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A forecast air pollution model applied to a hypothetical urban road pricing scheme: An empirical study in Madrid

Juan Pedro Muñoz Miguel [a,*], Clara Simón de Blas [b], Ana Elizabeth García Sipols [c]

[a] Departament of Business Economics, Faculty of Social Sciences, Rey Juan Carlos University, Madrid City, Spain
[b] Departament of Computer's Sciences, Technical School of Computer Engineering, Rey Juan Carlos University, Madrid City, Spain
[c] Departament of Finance & Accounting II, Faculty of Social Sciences, Rey Juan Carlos University, Madrid City, Spain

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ABSTRACT

Reducing the air pollution from increases in traffic congestion in large cities and their surroundings is an important problem that requires changes in travel behavior. Road pricing is an effective tool for reducing air pollution, as reflected currently urban road pricing outcomes (Singapore, London, Stockholm and Milan). A survey was conducted based on establishing a hypothetical urban road pricing system in Madrid (a random sample size n = 1298). We developed a forecast air pollution model with time series analysis to evaluate the consequences of possible air pollution decreases in Madrid. Results reveal that the hypothetical road pricing for Madrid could have highly significant effects on decreasing air pollution outside of the city and in the inner city during the peak operating time periods of maximum congestion (morning peak hours from 7:00 to 10:00 and evening peak hours from 18:00 to 20:00). Furthermore, this system could have significant positive effects on a shift toward using public transport and non-motorized modes inside the hypothetical toll zone. This reveals that the system has a high capacity to motivate a decrease in air pollution and impose more sustainable behavior for public transport users.

1. Introduction

Increases in motor traffic in large cities and their surrounding areas cause numerous social, environmental, and economic problems that are often due to mass automobile use as the principal transport mode in urban shifts. In this context, transport policies, such as Low Emissions Zones (LEZ), emission standards, bypass capacity to guide traffic around the city center (Wolff, 2014; De Borger and Proost, 2013), traffic restrictions on some days according to license plate numbers (Wang et al., 2014) or road pricingschemes to reduce traffic congestion (Anas and Lindsey, 2011;Eliasson et al., 2009; Li and Hensher, 2012; Santos, 2008; Schade, 2005) may be potentially effective measures to reduce externalities. Urban road pricing implementations is the most suitable system for regulating the consumption of or access to scarce resources (Pigou, 1920), through using road tolls to effectively regulate traffic congestion (Walters, 1961; Vickrey, 1963) and requires automobile users to pay a fee when using their vehicles in a specific area or on a specific road (Jaensirisak et al., 2005); however, the

* Corresponding author at: Universidad Rey Juan Carlos, Facultad de Ciencias Jurídicas y Sociales, Edificio departamental, Paseo de Artilleros s/n, 28032 Vicálvaro, Madrid, Spain.
E-mail addresses: juanpedro.munoz@urjc.es (J. Pedro Muñoz Miguel), clara.simon@urjc.es (C. Simón de Blas), anaelizabeth.garcia@urjc.es (A. Elizabeth García Sipols).

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effectiveness of this measure to reduce traffic congestion will depend on how drivers respond and scope of its response (Gibson and Carnovale, 2015).

The effectiveness of urban road pricing is demonstrated in its ability to achieve specific objectives, including congestion relief, environmental improvements, revenue generation, equity, economic growth, health, safety, and habitability (Curacao Project-Promoting Progressive Pricing, 2009a). These results are verified by previous urban road pricing systems that are currently working, such as those implemented in Singapore, the Licensing Scheme Area in the mid-1970 s (Holland and Watson, 1978), London, Stockholm and, more recently, Milan (for London, see Santos and Fraser, 2006; Leape, 2006; for Stockholm, see Eliasson, 2008; for Milan, see Rotaris et al., 2010).

The tax fees applied to congestion with the aim of decreasing environmental impacts from motor traffic have direct effects on reducing urban congestion as well as air and noise emissions in large cities and the surrounding areas (Royal Commission on Environmental Pollution, 1994). In theory, road price charges – tax fee – ensure that the only drivers who travel are those whose car use utility exceed the sum of the imposed congestion and environmental costs included in such paid tax fee (Button, 1991).

One of the main arguments in defense of applying congestion pricing is the direct relation between vehicles, congestion and vehicle's environmental impact (Oldridge, 1990). Jaensirisak et al. (2005) found that congestion charging in the UK is more acceptable to people who perceived air pollution and congestion as a current situation unacceptable, and believed that road pricing is able to reduce congestion. Percoco (2013) perceives from a study related to Ecopass road pricing in Milan that toll price systems reduces significatively the concentration of some pollutants, especially carbon monoxide and particulates, – but only in the short run – and Noordegraaf et al. (2014) state that one of the main success in the Stockholm congestion charging establishment was derived from the scheme branded as an environmental charge (Börjesson et al., 2012; Eliasson and Jonsson, 2011). Furthermore, congestion pricing is effective in reducing traffic jams and travel times (Transport for London, 2003, 2007; Eliasson et al., 2009), providing a modal shift toward public transport and non-motorized modes and improving the urban and environmental quality of the urban areas where it is implemented (Banister, 2003).

There are several studies on the environment and pollution effects associated to the main European urban road pricing currently operating – London, Stockholm or Milan – after their implementation (Transport of London, 2004; Beevers and Carslaw, 2005; Eliasson, 2009; Eliasson et al., 2009; Rotaris et al., 2010). These studies reveal a significant reduction of pollutant emissions-Nox, PM10, CO2-. In the case of Stockholm road pricing, Eliasson (2009) estimates the reduction of pollution using an air quality dispersion model. Percoco (2013) concludes that the implementation of Ecopass road pricing allows a significant reduction in the concentration of pollutant particles but only in the short term. Coria et al. (2015) analyze the effects of the temporal variation of pollution dispersion with respect to the traffic flows and the vehicle emission on pollution concentration in Stockholm and the need to apply a differentiated rate for each level of pollution. Carnovale and Gibson (2015) through a natural experiment evaluate the response of the drivers in the road pricing of Milan. Their results show that there is evidence of intertemporal and spatial substitution in the use of car toward unpriced roads, so that they conclude that Milan's pricing policy is capable to effectively reduce congestion and pollution.

In this context, the purpose of the present study is to analyze the reductions in air pollution and environmental improvements that result from applying hypothetical urban road pricing in the city of Madrid (Spain). The novelty of our study is that it is applied on a hypothetical road pricing as opposed to the existing ones, which either, constitutes natural experiments or handles ex ante/expost data as a basis for analysis.

We performed a random population survey of habitants in the city of Madrid that makes usual shifts in the area of Madrid to obtain information and evaluate mobility behavior in transportation modalities under the assumption of hypothetical urban road pricing in the M-30 (the 1st orbital road that circumscribes Madrid's city center). The results from the survey allow for identifying the effects caused by implanting hypothetical urban pricing for vehicle use, such as a modal shift toward public transport and non motorized modes, changes in alternative routes and combined intermodal of vehicles and public transports; behaviors that indicate a decrease in using vehicles in routine shifts, reducing congestion and, therefore, reducing air pollution levels in the urban area. The survey responses were grouped in three differentiated areas for the analysis: inside the M-30 (inside the toll zone), outside the M-30 (outside the toll zone) and was aggregated to examine inside/outside theM-30 (inside & outside zones) to evaluate the global effect.

Second, we construct a new time series variable, Air pollution (Poll), which is an aggregated factor that reflects a set of air emissions variables in accord with monthly time series emission variables for the time period 1999–2012 in the area of Madrid. We propose a model to explain the new time series variable Air pollution (*Poll*) by petrol variables (Petrol-95 (Gas_{95}), Petrol-98 (Gas_{98}) and Diesel A (Die_A)) and a measure of Madrid's traffic congestion (Congestion (*Cong*)). This model allows us to develop a forecasting model of air pollution in the area of Madrid and estimate decreases in air pollution in Madrid by applying a hypothetical urban road pricing. This forecasting model was developed for each scenario under study: inside the toll zone, outside the toll zone and inside & outside the toll zones. The results show that the proposed urban road pricing significantly reduces air pollution in the area of Madrid during certain operating times (the peak hours) and has a high capacity to provide a modal shift toward public transport and non motorized modes. Likewise, these results allow for identifying mobility patterns that can specifically optimize urban road pricing and the general public transportation system through competent authority's management decisions for improving efforts to decrease air pollution. Therefore, this study contributes to the literature in obtaining estimates of the expected impact on reduction of congestion and therefore reduction of pollution through a hypothetical road pricing as a traffic calming policy by applying our forecasting model of air pollution for each analyzed zone in Madrid. Finally, our study reveals that reductions in air pollution resulting from the