Journal of Environmental Economics and Management 82 (2017) 181–220

Contents lists available at ScienceDirect

Journal of Environmental Economics and Management

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

The effects of license plate-based driving restrictions on air quality: Theory and empirical evidence ☆

Wei Zhang [a], C.-Y. Cynthia Lin Lawell [b,*,1], Victoria I. Umanskaya [c]

[a] Connecticut College, United States
[b] University of California at Davis, United States
[c] Occidental College, United States

ARTICLE INFO

Article history:
Received 11 July 2014
Available online 8 December 2016

JEL codes:
Q58
R48
Q53

Keywords:
Driving restriction
Air quality

ABSTRACT

A typical driving restriction prohibits drivers from using their vehicles on given weekdays, based on the last digits of their vehicles' license plates. A number of cities in developing countries have used license plate-based driving restrictions as a policy for reducing urban air pollution and traffic congestion. This paper develops a theoretical model of the effects of license plate-based driving restrictions on air quality that combines an economic model with information about the sources and atmospheric chemistry of different air pollutants. We then draw upon suggestive empirical evidence from license plate-based driving restrictions implemented in Bogotá, Colombia. Consistent with our theory model, we find suggestive empirical evidence that under certain circumstances, due to substitution, the purchase of a second car, the use of alternative modes of transportation, and/or atmospheric chemistry, it is possible for license plate-based driving restrictions to increase air pollution. Also consistent with our theory, we find that license plate-based driving restrictions may have different effects on different air pollutants, reflecting heterogeneity in the sources and atmospheric chemistry of the pollutants. In particular, owing to atmospheric chemistry, it is possible for a license plate-based driving restriction to cause a significant decrease in NO and a significant increase in NO_2, NO_x, and O_3.

1. Introduction

Vehicular emissions are an important source of air pollution and a major environmental concern in urban areas. Motor vehicles are the primary source of carbon monoxide (CO), and an important source of volatile organic compounds (VOC) and nitrogen oxides (NO_x, which consist of both nitrogen oxide (NO) and nitrogen dioxide (NO_2)) responsible for the formation of photochemical smog and ground-level ozone (O_3). Vehicular emissions also contribute to the ambient air concentrations of sulfur dioxide (SO_2) and particulate matter (PM_{10}) (U.S. EPA, 1994). Common policies addressing vehicular emissions include dirty vehicle retirement policies, policies increasing fuel economy, emissions testing standards, technology

☆ We thank the Secretaría Distrital de Ambiente of Bogotá for providing air pollution and meteorological data and helpful information of the policies and the air quality monitoring systems. We thank Lucas Davis, Juan-Pablo Montero, Andres Moya, Dan Phaneuf, Aaron Smith, Chris Timmins, and Hendrik Wolff for valuable comments and discussions. Seminar participants at the University of California at Davis and at the AAEA Annual Meeting provided helpful comments. All errors are our own.

* Corresponding author.
E-mail address: cclin@primal.ucdavis.edu (C.-Y. Cynthia Lin Lawell).

[1] Lin Lawell is a member of the Giannini Foundation of Agricultural Economics.

http://dx.doi.org/10.1016/j.jeem.2016.12.002
0095-0696/

standards requiring catalytic converters, and policies altering gasoline content. This paper focuses on another such policy: vehicle driving restrictions.

A typical driving restriction prohibits drivers from using their vehicles on given weekdays, based on the last digits of their vehicles' license plates.[2] License plate-based driving restrictions have been widely used as a method to reduce urban air pollution and traffic congestion in developing countries. Santiago, Chile introduced a license plate-based driving restriction in 1986 and Mexico City, Mexico introduced a driving restriction, *Hoy No Circula*, in 1989. Following these two, several more Latin American cities have introduced license plate-based driving restrictions, including Bogotá, Colombia[3] and São Paulo, Brazil. Beijing and its neighboring city Tianjin also implemented license plate-based driving restrictions during the 2008 Olympic Games and a modified version of the restriction continued in Beijing after the Olympics. Driving restrictions have also been implemented in cities of some developed countries as well, including Paris in 2015.

In the previous literature on the effects of license plate-based driving restrictions, Eskeland and Feyzioglu (1997) examine the effect of *Hoy No Circula* on gasoline demand and car ownership in Mexico City during the period 1984–1993. Davis (2008) measures the effect of *Hoy No Circula* on air quality during the period 1986–1993 by using a regression discontinuity design to control for possible confounding factors. These two studies find no evidence that *Hoy No Circula* improved air quality in Mexico City.[4]

We build upon and synthesize the existing literature by developing a theoretical model of license plate-based driving restrictions that incorporates three behavioral channels highlighted by the literature that may affect the effectiveness of a license plate-based driving restriction. One behavioral channel that may affect the effectiveness of license plate-based driving restrictions is the possibility that households may intertemporally substitute their driving during restricted hours with driving during unrestricted hours. Davis (2008) finds that estimates for the effects of *Hoy No Circula* on air pollution during nonpeak weekdays and weekends tend to be positive, consistent with intertemporal substitution toward nighttime and weekend driving when the driving restrictions are not in place.

Two other behavioral channels that may affect the effectiveness of license plate-based driving restrictions that we incorporate in our theory model are the possibility that households may purchase a second car and the possibility that households may take an alternative mode of transportation. Davis (2008) explains the lack of an improvement in air quality resulting from *Hoy No Circula* with data from vehicle registrations and automobile sales which indicate that the program led to an increase in the total number of vehicles in circulation as well as a change in the composition of vehicles toward used, and thus higher-emitting, vehicles. In addition, Davis (2008) finds no evidence of an increase in public transportation ridership.

In addition to identifying substitution, the purchase of a second car, and the use of alternative modes of transportation as three behavioral channels through which license plate-based driving restrictions may be ineffective or even potentially increase air pollution, our theoretical model also incorporates insights from differences in the sources and atmospheric chemistry of different air pollutants. We show that the complex atmospheric chemistry of ozone smog formation may further cause driving restrictions to be ineffective or even have perverse consequences. The difficulty of regulating ozone smog in particular is also examined by Auffhammer and Kellogg (2011), who find that federal gasoline standards, which allow refiners flexibility in choosing a compliance mechanism, do not reduce ozone pollution because minimizing the cost of compliance does not reduce emissions of those compounds most prone to forming ozone; and by Salvo and Wang (2016), who find that increased ethanol use in the gasoline-ethanol vehicle fleet leads to higher ozone concentrations in urban São Paulo's ambient air.

After developing a theoretical model of license plate-based driving restrictions that incorporates substitution, the possibility of purchasing a second car or taking public transit, sources of air pollutants, and atmospheric chemistry, we examine the hypotheses of our model in light of suggestive empirical evidence from the license plate-based driving restriction implemented in Bogotá, Colombia.

Consistent with our theory model, we find suggestive empirical evidence that under certain circumstances, due to substitution, the purchase of a second car, the use of alternative modes of transportation, and/or atmospheric chemistry, it

[2] In addition to license plate-based driving restrictions, another type of driving restriction are low emission zones, which define areas that vehicles may enter only if they are classified as low emission vehicles (Wolff and Perry, 2010); and another form of driving regulation are congestion charges (Leape, 2006; Gibson and Carnovale, 2015). In this paper, we focus on license plate-based driving restrictions, and use the terms "driving restrictions" and "license plate-based driving restrictions" interchangeably.

[3] Other Colombian cities that have implemented license plate-based driving restrictions include Bucaramanga, Cartagena, Manizales, Pereira, Barranquilla, Armenia, Cali, and Medellín.

[4] Moreover, Gallego, Montero and Salas (2013a,b) find in their analysis of *Hoy No Circula* that policies that may appear effective in the short run can be highly detrimental in the long run, after households have adjusted their stock of vehicles. In the literature on license plate-based driving restrictions in China, Chen et al. (2013) find that the measures that China adopted during the 2008 Olympic Games in Beijing, particularly the driving restriction and plant closure, improved the Air Pollution Index (API) of Beijing during and after the Olympics,though most of the effect faded away by the end of October 2009. The credibility of China's API data has been questioned (Andrews, 2008, Ghanem and Zhang, 2014), but Chen et al. (2013) do not find any evidence of gaming of the API in Beijing. In their analysis of the effect of Beijing's driving restrictions on pollution and economic activity, Viard and Fu (2015) find that air pollution falls 20% during the every-other-data driving restriction and 9% during the one-day-per-week driving restriction. Cao, Wang and Zhong (2014) find that although their OLS regression results show such that Beijing's driving restriction policies are effective, their regression discontinuity results show that driving restriction policies, especially the one-day-per-week restriction policy, had little impact on air pollution concentrations. Huang, Fu and Qi (forthcoming) use internet data to analyze the effects of driving restrictions on air quality in Lanzhou, China, and find that the driving restrictions are effective in the short run, but ineffective in the long run.