

School Buses, Diesel Emissions, and Respiratory Health

Timothy K.M. Beatty and Jay P. Shimshack*
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Timothy K.M. Beatty
Department of Economics
York University
Heslington, UK, YO10 5DD
tb526@york.ac.uk
(phone) +44 1904 433788

Jay P. Shimshack
Department of Economics
Tufts University
Medford, MA 02155
jay.shimshack@tufts.edu
(phone) 617.627.5947

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ABSTRACT

School buses are ubiquitous, frequently old, and travel primarily in residential areas. Research also indicates that diesel air pollutants may collect inside of buses themselves. Consequently, emerging school bus clean-up programs are among the most aggressive diesel emissions reduction programs. Yet, we know very little about the effects of these policies. This paper uses novel data and a difference-in-differences research design to examine the impact of Clean School Bus programs on health outcomes. We find significant evidence that bus retrofits reduce children's hospital visits for bronchitis, asthma, pneumonia, and pleurisy. Total program costs are substantially less than annual benefits.

1. Introduction

The health consequences of exposure to diesel exhaust are well understood. 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, other respiratory ailments, and cancer. Recent policy initiatives, including the Clean Air Diesel Non-Road Rule and the Heavy-Duty Highway Rule, directly target emissions from diesel vehicles. This paper studies the health impacts and cost effectiveness of some of the newest and most aggressive diesel emissions reduction programs, the Clean School Bus Initiatives.

Diesel emissions from school buses are a particularly prominent public health risk. Put simply, school buses are old. The national average bus age is over 9 years, and many states' fleets are considerably older. Estimates suggest that the average school bus emits twice as many contaminants per mile as the average tracker-trailer truck (Monahan 2006). School buses are also ubiquitous. In 2005, buses traveled between 5 and 6 billion miles in the United States. In contrast to other diesel vehicles, these buses primarily traveled through residential areas. Finally, recent research indicates that diesel air pollutants often collect inside of school buses themselves. Within-bus concentrations are of particular concern since children's exposure is high. Buses carry nearly 25 million children annually, and the average route exceeds 30 minutes for many suburban and rural kids. Children's developing systems and high activity levels make them especially prone to diesel-related illness.

School bus emissions are an environmental health risk that society can readily limit. Many states, in cooperation with the Environmental Protection Agency, have begun

instituting school bus clean-up programs. Most notably, many states have begun retrofitting old buses with modern pollution control technology. Estimates suggest these retrofits can reduce contaminant emissions by over 70 percent and may reduce within-bus concentrations as well. Changes in sensitive populations' health outcomes following one of the country's most progressive retrofit programs are the focus of this study.

Despite the importance and growing prominence of Clean School Bus Initiatives, we know very little about the effects of these policies. Most notably, no systematic revealed evidence exists on the consequences of bus retrofits for public health. This study fills that gap. We ask the following questions. To what extent did Clean School Bus programs reduce children's major respiratory illnesses? Similarly, to what extent did Clean School Bus programs reduce major respiratory illness among adults with chronic lung conditions?

The dearth of empirical studies on the efficacy and cost effectiveness of school bus retrofits stems from at least two challenges. First, Clean School Bus Initiatives are relatively new and data are therefore scarce. This paper uses detailed program data from the Puget Sound area in Washington State. We combine novel bus-level data on vehicle characteristics, retrofit type, retrofit date, and exact retrofit cost with health outcome data from the state's Comprehensive Hospital Abstract Reporting System (CHARS). CHARS data include patient-level information on diagnosis, treatment, billed charges, extensive demographics, and home zip code. Our final dataset permits the first detailed assessment of clean school bus programs.

The second difficulty with this type of program evaluation is policy endogeneity. Perhaps health outcomes drive program adoption rather than vice versa. Additionally,

significant unobservable factors may influence both program adoption and health outcomes. In order to identify the treatment effect of program retrofits, we isolate causality and control for confounding factors with a difference-in-differences research design. The treatment group is school districts with substantial bus retrofits, and the quasi-control group is school districts with no bus retrofits. The standard intuition applies. School districts without retrofits provide information on the expected change in health outcomes for those districts with substantial retrofits, had these areas not implemented the clean school bus program. The difference-in-differences research strategy permits treatment effect identification even if the treatment is endogenous to baseline health levels.

We find that retrofits induced statistically and economically significant reductions in bronchitis, asthma, pleurisy, and pneumonia incidence for sensitive populations. Respiratory illness reductions are typically more significant for children than for adults with chronic respiratory conditions, suggesting that the impacts of Clean School Bus programs may operate through acute within-bus channels as well as ambient air quality channels. To put our results in context, we compare observed program implementation costs to benefit estimates obtained by evaluating our empirical estimates with the health valuation literature. *Total* program costs are substantially less than *annual* program benefits for children alone, so overall net benefits are significantly positive.

2. Diesel Emissions, Respiratory Health, and Clean School Bus Initiatives

Diesel Emissions and Respiratory Health

Air pollution is generally accepted to be detrimental to human health, and the link is demonstrated in the epidemiological and medical literatures. See, for example,

Brunekreef and Holgate (2002) for a survey. Diesel fumes are a particularly important contributor to air contaminants. For example, the American Lung Association reports that 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.

Specific health consequences of the fine particulates common in diesel emissions include reduced lung function and increased incidences of pneumonia (McCreanor et al. and Cohen and Nikula). For adults, morbidity is most pronounced for individuals with pre-existing respiratory ailments. Diesel fumes are also an important source of nitrogen oxides, which cause ground-level ozone. High ozone concentrations are associated with reduced lung function, aggregated respiratory illness, and increased respiratory symptoms.

Children are thought to be at greater risk from the adverse effects of air pollution, especially particulates and ozone (Pediatrics Committee on Environmental Health 2004). This is due to ongoing physiological respiratory development, smaller average lung size, and increased activity levels. The fine particulates contained in diesel exhaust have been shown to contribute significantly to children's morbidity and mortality. The scientific evidence suggests that fine particulates affect both lung function and lung growth in children (Gauderman et al. 2000, Gauderman et al. 2004). Diesel fumes can also increase the severity of children's asthma and can induce asthma in otherwise healthy children (Peters et al. 2004, McConnell et al. 2002).

Clean School Bus Initiatives

Recent federal and state initiatives directly target emissions from school buses. This study examines the impacts of the Washington State Clean School Bus Program, one of the nation's most progressive bus policies. State senate bill ESSB6072 authorized Washington's program. The act provided \$5 million in annual funding for the five years spanning 2003-2008. The legislation's primary goal was to retrofit approximately 7500 of its 9000 school buses with modern pollution control equipment. Legislative priorities include targeting buses with model years prior to 1994, since retrofitting older buses yields more substantial emissions reductions than retrofitting newer buses (Boyer and Lyons 2004).

Under ESSB6072, the state offers school districts complete retrofit rebates. Further, a small number of districts are eligible for federal funding from the US Environmental Protection Agency's Clean School Bus USA Program. Washington's Department of Ecology and the state's seven air quality control agencies administer the program. As noted, Washington emphasizes retrofits, and approximately 88 percent of expenditures were devoted to equipment installations in the program's first operational year. Seven percent of expenditures were devoted to administration and less than 5 percent went to low sulfur diesel fuel programs.¹

Diesel oxidation catalysts (DOCs) and crankcase ventilation filters (CCVs) are the predominantly installed retrofits. DOCs are add-on ceramic substrate devices that catalyze chemical reactions in emissions, breaking down harmful pollutants into less

¹ Lower sulfur diesel, typically in the form of 20% biodiesel, reduces particulates by a considerably smaller amount than retrofits. Since lower sulfur fuels have historically been a dramatically smaller priority than retrofits, and since lower sulfur fuels have a smaller impact on total air pollution outcomes, we ignore fuel programs in the analysis that follows.

harmful substances. Washington's Department of Ecology and its contractors maintain that DOC installations alone are most appropriate for buses with 1982-1987 model years. On average, DOCs are expected to reduce particulates from these vehicles by approximately 20-25 percent and hydrocarbons by as much as 50-70 percent.

More recently, the program has begun augmenting DOC retrofits with additional crankcase ventilation filter retrofits. CCVs are add-on devices that filter all emissions from the crankcase, the largest chamber of most diesel engines. When CCVs are installed, they are almost always coupled with diesel oxidation catalysts. Washington's Department of Ecology and its contractors maintain that CCV installations are most appropriate for buses with model years after 1987. CCVs are particularly effective for especially harmful fine particulates, and they are expected to reduce PM levels by 10-20 percent more than DOCs alone. There is also emerging evidence that CCVs may reduce pollutant concentrations within buses themselves.

3. Data

To answer our key research questions, we use information on both retrofit programs and children's health outcomes. To this end, we combine administrative data on school bus retrofits with health care utilization data. One key challenge in combining data from disparate sources into a single dataset suitable for econometric analysis is choosing a suitable level of aggregation. Because retrofit decisions are made at the school district level, we focus on the school district as our unit of analysis.

Data Sources and Content

Our information on the school bus retrofit program consists of an administrative database of approximately 4200 buses in the Puget Sound area. For each bus, we observe

information related to equipment installations such as the retrofit type (DOC/CCV), the date of the retrofit, and the cost of the retrofit. In addition, we observe basic bus characteristics such as age, size, and make. Information on individual buses is then aggregated to the district level to construct a district fleet profile consisting of the cumulative share of buses having undergone each type of retrofit over the sample period.

Data on health outcomes is extracted from the Washington State Comprehensive Abstract Reporting System (CHARS). CHARS data include a complete record of hospital inpatient discharges for the entire state. Each observation consists of information on the patient and illness, such as age, sex, home zip code, detailed diagnosis code, and billed charges. Since we focus on an air pollution control program, our primary analysis emphasizes the major respiratory ailments: bronchitis, asthma, pleurisy, and pneumonia.²

Constructing measures of health outcomes at the school district level from data collected at the zip code level presents several challenges. We first compile a list of zip codes for all public schools within a district. The vast majority of cases are straightforward. Here, a zip code contains only schools from a single district. All patients in that zip code are therefore assigned to the corresponding district. When a given zip code contains multiple districts, we assign shares of outcomes to each district in proportion to the number of schools each district has in a given zip code. For example, if a zip code contains two schools from district A and 3 schools from district B, we would assign $2/5^{\text{th}}$ of all health outcomes in that zip code to district A and $3/5^{\text{th}}$ to district B. Finally, in the rare case that a given zip code has no schools, we assign outcomes in these zip codes to the nearest school district.

² Pleurisy is an inflammation of the mucus membrane enveloping the lungs and rib cage. Individuals suffering from pleurisy typically report difficult and painful breathing.

In order to scale health outcomes and examine the impact of community characteristics, we also match program and health data to district-level demographic variables. We obtain demographic data from the National Center for Education Statistics (NCES). Information of interest includes student population, adult population, per capita income, racial composition, and average staff-to-student ratios.

Figure 1. Washington State’s Puget Sound Region

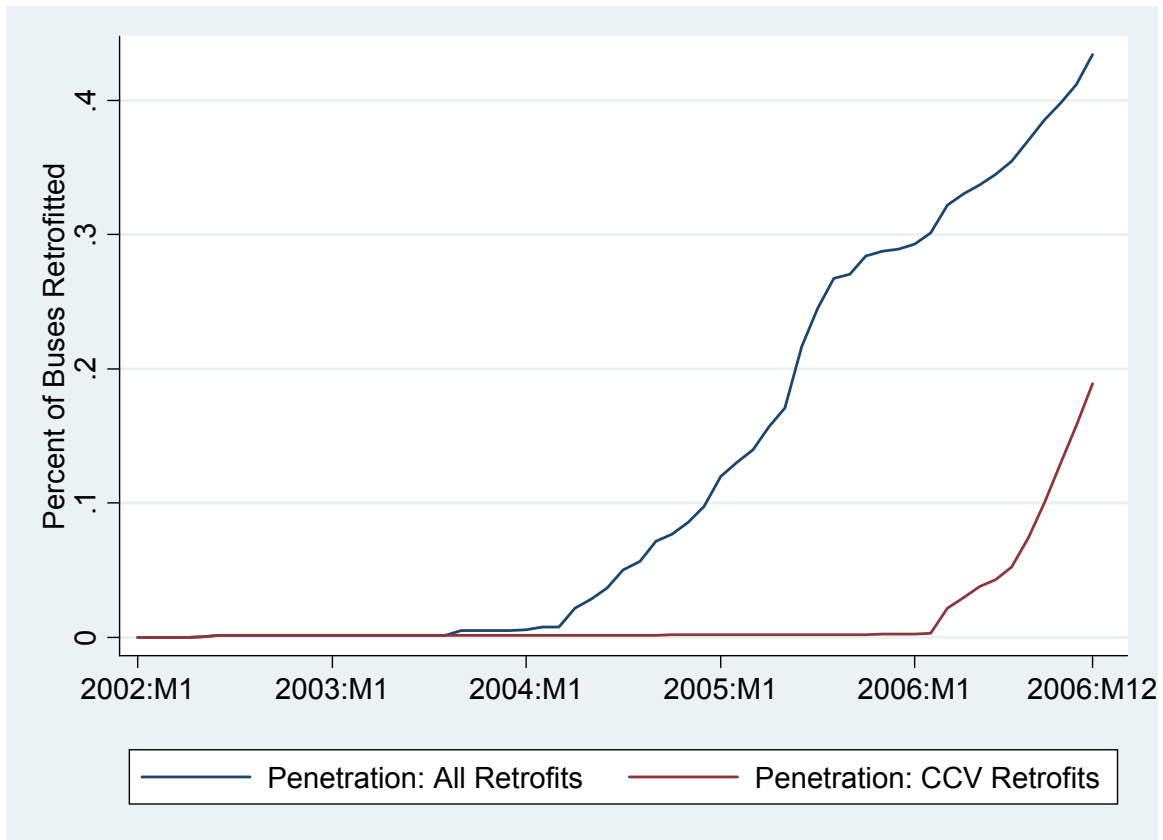


Our sample

Our sample of bus-level and health outcome data consists of observations from the four most populated counties in the Puget Sound region of Washington: Snohomish, King, Pierce, and Kitsap. Figure 1 provides a map of the study area. We focus on the state of Washington because its respiratory illness rates are among the highest in the nation. Further, it is an innovator in school bus programs. For example, Washington was only one of two states to receive a ‘good’ rating for bus cleanup from the Union of

Concerned Scientists. We examine the Puget Sound region because of extensive administrative data collection and relative homogeneity. The majority of the state population lives in our four-county study area.

Figure 2. Average Retrofit Penetration, 2002 – 2006



The study area contains 53 major school districts. For each of the school districts, we have both program adoption and health outcome data at the month-level. Figure 2 displays a synopsis of average program penetration over our 53 districts. Diesel oxidation catalyst installations began in earnest early in 2004 and steadily increased over the remaining three years of the sample period. Crankcase ventilation filter installations began in earnest in late 2005 and increased relatively rapidly until the end of the sample period.

Our final complete sample includes data from 2002, before any retrofit programs were implemented. The sample also includes data from 2006, after many districts had retrofitted a substantial number of buses. For the analysis that follows, we omit July and August from both years of the sample since schools are not in session. The resulting dataset consists of 1060 observations: we observe 53 school districts over 10 months in 2002 (before the retrofits) and over 10 months in 2006 (after the retrofits).

Summary Statistics

Summary statistics, broken down by retrofit type and health outcome, are presented in Tables 1 and 2. These tables present retrofit results for any type of retrofit. Here, school districts that retrofitted more than 30 percent of their bus fleet with diesel oxidation catalysts (DOCs) and/or crankcase ventilators (CCVs) by summer 2006 are considered substantial adopters.³ Tables 1 and 2 compare health outcomes for the substantial adopter districts to health outcomes for districts that retrofitted no buses by the summer 2006.

The first two rows of Table 1 indicate that bronchitis and asthma hospital admissions for children under 17 in substantial adopter districts declined by 9.95 cases per 100000 children per month. In contrast, bronchitis and asthma hospital admissions for children under 17 in non-adopter districts declined by only 2.65 cases per 100000 children per month. The difference-in-differences summary statistic is 7.30 cases per 100000 children per month (23 percent of baseline levels). The first two rows of Table 1 suggest that bus retrofits may have reduced children's bronchitis and asthma cases. Standard deviations, however, are large and none of the reported differences are statistically significant.

³ We later consider the sensitivity of our results to alternative 'hi adoption' / 'no adoption' definitions.

Results in the last two rows of Table 1 tell a similar story for adults with chronic respiratory conditions. Bronchitis and asthma hospital admissions for adults with chronic illness in substantial adopter districts fell by 0.73 cases per 100000 adults per month. In contrast, bronchitis and asthma hospital admissions for adults with chronic illness in non-adopter districts increased by 1.04 cases over the sample period. The difference-in-differences summary statistic is 1.77 cases per 100000 adults per month (65 percent of baseline levels). The last two rows of Table 1 suggest that bus retrofits may have reduced bronchitis and asthma cases for adults with chronic illness. Again, however, standard errors are large and none of the reported differences are statistically significant.

Table 2 replicates the summary statistics for pneumonia and pleurisy admissions, rather than asthma and bronchitis admissions. Here, the children's difference-in-differences summary statistic is 5.53 pleurisy and pneumonia cases per 100000 children per month (36 percent of baseline levels). The chronic condition adults' difference-in-difference summary statistic is 3.12 pleurisy and pneumonia cases per 100000 adults per month (15 percent of baseline levels). Table 2 suggests that bus retrofits may have reduced pleurisy and pneumonia cases for both children and adults with chronic respiratory ailments.

In sum, the summary statistics suggest potentially important effects of DOC and CCV retrofits on children's incidences of bronchitis, asthma, pleurisy, and pneumonia. Retrofits seem to reduce bronchitis, asthma, pleurisy, and pneumonia incidence for adults with chronic respiratory ailments as well. The summary statistics also suggest some degree of endogeneity in levels. Most notably, substantial retrofits occur more frequently in districts with higher levels of children's respiratory illness.

4. Empirical Methods and Results

Empirical Methods

This section presents our more formal empirical analysis. Here, we first parameterize the informal difference-in-differences comparisons presented Tables 1 and 2. The main advantage of the regression approach is that parametric structure allows for more precise estimation. Point estimates and the fundamental identification approach, however, remain the same.

Regressions are parameterized following the difference-in-differences literature. We include a treatment variable alone, a before (2002) and after (2006) time dummy alone, and the treatment variable interacted with the time dummy. Again, the treatment indicates that the school district is a substantial retrofit adopter. For example, for initial regressions, a district is in the treatment group if it retrofits more than 30 percent of its buses by summer 2006. A district is in the quasi-control group if it does not retrofit any of its buses by summer 2006.

Our baseline empirical model can be represented by:

$$(1) \quad y = \alpha + \delta TIME + \gamma TREATMENT + \beta TIME * TREATMENT + \varepsilon ,$$

where y represents health outcomes and ε represents the standard error term. ε is assumed orthogonal to both time and treatment status. In other words, treatment may be endogenous to health levels, but not to changes in health outcomes. Non-treated districts provide information on the expected change in health outcomes for the treated in the absence of the treatment. The coefficient δ represents the effect of time on health outcomes for the non-treated group and γ represents the effect of the treatment on health

outcomes in the pre-treatment period. β is the coefficient of interest, and it represents the difference-in-differences effect of the treatment on the treated.

Baseline Empirical Results

Baseline regression results for all retrofit adoptions, broken down by health outcome, are presented in Tables 3 and 4. T-statistics, based on robust standard errors, are reported in parentheses below the coefficient estimates.

We first examine regression results for the impact of all retrofits on bronchitis and asthma cases reported in Table 3. The key difference-in-difference (DID) coefficients are all economically significant and typically statistically significant as well. Results indicate that, after controlling for changes to a quasi-control group, districts with substantial retrofits experienced 7.3 fewer bronchitis and asthma cases per 100000 children per month. Similarly, after controlling for confounding factors, districts with substantial retrofits experienced 1.8 fewer bronchitis and asthma cases for those with chronic conditions per 100000 adults per month. These are large changes. 7.3 cases per 100000 children per month is a 23 percent drop relative to pre-retrofit levels for the substantial adopter districts.

Results for pleurisy and pneumonia are also economically meaningful. The key DID coefficients in Table 4 are economically and statistically significant for children. Results indicate that, after controlling for changes to a quasi-control group, districts with substantial retrofits experienced 5.3 fewer pleurisy and pneumonia cases per 100000 children per month. This reduction represents a 36 percent drop relative to pre-retrofit levels for the substantial adopter districts. Results for adults with chronic conditions, however, are not statistically significant and relatively small. The point estimate

represents a 15 percent drop relative to pre-retrofit levels for the substantial adopter districts.

CCV Empirical Results

We next examine parallel regression results for the subset of total retrofits that include more aggressive crankcase ventilation filter (CCV) installations. Recall that CCV retrofits typically augment diesel oxidation catalyst with add-on devices that further reduce particulates and may reduce within-bus pollution concentrations as well. Here, the treatment indicates that the school district is a substantial CCV retrofit adopter. More precisely, school districts that retrofitted more than 10 percent of their bus fleet with CCVs by summer 2006 are considered substantial CCV adopters.⁴ The quasi-control group remains school districts that did not retrofit any buses with either DOCs or CCVs by summer 2006.

CCV regression results, broken down by health outcome, are presented in Tables 5 and 6. T-statistics, based on robust standard errors, are again reported in parentheses below the coefficient estimates. The key difference-in-difference (DID) coefficients in Table 5 are all economically and statistically significant. Results indicate that, after controlling for changes to a quasi-control group, districts with substantial CCV retrofits experienced 13.7 fewer bronchitis and asthma cases per 100000 children per month. Similarly, after controlling for confounding factors, districts with substantial retrofits experienced 1.8 fewer bronchitis and asthma cases for those with chronic conditions per 100000 adults per month. These are large changes. 13.7 cases per 100000 children per month is a 32 percent drop relative to pre-retrofit levels for the substantial CCV adopter districts.

⁴ We later consider the sensitivity of our results to alternative ‘hi adoption’ / ‘no adoption’ definitions.

Results for pleurisy and pneumonia are also economically meaningful. The key DID coefficients in Table 6 are economically and statistically significant for children. After controlling for changes to a quasi-control group, districts with substantial CCV retrofits experienced 6.7 fewer pleurisy and pneumonia cases per 100000 children per month. This reduction represents a 39 percent drop relative to pre-retrofit levels for the substantial adopter districts. Results for adults with chronic conditions, however, are once again not statistically significant.

Statistical Concerns

As is frequently the case in applied policy evaluations, our treatment status is not randomly or exogenously assigned. The difference-in-differences research strategy is designed to allow for endogeneity of the retrofit treatment with initial health levels. For example, suppose that school districts with higher initial respiratory illness levels more readily instituted Clean School Bus Initiatives. Indeed, we find considerable evidence that programs are more frequently implemented in districts with high initial asthma, bronchitis, pleurisy, and pneumonia illnesses among children. Fortunately, the DID research design still identifies the appropriate treatment effect.

It is plausible, *a priori*, that some unobserved factor was associated with both a decrease in health incidences and an increased likelihood of School Bus retrofits. For example, active policy-makers might implement other air pollution or public health policies in conjunction with clean school bus programs. In this omitted variable case, our identification strategy may fail. However, this is unlikely in our context. First, school bus retrofit decisions and implementation occur at the school district level, while most air quality and public health programs are instituted at the county, state, or national level.

Second, our research area is relatively small and relatively homogeneous. Neither treatment nor control groups are geographically clustered together, and treatment and control districts do not systematically differ on most important demographic characteristics. Table 7 compares high-adopters and non-adopters. Per capita income, racial composition, and school staffing ratios are extremely similar across adoption classification. Treatment districts are systematically smaller, but we already scale results for population size. Third, we replicated our analysis for the pre-adoption period. High-adopter districts had similar changes in respiratory ailments to non-adopter districts between 2001 and 2002, before the retrofits began in earnest. Economically and statistically significant differences in health outcome changes between adopters and non-adopters only appear over the sample period when retrofits were installed.

It is also possible, *a priori*, that school districts that experience or expect falling health outcomes over time were more likely to adopt Clean School Bus programs. In this reverse causality case, our identification strategy may again fail. We are unable to fully account for this possibility, but some simple sensitivity analyses alleviate concerns. First, we examined the difference-in-differences results for children and chronic condition adult health ailments that are unlikely to be driven by ambient air quality changes. Results are presented in Table 8. We find no significant differences in gastrointestinal or kidney/urinary tract illness changes between treated and quasi-control districts over our sample period. Further, we checked whether bronchitis, asthma, pleurisy, and pneumonia incidences among healthy adults differed between treatment and quasi-control groups. Results are presented in Table 9. We find no consistent difference in major respiratory ailment changes for healthy adults between treatment and control groups. Cross-equation

equality of DID coefficient tests typically statistically reject the equivalence of the results in Tables 3 and 4 with the results in Table 9.

Finally, our treatment definition is *ad hoc*. However, results are not sensitive to the substantial adopter classification for either all retrofit installations or CCV installations. We increased and decreased the substantial adopter threshold by as much as 50 percent for both all retrofit and CCV retrofit analyses. We also defined adopter classifications for the beginning and the end of 2006, rather than summer 2006. In all cases, a variety of plausible treatment definitions yielded results that were practically and statistically similar to those in Tables 3-6.

5. Discussion and Conclusion

Interpretation

We find that school bus retrofits induced statistically and economically significant reductions in bronchitis, asthma, pleurisy, and pneumonia incidence for sensitive populations. Districts with substantial retrofits experienced 23 percent fewer children's bronchitis and asthma cases per month, relative to a control group. These same districts also experienced 36 percent fewer children's pleurisy and pneumonia cases per month.

We also find consistently larger effects for the CCV analyses, suggesting that the more modern crankcase ventilation filters play a larger role in health improvements than diesel oxidation catalysts alone. Districts with substantial CCV retrofits experienced 32 percent fewer children's bronchitis and asthma cases per month, relative to a control group. These same districts also experienced 39 percent fewer children's pleurisy and pneumonia cases per month.

To put our key results in context, consider that the medical literature estimates health care costs per inpatient episode of bronchitis, asthma, and pneumonia at approximately \$3000-\$7000/visit. See, for example, Stanford et al. (1999) and Lave et al. (1999), for a more complete discussion. The average school district in our dataset serves approximately 10000 children. For the average district, our CCV coefficients approximately translate into 16.4 avoided hospital visits for children's asthma and bronchitis per year. Similarly, CCV coefficients approximately translate into 8.1 avoided hospital visits for children's pneumonia and pleurisy per year. A single district's annual benefits for children's health from observed CCV adoption are therefore approximately \$73500 (24.5 visits times \$3000/visit). Note these benefit calculations exclude adults with chronic conditions, employ conservative cost of treatment assumptions, and omit suffering considerations.

The average substantial CCV adopting school district retrofitted approximately 25 of its 66 buses over the sample period. Each CCV retrofit cost approximately \$1200 in total, including parts and labor. Therefore, the average high adopter school district spent approximately \$30,000 (25 buses times \$1200) on CCV retrofits over the sample period. *Total* costs are substantially less than *annual* benefits for children alone. These preliminary back of the envelope calculations suggest that Clean School Bus retrofits are likely to exhibit significant net benefits in total.

We also consistently find that asthma and bronchitis illness reductions occurred for both children and adults with chronic conditions. Therefore, clean school bus programs are likely to at least partially impact ambient air quality. Interestingly, however, we also consistently find that significant pleurisy and pneumonia illness reductions

occurred for children but not for adults with chronic conditions. This result is especially pronounced for the more modern crankcase ventilation filter retrofits. While there are several plausible explanations, these results are consistent with school bus programs importantly impacting public health through acute within-bus exposure. As ambient air quality improves, localized acute exposures are likely to become more important targets of public policy.

Future Directions

This paper is a work in progress, and work remains. Directions for future research related to identification include the exploitation of a natural experiment afforded by summer vacations. The idea is simple. The school year versus summer difference in health outcomes for school districts without clean school bus programs should be pronounced. In contrast, the difference in health outcomes for school districts with clean school bus programs should be considerably smaller. The schools without clean school bus programs effectively become a control group and the difference in school/summer health differences is the effect of the clean school bus program in the districts where it exists.

Directions for future research related to the scope of the analysis include analyses of ambient air quality, school absences, and educational test scores. We hope to collect air quality data for the Puget Sound region and link particulate and ozone measurements to program implementation. Further, there has been frequent speculation in the public health literature that air pollution causes persistent school absences and reduced educational performance due to respiratory illness. Therefore, our future plans include

tests of the hypotheses that Clean School Bus programs reduce school absences and improve test scores.

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**Table 1. Summary Statistics for All Retrofits:
Bronchitis and Asthma Cases (per 100000 individuals)**

Group	2002	2006	Difference	Diff-in-Diff
<u>Children</u>				
Districts with Substantial Retrofits	32.20	22.25	9.95	
Districts with no Retrofits	18.52	15.87	2.65	7.30
<u>Adults w/ Chronic Conditions</u>				
Districts with Substantial Retrofits	2.73	2.00	0.73	
Districts with no Retrofits	0.68	1.72	-1.04	1.77

**Table 2. Summary Statistics for All Retrofits:
Pleurisy and Pneumonia Cases (per 100000 individuals)**

Group	2002	2006	Difference	Diff-in-Diff
<u>Children</u>				
Districts with Substantial Retrofits	14.80	8.30	6.50	
Districts with no Retrofits	4.29	3.12	1.17	5.33
<u>Adults w/ Chronic Conditions</u>				
Districts with Substantial Retrofits	20.38	20.75	-0.37	
Districts with no Retrofits	14.32	17.81	-3.49	3.12

**Table 3. Regression Results for All Retrofits:
Bronchitis and Asthma Cases (per 100000 individuals)**

	Dependent Variable: Cases Among Sensitive Populations	Dependent Variable: Cases Among Children	Dependent Variable: Cases Among Adults w/ Chronic Illness
Constant	4.55** (5.63)	18.52** (4.99)	0.682** (2.79)
Substantial Retrofits? “Treatment”	4.62** (4.63)	13.68** (3.31)	2.05** (3.63)
Post Installation? “Time”	0.281 (0.18)	-2.65 (-0.40)	1.04 (1.52)
Treatment * Time	-3.04* (-1.82)	-7.30 (-1.05)	-1.77* (-2.04)
Observations	860	860	860
F-statistics	9.35	8.94	8.34
Prob > F	0.001	0.001	0.001

**Table 4. Regression Results for All Retrofits:
Pleurisy and Pneumonia Cases (per 100000 individuals)**

	Dependent Variable: Cases Among Sensitive Populations	Dependent Variable: Cases Among Children	Dependent Variable: Cases Among Adults w/ Chronic Illness
Constant	12.02** (7.01)	4.29** (2.65)	14.32** (6.85)
Substantial Retrofits? “Treatment”	7.23** (3.96)	10.51** (4.95)	6.06** (2.78)
Post Installation? “Time”	2.66 (0.88)	-1.17 (-0.62)	3.49 (0.92)
Treatment * Time	-4.03 (-1.27)	-5.32** (-2.19)	-3.12 (-0.79)
Observations	860	860	860
F-statistics	5.97	17.74	2.95
Prob > F	0.001	0.001	0.032

**Table 5. Regression Results for CCV Retrofits:
Bronchitis and Asthma Cases (per 100000 individuals)**

	Dependent Variable: Cases Among Sensitive Populations	Dependent Variable: Cases Among Children	Dependent Variable: Cases Among Adults w/ Chronic Illness
Constant	4.55** (5.61)	18.52** (4.97)	0.682** (2.78)
Substantial CCV Retrofits? “Treatment”	7.03** (5.68)	23.91** (4.20)	2.16** (4.80)
Post Installation? “Time”	0.281 (0.18)	-2.65 (-0.40)	1.04 (1.52)
Treatment * Time	-4.60** (-2.39)	-13.68* (-1.62)	-1.82 (-2.12)
Observations	340	340	340
F-statistics	11.97	7.33	8.88
Prob > F	0.001	0.001	0.001

**Table 6. Regression Results for CCV Retrofits:
Pleurisy and Pneumonia Cases (per 100000 individuals)**

	Dependent Variable: Cases Among Sensitive Populations	Dependent Variable: Cases Among Children	Dependent Variable: Cases Among Adults w/ Chronic Illness
Constant	12.02** (6.99)	4.29** (2.64)	14.32** (6.82)
Substantial CCV Retrofits? “Treatment”	7.54* (3.50)	12.80** (4.60)	6.00** (2.46)
Post Installation? “Time”	2.66 (0.87)	-1.17 (-0.61)	3.49 (0.92)
Treatment * Time	-5.64* (-1.64)	-6.72** (-2.09)	-5.02 (-1.21)
Observations	340	340	340
F-statistics	4.30	13.29	2.05
Prob > F	0.005	0.001	0.107

Table 7. Treatment vs. Control Group Characteristics

Characteristic	Districts with Substantial Retrofits	Districts with No Retrofits	Difference	p-value for Difference
Student population	2335	10597	-8262	0.00
Per capita income	23609	24166	-557	0.79
Percent below poverty line	.086	.075	.011	0.48
School staff members per student	.104	.093	.011	0.22
Percent white	.754	.722	.032	0.50

**Table 8. Regression Results for All Retrofits:
Non-Respiratory Ailment Cases (per 100000 individuals)**

	Dep Var: Gastrointestinal cases among children	Dep Var: Gastrointestinal cases among adults w/ chronic illness	Dep Var: Kidney and urinary tract cases among children	Dep Var: Kidney and urinary tract cases among adults w/ chronic illness
Constant	10.02** (3.89)	9.90** (3.69)	13.83 (1.46)	2.88** (4.80)
Substantial Retrofits? "Treatment"	2.90 (1.08)	3.42 (1.24)	-6.36** (-0.67)	4.10** (6.17)
Post Installation? "Time"	-0.803 (-0.24)	2.93 (0.72)	-9.60 (-1.00)	3.65 (1.35)
Treatment * Time	0.139 (0.04)	0.336 (0.08)	9.38 (0.97)	-1.53 (-0.55)
Observations	860	860	860	860
F-statistics	1.28	5.40	1.59	19.70
Prob > F	0.281	0.001	0.189	.001

**Table 9. Sensitivity Analysis Results for All Retrofits:
Cases (per 100000 individuals)**

	Dependent Variable: Bronchitis and Asthma Cases Among Healthy Adults	Dependent Variable: Pleurisy and Pneumonia Cases Among Healthy Adults
Constant	3.52* (1.66)	1.98** (3.24)
Substantial DOC Retrofits? “Treatment”	0.577 (0.24)	0.946 (1.19)
Post Installation? “Time”	-2.29 (-1.04)	-0.960 (-1.40)
Treatment * Time	-0.210 (-0.09)	0.234 (0.24)
Observations	860	860
F-statistics	2.13	3.86
Prob > F	0.095	0.009