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Optimal environmental road pricing and daily commuting patterns☆

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ABSTRACT

Road pricing can improve air quality by reducing and spreading traffic flows. Nevertheless, air quality does not depend only on traffic flows, but also on pollution dispersion. In this paper we investigate the effects of the temporal variation in pollution dispersion on optimal road pricing, and show that time-varying road pricing is needed to make drivers internalize the social costs of both time-varying congestion and time-varying pollution. To this end, we develop an ecological economics model that takes into account the effects of road pricing on daily commuting patterns. We characterize the optimal road pricing when pollution dispersion varies over the day and analyze its effects on traffic flows, arrival times, and the number of commuters by car.

1. Introduction

In 2010, the health costs of air pollution due to road transportation corresponded to about USD 1 trillion in OECD countries and about USD 1 trillion in China and India alone (OECD, 2014). These costs account for the effects of exposure to air pollution on the development of chronic diseases, respiratory illness, and premature mortality. The negative effect of high pollution concentrations was established already in the mid-twentieth century after a series of extreme episodes of poor air quality in the United States and Europe (Logan and Glasg, 1953; Ciocco and Thompson, 1961). High spikes of pollution – rather than prolonged lower-level exposure – impose the largest health hazards for those with impaired respiratory systems (Heal et al., 2012). An increased bulk of recent epidemiological studies have shown, however, an approximately linear increase in health risk with increasing exposure to urban air pollutants, with no clear threshold below which no effects are quantifiable (see, e.g., Naess et al. (2007); Stieb et al. (2008); Cesaroni et al. (2013)). Estimates also indicate that more than 80% of people living in urban areas that monitor air pollution are exposed to air quality levels that exceed World Health

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Organization (WHO) limits, that transportation contributes more than half of the many pollutants emitted into the air, and that despite improvements in some regions, urban air pollution continues to rise (WHO, 2016).

Empirical evidence shows that road pricing can play an important role in reducing traffic flows and spreading traffic peaks, and thus in reducing and smoothing the emissions of several pollutants over time. The charging of fees to enter congested downtown areas in Europe and the United States has been proven to curb congestion and vehicle emissions and to spread traffic volumes by inducing intertemporal substitution toward unpriced times and spatial substitution toward unpriced roads (see e.g., Foreman (2016); Gibson and Carnovale (2015), and Daniel and Bekka (2000)). The charges have also brought reductions in emissions due to an increased vehicle speed (see e.g., Percoco (2014); Banister (2008), and Beevers and Carslaw (2005)). Notably, the positive effects of road pricing on environmental quality might also help to ease the political economy behind implementation of road pricing. For instance, Stockholm's congestion charge was actually re-labeled to "environmental charge" to emphasize the positive effects on air quality and connect to strong attitudes regarding local and global environment (see Eliasson (2014)).

Time-varying road pricing offers a more cost-effective means of reducing congestion since unlike other policy instruments that raise the cost of all driving regardless of where and when the driving occurs, they encourage people to both use less congested routes and drive a little earlier or later to avoid rush hours. Moreover, the timing of emissions reduction is important because air quality does not depend only on the emission rates of pollutants, but also on pollution dispersion-understood here as the scattering of pollutants in the atmosphere so that they become progressively less concentrated (see Wendell Hewson (1956)). The scientific literature shows that temporal variations in the meteorological factors that govern air mixing and thus dispersion of locally emitted pollutants (such as wind speed, vertical temperature stratification, and mixing height) can exert strong pressures on the dynamics of air quality (see, e.g., Hayas et al. (1981); Viana et al. (2005), and Kim et al. (2012)). Due to the large temporal variation in these meteorological factors, there is strong average diurnal variation in pollution dispersion in addition to the variation in hourly traffic flows and consequently vehicular emissions (see Toth et al. (2011) and Kim et al. (2012)). For instance, anticyclonic weather and temperature inversions near the ground favor high pollutant concentrations. During these conditions, a stagnant layer of air traps air pollutants near the ground, impeding pollutant dispersion (e.g., Holzworth (1967); Holst et al. (2008); Rost et al. (2009), and Grundström et al. (2011)). Thus, one would expect that in most cities, the negative effects of traffic volumes on air pollution concentration are larger during the dark hours as a consequence of less air mixing when the sun is below the horizon. The extent of this effect will, however, vary across cities located in different climatological zones of the world. For instance, it will be stronger in inland valley cities, where strong nocturnal inversions develop as cold air accumulates in the valley basin during the night, than in cities near a coast where the maritime influence will tend to reduce the development of nocturnal inversions.

This paper investigates the effects of the temporal variation of pollution dispersion on optimal road pricing. There are a number of atmospheric processes which lead to dispersion of contaminants. In this paper we study the effects of pollution dispersion due to the natural cleansing of the atmosphere (which we refer to as natural decay), and transport by winds (which we refer to as spatial transport of pollution). We develop an ecological economics model of road pricing that takes into account the dynamics of transport-related air pollution. In the model, commuters make decisions about arrival times and travel mode and the regulator chooses a time-varying road charge to minimize the social costs of commuting. In particular, we assume that the total number of commuters can choose to commute by either car or public transport. Those who decide to commute by car choose a time of arrival at work and a time of arrival at home to minimize their private trip cost, which consists of three components: the travel time cost, the schedule delay cost, and the time-varying road charge. Moreover, commuters select the transport mode by comparing the cost of a round trip by car with the cost of a round trip by public transportation. Hence, the round trip by each transportation mode is not perfectly inelastic to its price since there is substitution between transportation modes. In such a setting, we characterize the optimal time-varying road charge and compare it with a charge that disregards the temporal variation in pollution dispersion.

The contribution of our paper to the literature is twofold. First, it contributes to a better understanding of economy-ecology interactions in road transportation, as well as practical policy insights since time-varying road pricing designed only to spread out congestion peaks might lead to increased traffic flows when pollution dispersion is the lowest (see e.g., Bonilla (2016)).[1] Second, it contributes to the literature on transport economics since although a large literature acknowledges significant differences between morning and evening commuting patterns, it is mainly the morning traffic patterns which have been investigated extensively in the literature, while the evening trip is often assumed to be a simple mirror symmetry of the morning trip (e.g., Hurdle (1981), and Gonzales and Daganzo (2013)). However, if pollution dispersion varies over the day, the environmental damage and social costs of road transportation are not symmetric even if the schedule-delay costs for morning and evening commutes are the same. When deciding whether or not to drive a car, the commuters compare the cost of driving (which includes the cost for both morning and evening commuting and is endogenous to the magnitude of the time-varying charge) with the cost of public transportation. Analyzing the effects of road pricing on a setting that captures neither asymmetries in the social cost of road transportation over the day nor the price elasticity of

[1] The fact that temporally varying externalities are better addressed by instruments that follow the variation in damage (and hence the variation in the externality) is well established in the environmental economics literature. See Coria (2011) for practical examples of where the stringency of environmental regulations is significantly increased to account for the variability in the assimilation capacity of the environment, which poses difficult problems for pollution control policies.