taxes can effectively reduce the air pollution cost and increase the total social welfare of the urban system; and (iii) the emission tax policy may incur inequity issue in terms of change in utility levels of different income classes before and after introducing the vehicle emission taxes.

1. Introduction

Smog and haze weather has currently become a serious threat to people's health in many large Chinese cities. There is a wide consensus that transportation is a main contributor to air pollution and climate change due to vehicle emissions (Black and Sato, 2007; IPCC, 2013). According to the latest report by the Beijing Environmental Protection Bureau (BJEPB, 2014), about 31.1% of total amount of PM2.5 caused by the local pollutants in Beijing comes from transportation. The continuing growth in the number of motorized vehicles due to rapid urban expansion and economic growth is further exacerbating the environmental problems. Taxing vehicle emissions has been advocated as an effective measure to control pollutant emissions so as to create a sustainable urban transportation system (Sevigny, 1998). The implementation of the vehicle emission taxes will increase the commuting cost, and thus affects the households' residential location choices. Naturally, this raises an interesting and important question: how do the vehicle emission taxes affect the urban residential patterns?

It has currently been observed in some large Chinese cities that high-income households and low-income households live separately in space with each other (Zhou et al., 2015). Such a phenomenon is called residential segregation by

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http://dx.doi.org/10.1016/j.trd.2016.08.016
1361-9209/

income (Watson, 2009; Reardon and Bischoff, 2011). Particularly, high-income households in China prefer to reside in the urban central areas, whereas low-income households tend to live in the suburban areas. However, a reverse residential pattern (i.e., high-income households reside in the suburbs, whereas low-income households reside in urban central areas) occurs in some other countries or areas, such as Detroit in the United States (Brueckner et al., 1999; Glaeser et al., 2008). Obviously, the urban residential patterns can affect travel demand distribution and traffic emissions over the city, and thus the specification/determination of the vehicle emission taxes. This raises another important question: how to design the optimal vehicle emission taxes such that the social welfare of the urban system is maximized?

To address these intriguing problems, an advanced urban model should be developed to help explain and evaluate the effects of the vehicle emission taxes on urban system. In the literature, the classical monocentric urban model, which was developed by Alonso (1964), Muth (1969) and Mills (1972), and was summarized and developed nicely by Brueckner (1987), has been widely recognized as a benchmark representation of the urban spatial structure. In the classical urban model, it was usually assumed that all the households are homogenous in terms of their income levels, which may cause a significant bias in the prediction capability of the model in the urban spatial structure and thus hinder its application in practice. Wheaton (1976) extended the classical single-class urban model to a two-class monocentric urban model and investigated the effects of change in household's income level on the welfares of rich and poor people. His model has already been widely extended by some previous studies. For example, Hartwick et al. (1976) carried out the comparative static analysis of a general model with several household classes. Sasaki (1990) extended the Wheaton's model to consider transportation mode choice in the two-class monocentric urban model. Kwon (2003) identified a sufficient condition under which an increase in the wages of the rich living in the suburban area of a city harms the welfare of the poor living in the central area of the city. Borck and Wrede (2005) analyzed the effects of commuting subsidies on the equilibrium utilities of rich and poor people under different land ownerships and residential patterns. However, these aforementioned studies usually assumed a given and fixed residential pattern and thus cannot explain the residential segregation phenomenon. Brueckner et al. (1999) presented a new two-class monocentric urban model based on an amenity-based theory to explain why central Paris was rich and downtown Detroit was poor. Glaeser et al. (2008) further addressed this issue from the perspective of the accessibility to public transportation.

However, all these previous related studies did not consider the environmental externalities caused by vehicular usage and the effects of the vehicle emission taxes on urban system. It has been shown in Verhoef and Nijkamp (2002, 2008) that the environmental externalities can affect households' residential location choices and thus the urban residential patterns (i.e., the distribution of residential locations of households with different income levels). In addition, studies have shown that congestion tax pricing can induce changes in urban land use patterns and housing market, and thus affects the urban residential patterns (e.g., see Eliasson and Mattsson, 2001; De Lara et al., 2013; Li et al., 2013; Li and Guo, 2015). Anas and Hiramatsu (2013) revealed the residential relocation phenomenon due to congestion tax pricing according to the empirical data of the Chicago MSA. It is thus expected that the vehicle emission taxes, similar to congestion taxes, may also change the households' residential location choices and urban spatial structure. On the contrary, households' residential patterns in an urban system may affect its travel demand distribution and thus vehicle emissions. As a result, the optimal vehicle emission taxes that maximize the social welfare may change. Therefore, there is a need to reveal the interactions among the vehicle emission taxes, households' residential location choices, and air pollutant emissions.

In view of the above, this paper investigates the effects of the vehicle emission taxes on the urban residential patterns. Methodologically, this paper builds on the standard monocentric urban model with two income classes (e.g., see Wheaton, 1976; Hartwick et al., 1976; Kwon, 2003). The main contributions of this paper are twofold. First, a novel two-class monocentric urban model that considers the effects of vehicle emission taxes is presented to address the interaction between the vehicle emission taxes and the residential location choices of different income classes. The households in the urban system are categorized into high- and low-income classes by their income levels. The spatial competition between different income classes, the land value, and the housing market structure in terms of housing rental price and housing space can endogenously be determined by the two-class monocentric urban model. We identify the conditions under which either the rich or the poor lives in the urban central area while the other class in the suburb. Second, a system optimum model that maximizes the social welfare of the urban system is proposed for determining the optimal level of the vehicle emission taxes. The effects of the vehicle emission taxes on the social welfare, utility levels of different-income classes and the traffic emissions are examined, together with the effects of households' values of time (VOTs) and the proportion of household classes on the urban system. The findings show that the vehicle emission taxes might cause a shift from one residential segregation pattern to the other, and a social inequity issue in terms of the change in the utility levels of different income classes before and after introducing the vehicle emission taxes.

The remainder of this paper is organized as follows. In the next section, the two-class monocentric urban equilibrium model is formulated, which includes the residential location choice equilibrium of heterogeneous households and the housing demand-supply equilibrium. Section 3 presents a system optimum model for determining the optimal level of the vehicle emission taxes. In Section 4, a numerical example is provided to illustrate the applications of the proposed model. Finally, conclusions are given in Section 5 together with recommendations for further studies.