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Evaluation of the impact of Bus Rapid Transit on air pollution in Mexico City

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ABSTRACT

Mexico City's bus rapid transit (BRT) network, Metrobus, was introduced in an attempt to reduce congestion, increase city transport efficiency and cut air polluting emissions. In June 2005, the first BRT line in the metropolitan area began service. We use the differences-in-differences technique to make the first quantitative assessment of the policy impact of a BRT system on air polluting emissions. The air pollutants considered are carbon monoxide (CO), nitrogen oxides (NO_X), particulate matter of less than 10 μm (PM_{10}), and sulfur dioxide (SO_2). The ex-post analysis uses real field data from air quality monitoring stations for periods before and after BRT implementation. Results show that BRT constitutes an effective environmental policy, reducing emissions of CO, NO_X, and PM_{10}.

1. Introduction

In the literature of environmental and transport economics, road transport is widely considered one of the main sources of air pollution. More specifically, a large fraction of GHG emissions and air pollutants are recognized as being derived from road traffic: "In 2004, transport accounted for almost a quarter of carbon dioxide (CO_2) emissions from global energy use. Three-quarters of transport-related emissions are from road traffic" (Woodcock et al., 2009, p. 2).

The source of emissions coming from road transport is different depending on the area. While freight transport is an important source of polluting emissions in interurban areas, private vehicles are considered one of the main sources of emissions in urban areas. Moreover, pollution levels are particularly high in urban areas that suffer severe levels of traffic congestion such as the metropolitan area of Mexico City. Conventional road transport in metropolitan areas produces a series of pollutant emissions, which in high concentrations represent a hazard for the inhabitants. The most usual pollutants are particulate matter of different size fractions (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NO_X), and carbon dioxide (CO_2).

Urban road transit can be broken down into different sectors, with one of the most relevant being that of public transport. Urban buses emit relatively high levels of CO, NO_X, PM_{10}, and CO_2. However, due to the use of cleaner, better quality fuels and to stricter regulations on road traffic emissions, the net air quality impact of buses can be positive if vehicles are replaced periodically. This is particularly true if cities adopt electric vehicles and this energy is generated from renewable sources.

Public transport systems, such as subways and light rail networks, are emission friendly transport options (compared to private combustion engine vehicles) that are able to transport huge numbers of people on daily basis. The downside of these modes of transportation, however, is the enormous initial investment they require, the rigidity of their services and the GHG emissions generated by their electricity source. Most governments operate under considerable budget constraints so that building or expanding local public transport infrastructure requires massive investment, while construction is not always feasible owing to the nature of the local geography.

In the last few decades, governments have sought alternatives that are similarly effective but at the same time more affordable. One such option is the Bus Rapid Transit (BRT) system, a high-quality bus service with a similar performance to that of a subway, but provided at a fraction of the construction cost (Cervero, 1998). Many countries around the world such as Brazil, China, South Africa and Turkey have adopted BRT systems. The main factors in their favor are the low initial investment costs (especially compared to a subway line), low maintenance costs, operating flexibility, and the fact that they provide a rapid, reliable service (Deng and Nelson, 2011). If a BRT line is unable to capture the projected transport demand, or if the usual route is under maintenance, the line can easily be rerouted.

The literature addressing the impact of BRT on air quality does not quantify the reduction in concentrations of the different pollutants. Most

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assessments are qualitative studies, computational simulations or take the form cost-benefit analyses that fail to provide details about individual pollutant levels. Our research seeks to address this gap in the literature. We study the impact of the BRT introduction in the Mexico City Metropolitan Area on the concentration of different air pollutants. The contributions of this paper are, as such, easily identifiable: a) to provide a rigorous quantification of the short-term impact on air quality of the introduction of a BRT network in the Metropolitan Area of Mexico City; b) to add to the few analyses to date that employ actual field data in their evaluations of public transport policy; and c) to employ the econometric-based method of differences-in-differences to analyze the environmental impact of a public transportation system like BRT.

2. Related literature

2.1. Studies on polluting emission reductions

Several studies have examined the impact of pollutants and report the potential effects for health. PM_{10} and $PM_{2.5}$ have been linked with a decrease in respiratory capacity, aggravating asthmatic conditions, and with severe heart and lung damage (WHO, 2001). Nitrogen oxides (NO_X) affect the respiratory system, Sulfur dioxide (SO_2) can worsen respiratory or cardiovascular diseases, and carbon monoxide (CO) is poisonous and in high concentrations can lead to unconsciousness and even death (Neidell, 2004; Schlenker and Walker, 2011). The effects of alleviating traffic congestion on infant health are analyzed in Currie and Walker (2011), who show that a reduction in congestion increases the health and development of infants (see also Kampa and Castanas, 2008; Wilhelm et al., 2008; and Lleras-Muney, 2010).

Many governments have introduced policies to reduce the emissions generated by their mobility services. Building up and expanding public transport infrastructure is a common strategy undertaken to reduce travel times, road congestion and polluting emissions. The study by Chen and Whalley (2012) looks at the introduction of Urban Rail Transit – the Metro – in Taipei and finds a reduction of between 5 and 15% in CO emissions. Topalovic et al. (2012) analyses the case of Hamilton in the US and points out that Light Rail Transit reduces emissions by displacing automobiles to alternative roads. An emission comparison between different transport modes, such as LRT and automobiles, is done by Shapiro et al. (2002), showing the benefits of public transport opposite to private car use. Similarly, Puchalsky (2005) also estimates lower emissions coming from electric forms of urban transport (LRT) compared to combustion engines such as the ones used by BRT units.

An alternative policy for abating emissions from road traffic is the introduction of maximum speed limits on highways or in certain metropolitan areas. Many studies have examined the impact of such policies by employing a vast range of analytical techniques. In this way, we find Gonçalves et al. (2008), who report modest reductions of polluting emissions in Barcelona; Keuken et al. (2010), who find a substantial reduction in polluting levels in the Netherlands; and, Keller et al. (2008), who estimate a 4% reduction in NO_X due to this policy in Switzerland. An alternative way of evaluating the impact of a policy on pollution levels is to measure the effect ex-post using field data. However, few studies of this type have been reported to date. Exceptions include Bel and Rosell (2013) and Bel et al. (2015) on the impact of an 80 km/h speed limit and a variable speed limit policy in the metro-area of Barcelona. They report that a variable speed limit was much more effective, reducing NO_X and PM_{10} emissions by 7.7–17.1% and 14.5–17.3% respectively. This suggests that reducing congestion (for which variable speed limit is a useful tool) is more effective than enforcing a fixed maximum speed limit. Another study that uses field data is that by Van Benthem (2015), who analyses speed limits on the U.S. West Coast highways, and concludes that the optimal speed, considering costs and benefits, is about 88 km/h (55 mph) and that increasing the speed would increase CO, NO_X, and O_2 levels.

2.2. Bus Rapid Transit and air pollution

Bus Rapid Transit –BRT– is a relatively new mode of public transportation that has found broad acceptance in developing countries since the early 1990s. By the end of 2016, 207 cities around the world had adopted some form of BRT. We find prominent examples in Bogotá, Curitiba, Guangzhou, Jakarta, and Istanbul. Latin America is seen as the epicenter of the global BRT movement (Cervero, 2013) with over 60 cities using BRT, moving about 20 million people each day; that is, 62% of the global demand for BRT services. Above all, cities in Brazil (34), Mexico (12) and Colombia (7) have led the rapid growth of BRT networks in the region. BRT has also developed in Europe and the U.S. Over 50 cities in Europe provide this service to an average of 2 million people daily. BRT systems exist in 18 cities in the US, transporting an average of almost half a million people daily (see http://brtdata.org/) for figures and statistics on BRT cities.

A key feature of BRT is that it acts not only as a transport policy, but also forms part of a country's environmental policy. In this latter regard, it needs to be borne in mind that old buses are being replaced by modern vehicles run on cleaner fuels, while the introduction of BRT lines should also reduce congestion. According to Cervero (2013, p. 19), BRT is ‘likely’ to have net benefits regarding emissions: “BRT generally emits less carbon dioxide than LRT [light rail train] vehicles due to the use of cleaner fuels”. Cervero and Murakami (2010) consider that attracting former motorists to BRT can reduce vehicle kilometers traveled and thus polluting emissions. In addition, Bubeck et al. (2014) suggest that a better integrated public transport system would attract higher passenger volumes resulting in lower emissions.

The reduction in emission levels thanks to the introduction of BRT systems is noticeable. In Bogotá’s TransMilenio, Hidalgo et al. (2013) estimate health-cost savings from reduced emissions following the completion of TransMilenio's first two phases at US$114 million over a 20-year period, based on a rough computation of data. They calculate that about 8% of total benefits can be attributed to air pollution and traffic accident savings (reductions in associated illnesses and deaths). However, the authors do not use real field data to quantify the pollution-reduction benefits. After the implementation of TransMilenio, the government of Bogotá reported a reduction of 43% in SO2 emissions, a reduction of 18% in NOx, and a 12% decline in particulate matter (Turner et al., 2012). Indeed, in Bogotá, the buses displaced by the BRT were reallocated to the urban edge and smaller surrounding townships, leading Echeverry et al. (2005) to argue that BRT may not have reduced the problem of polluting emissions but simply displaced it to other areas.

A study attempting to directly measure the air pollution impact of BRT is the one by Salehi et al. (2016), in which the authors study the development of different pollutants before and after the introduction of a BRT corridor in Tehran. Their measurements show a reduction of 5.8% for PM_{10}, 6.7% for CO, 6.7% for NO_x and 12.5% for SO_2. Their approach however does not consider the existence of a counterfactual, which would give their estimations broader validity. Using data from five air quality measuring stations during the time of the BRT introduction in Jakarta, Budi-Nugroho et al. (2011) find a reduction of PM_{10} and Ozone levels and argue that this decline is linked to the modal shift of commuters from private modes of transport to the BRT. By comparing polluting emissions from light rail trains and BRT in the UK, Hodgson et al. (2013) find that BRT produces lower PM_{10} emissions, but higher NO_x emissions.

The analysis of historical trends of energy demand, air pollutants and GHG emissions attributable to passenger vehicles commuting in Mexico City's metro-area done by Chávez-Baeza and Sheinbaum-Pardo (2014), reported that the primary sources of small particle matter are road passenger transport vehicles. According to in-vehicle measurements by Shiohara et al. (2005), carcinogenic risks caused by micro-buses were much higher than those caused by buses and the metro. In a related study, Gómez-Perales et al. (2004) measured (in-vehicle) commuters' exposure to $PM_{2.5}$, CO and benzene in micro-buses, buses and the metro