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Assessment of the effectiveness of fuel and toll pricing policies in motorway emissions: An ex-post analysis

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A B S T R A C T

In this paper the environmental impacts of fuel and toll pricing policies were evaluated for eight Portuguese motorways for the period between 2008 and 2011. To perform such study, firstly the analysis of the elasticity was done to assess the sensitive of traffic demand. Then emission costs were estimated considering an integrated approach of environmental and human health impacts. Two motorway groups were analyzed: one originally built with both conventional and electronic toll systems (G1); and another recently equipped with non-stop electronic tolls (G2). The results show that the elasticity of the system changes with the fluctuation prices, particularly influenced by toll prices variation. During the analysis period, traffic volumes decreased (8–11% in G1, and 15–41% in G2). About 75% of traffic flow shows a high statistical significance correlation ($p < 0.05$) with toll prices, which highlight the impact of toll prices. Differences between emission costs can be close to 50% in those motorway groups. Nevertheless, due the absence of data in alternative routes, the obtained results show only the potential maximum environmental gains of these policies in motorways. This limitation is very important in the quantification of the environmental global impacts. Non-toll roads are usually characterized by slower speeds and higher emissions. Therefore the above mentioned gains can be converted, in these cases, in losses.

1. Introduction

In the last 20 years, the economic growth (and sudden decline) as well as the profound changes in lifestyle have had a strong impact on the mobility patterns. Today, the transport sector is not only the higher contributor to worldwide primary energy consumption (IEA, 2009), but also an important source of emissions (EEA, 2013a). To minimize those impacts, in the last years, different systems of road traffic policies such as incentives for fuel taxes and road pricing schemes have been implemented to improve vehicle fleet composition and to reduce traffic flow. Currently, some road pricing strategies are an attractive option to finance road investments. In addition, some studies demonstrate that road transportation policies have some potential as an air quality management tool (Boogaard, 2012; Cesaroni et al., 2012), nevertheless, others demonstrate that the effective impact of some of those policies on emissions is not so linear (Burke & Nishitateno, 2012; Gallo, 2011).

A transportation policy with high impact on environment is usually based on fuel prices. In U.S. and in Netherlands the number of transit trips in an urban area increases significantly with the increase of fuel price (Maghelal, 2011; Yang & Timmermans, 2012). This allows a reduction of the Vehicle Kilometre Travelled (VKT) as well as on oil and emissions. Additionally, Yang and Timmermans (2012) explain that the increase of fuel prices have negative effects on fuel consumption and carbon dioxide (CO_2) emissions, but positive effects on travel distance by public transportation and soft modes. On the other hand, in Italy the introduction of a car pricing policy based on fuel surcharges shows that car users prefer to shift towards more efficient fuel vehicles than to use public transportation, producing a significant, but less than expected, reduction of greenhouse gases (GHGs) emissions (Gallo, 2011). This author explains that an increase in fuel prices of 22% corresponds only to a decrease of 2.6% in car use, while the diesel share increases

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significantly from 49.8% to 77.9%, the corresponding reduction in GHG emissions is 4.4%. In fact, according to other studies, a raise of 10% in the fuel prices is required to achieve 1% reduction in fuel consumption (Hughes, Knittel, & Sperling, 2008; Small & Kurt, 2007). Thus, a very high tax would be required to significantly reduce fuel use. Additionally, many researchers concluded that high fuel prices may reduce fuel consumption and therefore CO_2 emissions (Li, Linn, & Muehlegger, 2012; Lindsey, Schofer, Durango-Cohen, & Gray, 2011; Maghelal, 2011; Yang & Timmermans, 2012). However, this emission reduction can be less than expected. In fact, in countries where fuel surcharges are higher, the consumers tend to seek out more efficient vehicles (with an elasticity of +0.2) (Burke & Nishitateno, 2012).

On motorways, the impact of car use can be also affected by toll prices, which is a method that can reflect the true marginal cost of travel (Li et al., 2012; Lindsey et al., 2011; Maghelal, 2011; Pigou, 1920). Although the only objective of many tolls schemes is to generate revenue, some of them also have the aim at relieving congestion (Santos, Behrendt, Maconi, Shirvani, & Teytelboym, 2010). Nevertheless, in this assessment process, other externalities must be also considered; thus, the introduction of extensive national road pricing systems should involve a careful impact analysis (Steininger, Friedl, & Gebetsroither, 2007).

Today different road pricing schemes are available. Iseki and Demisch (2012) examined the linkages between electronic roadway tolling technologies and road pricing policy objectives. Several studies summarize recent road pricing experiences with respect to tolls. Based on a compilation of 17 studies, Odeck and Bråthen (2008) found a general consensus that transportation demand with respect to tolls is fairly inelastic. An increase in the toll rates leads to a reduction in the traffic volumes. Further, most of these studies have given values above −0.5, implying that a 10% increase in tolls will result in a 5% reduction in traffic volumes, or less. Additionally, Spears, Boarnet, and Handy (2010) concluded that, depending on conditions, typically elasticity ranges between −0.1 and −0.45, so a 10% toll increase will reduce the traffic on roadway in 1.0–4.5%. Roads with fewer essential trips, more viable alternatives or lower congestion levels tend to have higher elasticity. They also found that cordon tolls have reduced traffic volumes 12–22% in five major European cities (Spears et al., 2010).

Linking with environmental level, Bandeira, Coelho, Pimentel, and Khattak (2012) show that changes in traffic distribution caused by the introduction of tolls did not cause a significant impact in terms of emission factors on alternative routes. However, the traffic diversion of from motorways to local roads implies an increase in CO_2 emissions and a reduction in the emissions of local pollutants such as carbon monoxide (CO) and oxide nitrogen (NO_X). De Palma and Lindsey (2006) found that the benefits to users of a large fraction of toll revenues exceed the monetized value of reductions in noise, accidents and vehicle emissions. Coelho, Farias, and Rouphail (2005) explain that the highest percentage of emissions for a vehicle that stops at a pay toll is due to its final acceleration back to cruise speed after leaving the pay toll. Pérez-Martínez, Ming, Dell'Asin, and Monzón (2011) explain that energy consumption and CO_2 emissions are closely related to vehicle mass, wind exposure, engine efficiency and acceleration rate. The type of toll system used can have a high influence on energy efficiency of highway transportation and therefore it is necessary to consider free flow.

Table 1 summarizes some of the most relevant studies which assess the impact of fuel and toll price policies on atmospheric emissions. In these studies the parameters that were mostly taken into account were fuel consumption and CO_2 and passenger cars the main vehicle type analyzed. Usually, to perform these analyses real data are used. A few number of studies evaluate the impact of tolls on emissions (Bandeira et al., 2012; Coelho et al., 2005; De Palma & Lindsey, 2006; Pérez-Martínez et al., 2011).

From the above-mentioned works some observations can be inferred. First, only one study was found quantifying the real impact of tolls on fuel consumption on emissions simultaneously (Pérez-Martínez et al., 2011). Moreover, the identification of the main factors responsible for those emission impacts were not fully examined since the synergy between the effects of fuel price or toll price was not analyzed to local pollutants as PM, VOC and NO/NO_X. Second, CO_2 is typically used to quantify the impact of the policies but pollutant emissions as VOC and NO/NO_x are usually discarded (e.g. Giles, 2008; Maghelal, 2011). Third, although the integration of different environmental components is a priority highlighted by the White Paper of Transportation (EU, 2011), with exception of Gazis et al. (2012), the emission impact from different pollutants has been in majority assessed individually. Fourth, the studies often use short-run elasticity which understates long-term impacts (Litman, 2013). Thus, in this study, we analyzed how driver's response to the fuel and toll price changes in motorways, and the impact of such response on emission costs. Alternative non-toll areas were not considered. The analysis was conducted to all the vehicles categories considering different pollutants and emission costs criterion using long data series. The main questions of this paper are:

1. What is the impact of fuel and/or toll price policies on motorway emissions, recorded in motorways?
2. Can those variables be used to manage and/or define transportation policies for environmental purposes?
3. How can we use different pollutants, considering an integrated approach, to assess the environmental impact of a road traffic policy?

To address these questions an ex-post analysis was applied to compare the traffic flow variations of different motorway types with the fluctuations of fuel and/or toll prices. Such analysis was conducted for different pollutants: hydrocarbons (HC), NO_X, and particles (PM).

2. Material and methods

Methodology was split in two main steps: data collection (see Section 2.1) and model specifications (see Section 2.2). In the first step, the main variables which could influence road pricing policies were presented. These data were used to estimate the impact of fuel and toll prices on emission costs by combining an economic analysis with an environmental analysis. While in the economic analysis the elasticity was used to identify the main characteristics which can influence route choice in a motorway, in the environmental analysis the emission costs were estimated in order to quantify the environmental costs of such policies. Fig. 1 despites an overview of the overall methodology.

2.1. Data collection

In Portugal, motorway concessions are used as an important instrument for the expansion of the motorway network. Since the early 70s, different forms of tendering and contracting with private partners, as well as different forms of engaging revenues from users were recorded, in order to recover the construction, maintenance and operation costs of that infrastructure. Today, important revenues are obtained from tolls.

In the last decades, different toll systems were implemented in Portugal: in the first motorways, conventional toll systems (in