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School buses, diesel emissions, and respiratory health☆

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ABSTRACT

School buses contribute disproportionately to ambient air quality, pollute near schools and residential areas, and their emissions collect within passenger cabins. This paper examines the impact of school bus emissions reductions programs on health outcomes. A key contribution relative to the broader literature is that we examine localized pollution reduction programs at a fine level of aggregation. We find that school bus retrofits induced reductions in bronchitis, asthma, and pneumonia incidence for at-risk populations. Back of the envelope calculations suggest conservative benefit–cost ratios between 7:1 and 16:1.

1. Introduction

Pollution regulations are controversial, and economists and policy-makers debate their efficiency and cost effectiveness. Most economic evaluations of environmental quality examine the impact of ambient air pollution on health outcomes.[2] These studies are important for understanding national policy, but they are unlikely to shed light on programs targeting localized pollution exposure because widely dispersed ambient air quality monitors hide large local differences in pollution. Moreover, localized pollution policies may be especially effective at the margin; the basic insight is that abating pollution where people live, work, and study may return large benefits per dollar of cost.

This paper studies the health impacts and cost effectiveness of a new localized emissions reduction program that retrofits diesel school buses with aggressive pollution control technologies. We focus on school buses for several reasons. First, the particulate matter and air toxics common in diesel pollution may be responsible for as many as 15,000 premature deaths annually. In some regions, diesel mortality levels are similar to those of traffic accidents and second-hand smoke (CA Air Resources Board, 2002). Second, school buses are ubiquitous. In 2005, buses carried nearly 25 million children between 5 and 6 billion miles in the United States. Third, school buses are disproportionately dirty. The national average bus age is over 9 years, and estimates suggest that the average school bus emits twice as many contaminants per mile as the average tractor-trailer truck (Monahan, 2006). Fourth, school bus pollution has important local effects. In contrast to most diesel vehicles, buses primarily travel through residential areas and so individuals who are sensitive to pollution may be affected by bus emissions where they live. Diesel air pollutants also collect inside of passenger cabins and in schoolyards, so school-aged children may be further impacted. Recent research finds that within-bus concentrations of particulate matter and air toxics were 4–12 times higher than ambient pollution levels.

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[2] Notable studies in this vein include Chay et al. (2003), Chay and Greenstone (2003), Neidell (2004), Currie and Neidell (2005), Currie et al. (2009a,b), and Janke et al. (2009).

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Despite the potentially large health benefits of school bus retrofit programs, we know very little about their impacts. The dearth of empirical studies stems from at least two challenges. First, many of these programs are relatively new and data are scarce. Our study uses a comprehensive dataset on bus retrofits from the state of Washington, and detailed information includes retrofit type, retrofit date, and retrofit cost. We combine the novel program data with comprehensive morbidity and demographic data at the school district level. Second, statistical identification can be challenging. Health outcomes may drive program adoption or significant unobservables may influence both program adoption and health outcomes. We exploit a natural experiment and employ a differences-in-differences research design to help isolate causal impacts. Treatment school districts retrofitted eligible buses by the end of our sample period and control school districts retrofitted no buses by the end of our sample period. Identification exploits differences in adoption timing, rather than the adoption decision itself, as nearly all non-adopters began retrofits shortly after our sample period ends.

We find that school bus retrofits induced statistically significant and large reductions in bronchitis, asthma, and pneumonia incidence for both children and adults with chronic respiratory conditions. Empirical magnitudes are typically larger for children's health outcomes than for chronically ill adult outcomes. Results, especially for asthma and bronchitis incidence, are robust to several falsification and sensitivity checks. Most notably, while adopters and non-adopters experienced differential trends in health outcomes over the retrofit period, adopters and non-adopters experienced comparable trends in the pre-retrofit period. Adopters and non-adopters also experienced comparable trends over the retrofit period for illnesses plausibly unrelated to air quality.

To put our results in context, we combine our empirical results with the cost-of-treatment health valuation literature and perform a back of the envelope benefit–cost analysis. We conservatively estimate program benefits between 7 and 16 times program costs. This interpretation suggests that if the many states not aggressively pursuing school bus retrofits were to do so, social benefits are potentially large. Buses are an inexpensive and safe means of transport (in an accident sense), but our results suggest that they could be made safer (in the broadest sense) at modest cost.

We believe our analysis makes three contributions. First, our data and methods permit the first empirical economic assessment of the impact of *school bus retrofit programs* on morbidity outcomes. Second, we show that *local pollution policies* can significantly impact public health, and that these programs may produce a large "bang per buck". Third, our results may provide additional evidence on the broader effects of *air pollution on health*.[3] We cannot directly trace retrofit programs to lower ambient pollution levels, since our spatial unit of analysis is significantly smaller than the spatial distribution of pollution monitors. However, we do show that a program targeting air pollution exposure significantly reduces illnesses plausibly related to air quality (and only those illnesses).

The paper proceeds as follows. Section 2 provides institutional detail on school buses, diesel emissions, retrofit programs, and respiratory health. Section 3 describes our unique retrofit, demographic, weather, and health data. Section 4 presents our empirical methods and Section 5 presents key results. Section 6 explores our identification and other empirical assumptions. Section 7 provides a conservative back of the envelope benefit–cost assessment and concludes.

[3] In this sense, our paper is in the spirit of recent work by Currie and Walker (2011), Schlenker and Walker (2010), and Moretti and Neidell (2011).

2. Background

2.1. School buses and diesel emissions

Diesel emissions make up a substantial portion of ambient air pollution. Particulate matter from diesel engines accounts for 26 percent of total air pollution from fuel combustion and 66 percent of particulate air pollution from on-road sources (American Lung Association, 2008). On-road mobile sources emissions are often the largest single source of air pollution in a region.

School buses are common and polluting. In 2005, 25 million children traveled between 5 and 6 billion miles on school buses in the United States. Median routes for many of the buses in our sample were approximately 6 miles each way. The average child riding these buses spent nearly 45 min per day on the bus (Adar et al., 2008). The average bus age in the United States is over 9 years, and the average is substantially higher in many states. Research indicates that, per mile, school buses are twice as polluting as semi trucks. The average bus emits nearly 15 pounds of particulate matter and approximately 400 pounds of smog-forming nitrogen oxides and hydrocarbons per year (Monahan, 2006).

In addition to affecting background ambient air quality, school bus diesel pollution has important local effects. Since buses travel through residential areas, their emissions may impact at-risk individuals at a neighborhood level. Research indicates that people living near roads are exposed to pollution levels that are significantly greater than broad ambient levels (Pearson et al., 2000; Wilhelm and Ritz, 2003). Further, emissions from groups of buses idling outside schools can concentrate pollution within schoolyards and schools themselves.

Pollution exposure may be particularly high for children who ride buses. Air pollution concentrations inside mobile sources may be as much as 10 times background ambient levels (Shikiya et al., 1989; Chan et al., 1991; Lawryk et al., 1996). Diesel emissions collect through mechanisms such as direct flows from leaks or cracks in the crankcase or exhaust system. Such leaks or cracks may be more common in school buses than in other vehicles, as school bus engines are often less regularly maintained (Behrentz et al., 2004). Adar et al. (2008) installed pollution monitors in a subset of the vehicles in our study. Their estimates suggest that within-bus concentrations of harmful particulates were more than twice roadway concentrations and 4 times ambient levels. Related studies found that within-school bus concentrations of particulate matter and air toxics were 4–12 times higher than ambient levels (Wargo et al., 2002; Sabin et al., 2005).

2.2. Diesel emissions and respiratory health

Diesel fumes contain high levels of particulate matter, air toxics, nitrogen oxides, and hydrocarbons. Even at relatively low levels, these contaminants are known to exacerbate or cause asthma and other respiratory ailments. Daily changes in air pollution have been linked to daily changes in mortality, hospital admissions, and other public health indicators (Spix et al., 1998; Brunekreef and Holgate, 2002; Dockery, 2009). Air toxics defined broadly are associated with asthma, lung inflammation, coughing, wheezing, and reduced lung function (Peden, 2002). The fine particulate matter common in diesel emissions is linked to reduced lung function and increased incidences of pneumonia (Cohen and Nikula, 1999; McCreanor et al., 2007). Nitrogen oxides cause ground-level ozone, and high ozone concentrations are associated with aggravated respiratory illness and increased respiratory symptoms.

All children are potentially susceptible to the adverse effects of particulates and ozone (Committee on Environmental Health, 2004). Impacts on children are due to ongoing physiological res-