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The impact of Low Emission Zones on particulate matter concentration and public health

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ABSTRACT

A common policy for reducing particulate matter concentrations in the European Union is the introduction of Low Emission Zones (LEZs), which may only be entered by vehicles meeting predefined emission standards. This paper examines the effectiveness of LEZs for reducing PM_{10} levels in urban areas in Germany and quantifies the associated health impacts from reduced air pollution within the zones. We employ a fixed effects panel data model for daily observations of PM_{10} concentrations from 2000 to 2009 and control, inter alia, for local meteorological conditions and traffic volume. We apply the regression outputs to a concentration response function derived from the epidemiological literature to calculate associated health impacts of the introduction of LEZs in 25 German cities with 3.96 million inhabitants. Associated uncertainties are accounted for in Monte-Carlo simulations. It is found that the introduction of LEZs has significantly reduced inner city PM_{10} levels. We estimate the total mean health impact from reduced air pollution in 2010 due to the introduction of stage 1 zones to be ~760 million EUR in the 25 LEZ cities in the sample, whereas total mean health benefits are ~2.4 billion EUR for the more stringent stage 2 zones when applied in the same cities.

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1. Introduction

While road transport contributes significantly to the growth and development of economies (Fernald, 1999; Ozbay et al., 2007), this positive impact comes at an environmental cost. Externalities in relation to particulate matter (PM) emissions are one of the main current concerns (Forkenbrock, 1999; Krewski et al., 2009; Lee et al., 2012). The epidemiological literature shows that particulate matter has a significant negative impact on human health (Anderson et al., 2004; Anderson, 2009; Chay and Greenstone, 2003, 2005; Dockery et al., 1993; Ostro and Chestnut, 1998; Pope et al., 1995). Particulates contribute to premature mortality and morbidity, as they cause cardiovascular and respiratory diseases by penetrating the lungs and, depending on their size, by entering the blood system (Dockery et al., 1993; Hoffmann et al., 2009; Pope et al., 1995, 2002, 2011). Lahl and Steven (2005) show that particulate matter emissions lead to a decrease in average life expectancy of more than 8 months in the EU. Annualized costs of premature mortality and morbidity due to particulate matter are estimated to amount to between 270 and 780 billion Euro across the 25 EU member states for the year 2000 (Watkiss et al., 2005).

Studies conducted in the EU show that the health impact of PM is linked primarily to exposure to particles stemming from road transport (Viana et al., 2008). Road transport adds to PM levels through exhaust emissions, break and tire abrasion, road

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wear and the resuspension of road dust and soil. High PM levels are found particularly within cities along busy roads, and traffic is found to be the prime contributor to anthropogenic inner city concentration of PM (Diegman et al., 2006; Jörß and Handke, 2007; Krzyzanowski et al., 2005; Lenschow et al., 2001; Umweltbundesamt, 2011). At the same time, cities are densely populated and therefore, the number of people exposed to PM is high, which exacerbates the adverse health effects of PM emissions from road transport. Consequently, policies that aim at mitigating the impact of particulate matter often focus on road transport in cities.

One recent policy for reducing PM concentrations in the EU is the introduction of Low Emission Zones (LEZs), which refer to certain geographical areas in urban agglomerations that may only be entered by vehicles meeting predefined emission standards. LEZs have been implemented for urban areas in several European countries (Low Emission Zone in Europe Network, 2013), as well as in non-European cities such as Tokyo (Tokyo Metropolitan Government, 2012), Beijing and Shanghai (Amin, 2009). Low Emission Zones set standards that are limited in geographical scope, namely to the zone in question, and do not impose any limits on overall traffic throughput within this zone.

The purpose of this paper is to investigate the effectiveness of Low Emission Zones for reducing PM levels in German cities and to calculate and monetize the associated health impacts. We focus on PM that are smaller than or equal to 10 microns in diameter (PM_{10}), as ambient air quality data for our observation period is often only available for PM_{10}, on which there has been a generally stronger emphasis within EU regulation. We regard Germany as a particularly instructive sample case because of the widespread adoption of LEZs in German cities.

The contribution of the research is threefold. First, we add to the sparse literature on the evaluation of LEZs in Germany by using a particularly comprehensive dataset with respect to LEZs and cities considered (25 cities with LEZs, 112 cities without LEZs) and the temporal dimension (daily observations for the years 2000–2009). We also account for different stringencies of the LEZ introduced in a city. To the best of our knowledge, there is only one archival publication by Wolff (2014) whose cross-sectional scope is limited to nine LEZs, and whose temporal dimension captures a maximum of ten months after a zone was introduced.

Second, as traffic is a prime contributor to anthropogenic PM_{10} emissions (Viana et al., 2008), we use local information on traffic volume as an explanatory variable for particulate matter emissions. This approach has been omitted in previous econometric research on LEZs. By explicitly capturing changes in traffic volume, our analysis avoids bias that might stem from changes in PM_{10} levels being attributed to the introduction of LEZs, whereas they are actually caused by changes in traffic volume.

Third, we calculate the public health benefits of different stringencies of LEZs in terms of lower PM-attributable premature mortalities using a concentration response function obtained from the epidemiological literature and monetize the benefits using the value of a statistical life approach. Uncertainties in the main parameters of the health impact calculation are propagated through the calculations in a Monte-Carlo framework, which gives a more complete picture on the monetized health benefits of LEZs than previously available.

The remainder of this paper is organized as follows. Section 2 gives a brief overview of LEZs in Germany. Section 3 shows the strategy for estimating the impact of LEZs on inner city PM_{10} levels and Section 4 presents the data. In Section 5 we present the results of the estimation and discuss them. Section 6 uses the estimation results in Monte-Carlo simulations to quantify and monetize the public health benefits of LEZs. The final section concludes.

2. Low Emission Zones in Germany

Low Emission Zones in Germany have been introduced to ensure compliance with binding PM_{10} limit values in ambient air as defined by the European Union in Council Directive 1999/30/EC (European Commission, 1999). Starting from January 1, 2005, member states are obliged to implement provisions so that

(1) a 24 h limit of 50 $\mu g/m^3$ PM_{10} is not exceeded on more than 35 days per calendar year and
(2) the annual average does not exceed 40 $\mu g/m^3$ PM_{10}.

Germany applied the European Directive to national law in 2002 through the 22nd "Ordinance of the Federal Immission Control Act" (Bundes-Immissionsschutzgesetz – BImSchG). A second national regulation, the 35th "Ordinance of Marking Vehicles with Low Emissions", which came into effect on March 1, 2007, gives cities and municipalities the right to define geographical areas as LEZs. Starting in January 2008 with just three cities, 48 LEZs covering 76 cities have been introduced throughout Germany by October 2014 (Umweltbundesamt, 2014).

The "Ordinance of Marking Vehicles with Low Emissions" classifies vehicles according to emission classes. The system follows a simple color code (green, yellow, red). Vehicle owners can buy a colored sticker that shows which emission class their vehicle belongs to.

Table 1 shows the four different emission classifications and associated maximum emission levels required to obtain a certain sticker. Requirements are different for diesel- and gasoline-powered vehicles.

Low Emission Zones prohibit vehicles which do not meet a certain emission limit as indicated through the vehicle's emission classification from entering a specific geographical area. There are three stages of LEZs: Stage 1 LEZs only ban very high-emitting, non-sticker vehicles from entering the zone. Stage 2 LEZs ban non-sticker and red-sticker vehicles. Stage 3 LEZs only grant access to low-emitting vehicles with a green sticker. In all three stages of LEZs, certain exceptions apply,

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