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The effects of road pricing on driver behavior and air pollution

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ABSTRACT

Exploiting the natural experiment created by an unanticipated court injunction, we evaluate driver responses to road pricing. We find evidence of intertemporal substitution toward unpriced times and spatial substitution toward unpriced roads. The effect on traffic volume varies with public transit availability. Net of these responses, Milan's pricing policy reduces air pollution substantially, generating large welfare gains. In addition, we use long-run policy changes to estimate price elasticities.

1. Introduction

Growing air pollution, congestion, and accident externalities from vehicle traffic have produced increasing interest in policy remedies. Beijing and Mexico City bar vehicles from their roads on some days based on their license plate numbers (Davis, 2008; Viard and Fu, 2014; Wang et al., 2014). Many German cities have created Low Emissions Zones (Wolff, 2014), which prohibit dirtier vehicles within their borders. Stockholm, London, and Milan charge fees to enter congested downtown areas. In the US, the Department of Transportation is currently sponsoring a large number of road pricing experiments, including San Francisco's Golden Gate Bridge, Interstate 95 near Miami, SR520 near Seattle, and Interstate 35W near Minneapolis (DeCorla-Souza, 2004; Xie, 2013). Economists have raised concerns over non-price policies because behavioral responses can be so large that net policy benefits may be zero, or even negative (Davis, 2008; Gallego et al., 2013). Theory suggests that road pricing might be more efficient (Vickrey, 1963; Arnott et al., 1993), but this prediction depends on driver responses. On which margins do drivers respond to road pricing, and how large are such responses?

Confounding factors typically make traffic policies difficult to evaluate. Drivers know the policy start date well in advance and may begin to adjust their behavior beforehand, which attenuates estimated effects. Municipalities typically increase public transit service at the same time they implement road pricing or a driving restriction. This makes it impossible to estimate the effect of the policy in isolation. For example, Eliasson et al. (2009) point out that Stockholm expanded bus service at the same time it implemented a congestion charge. Because the buses used for the expansion were older and dirtier, the reduction in emissions within the charge area was muted. Milan first implemented a congestion charge concurrent with, "traffic calming measures, new bus lanes, increased bus frequency, increases in parking restrictions and fees, and medium-term policies such as park-and-ride facilities and underground network extensions" (Rotaris et al., 2010).

To address these identification challenges, we exploit a natural experiment: in late July 2012, an Italian court unexpectedly suspended Milan's road pricing policy, called "Area C." The city reinstated pricing eight weeks later. Using unique traffic data at 15-min resolution, our study examines behavioral responses to Milan's policy, which requires drivers entering the city center to pay €5 on weekdays 7:30AM–7:30PM. Drivers respond to pricing in two ways: (1) shifting trips to the unpriced period, just before 7:30AM or after 7:30PM; and (2) driving around the boundary of the priced area.

Net of these behavioral responses, we find the Area C policy reduces vehicle entries into the priced area by 14.5 percent and air pollution by 6 to 17 percent. The latter effect is large, particularly given that the priced region is just five percent of Milan's land

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area and the city has an unusually clean vehicle fleet. Using a well-identified US estimate of willingness to pay from Bayer et al. (2009) and scaling for income in Milan, we calculate that this pollution reduction increases welfare by approximately $3 billion annually. Routes without public transit experience large traffic changes from pricing, while those with public transit experience much smaller changes. We provide evidence that this surprising result may arise from residential sorting: residents who live near public transit may strongly prefer public transit. In addition, we use changes in Milan's pricing policy across the 2008–2011 and 2012 periods to estimate elasticities: city-center entries by charged vehicles decrease .3 percent in response to a one percent price increase.

This study contributes to the empirical literature on second-best road pricing policies (Small et al., 2005; Small and Verhoef, 2007; Xie, 2013). Closely related to our analysis are Olszewski and Xie (2005), which analyzes the cordon charge and expressway pricing in Singapore, Santos and Fraser (2006) and Santos (2008) on the London cordon charge, and Eliasson et al. (2009) on the Stockholm cordon charge. These studies find cordon charges do reduce traffic within the priced area. Also related are Foreman (2013) and Small and Gomez-Ibanez (1998), which find evidence of intertemporal substitution in response to time-varying tolls. Our work complements the theoretical literature on second-best road pricing (Lévy-Lambert, 1968; Marchand, 1968; Verhoef et al., 1996), particularly the literature on cordon charges (Mun et al., 2003; Verhoef, 2005). Finally, we contribute to the literature on environmental effects of traffic policies. Many such studies have found no evidence of air quality improvements (Transport for London, 2005; Transport for London, 2008; Invernizzi et al., 2011). Authors commonly attribute this to driver substitution behaviors or exploitation of policy loopholes (Davis, 2008; Gallego et al., 2013). In important work, Wolff (2014) finds that German Low Emissions Zones reduce the concentration of particles with a diameter of 10 microns or less (PM10) by approximately 9 percent; this study is particularly significant given efforts by European cities to meet stringent air quality standards.

Our study is unique in obtaining unconfounded causal estimates of behavioral responses to road pricing and net road pricing effectiveness. This is the first analysis to examine removal, rather than imposition, of a traffic policy. Other studies have used indirect measures of traffic (such as gasoline sales or vehicle registrations) or hourly vehicle counts, but to the best of our knowledge ours is the first to combine direct, high-resolution measures of traffic volume with air pollution data. Finally, our finding that the net effect of pricing varies with public transit availability is novel. It contributes to the literature on public transit and air quality (Friedman et al., 2001) and adds a new dimension to the literature on traffic policies.

The remainder of the paper proceeds as follows. Section 2 provides policy background and describes the natural experiment. Section 3 covers data, Section 4 describes our estimating equations, and Section 5 discusses results. Section 6 concludes.

2. Background

Located in the center of Milan, Area C includes approximately 8.2 square kilometers (5 percent of city land area) and 77,000 residents (6 percent of population). The boundary follows the *Cerchia dei Bastioni,* the route of the walls built under Spanish control in 1549. Many of the portals still stand today, though the walls are largely gone. Fig. A2 illustrates the area.

Milan provides high levels of public transit, including four subway lines, 19 tram lines, 120 bus lines, and 4 trolley lines. Together these lines transport 700 million passengers across 155 million kilometers per year. The 80-km subway network is larger than all other Italian subways combined (Azienda Transporti Milanesi, 2013). Public transit has a 41 percent mode share in the city, followed by cars at 30 percent, walking at 17 percent, bicycles at 6 percent, and motorbikes at 6 percent (Martino, 2012). The average round-trip commute in Milan takes 53 min, comparable to US cities like Dallas (52 min), Seattle (55 min), and Los Angeles (56 min; Toronto Board of Trade, 2011).

Milan is one of the most polluted large cities in Europe. From 2002 through 2010 the city exceeded the EU standard for PM10 on an average of 133 days per year (Danielis et al., 2011). Since the mid 1990s the city has experimented with traffic policies intended to curb its air pollution problem. Milan's first major road pricing program, called Ecopass, ran from January 1, 2008 to December 31, 2011. Drivers paid a fee to enter Area C that varied with the emissions from their vehicles. Vehicles meeting the Euro 3 standard paid nothing, while the dirtiest diesel vehicles paid €10.[1] The charge applied weekdays 7:30AM–7:30PM. Drivers could pay by internet, phone, or at the bank. The city enforced the charge using license plate-reading cameras located at the 43 entrances to Area C (Danielis et al., 2011). Drivers who entered without paying faced fines of €70–€275 (la Repubblica, 2008). Approximately 2 percent of entering vehicles each day incurred fines (Martino, 2012).

In June 2011 the voters of Milan overwhelmingly approved continued road pricing, with 79 percent in favor (Danielis et al., 2011).[2] As of January 16, 2012, the city implemented a €5 congestion charge for most vehicles entering Area C weekdays 7:30AM–7:30PM. This policy was named Area C.[3] Motorcycles and public vehicles (e.g. ambulances) were exempted.[4] Administrative details were largely the same as those for Ecopass. Drivers gained the option to pay by direct debit, using a radio reflector placed in the vehicle (similar to FasTrak or E-ZPass in the US). Violators were fined €87 (Carra, 2012).

On July 25, 2012, a court unexpectedly suspended the Area C congestion charge in response to a lawsuit by Mediolanum Parking (Povoledo, 2012). More than ten previous lawsuits against Ecopass and Area C had failed, so the suspension provoked surprise from the press (Carra and Gallione, 2012). Charge enforcement halted the next day, July 26. There was no press coverage prior to the court injunction, suggesting the decision was completely unanticipated. The duration of the suspension was unknown and some observers believed it would be permanent (Carra, 2012). Political forces marshaled on both sides. The mayor declared, "We will save Area C." Meanwhile the opposition called suspension the "death" of Area C, "the defeat of ideological fervor and the victory of Milan's productivity and good sense" (Carra, 2012). The city altered neither public transit service nor parking fees in response to the injunction. On September 6, the city announced the charge would be reinstated as of September 17, 2012.[5] For a timeline of these events, see Fig. 1.

3. Data

Our traffic data come from AMAT and the Settore Pianificazione e Programmazione Mobilità e Trasporto Pubblico Comune di

[1] Vehicles built prior to imposition of EU emissions standards were prohibited from October 15 through April 15. Drivers received a 50% discount on the first 50 entries and a 40% discount on the next 50 entries. Residents of Area C were also eligible for discounts (Rotaris et al., 2010).

[2] 49 percent of voters participated. The referendum did not specify the exact form the continued program would take.

[3] Vehicles classified diesel Euro 3 or below, or gasoline Euro 0 or below, were prohibited. Private vehicles over 7 m long were also prohibited. Scooters, motorcycles, and alternative-fuel vehicles, including hybrids, were exempted. Residents paid €2 per entry (City of Milan, 2012; Milan Tourism, 2012).

[4] This category includes mopeds and powered scooters.

[5] The reinstated charge now ends at 6PM on Thursdays, rather than at 7:30PM as before (Corriere della Sera, 2012a). Other features are unchanged.