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Ying-Ying Meng, Dahai Yue, John Molitor, Xiao Chen, Jason G. Su, Michael Jerrett

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Reductions in NO_2 and Emergency Room Visits Associated with California's Goods Movement Policies: A Quasi-Experimental Study

Ying-Ying Meng, DrPH

UCLA Center for Health Policy Research, University of California at Los Angeles, Los Angeles, CA, USA. 10960 Wilshire Boulevard, Suite 1550, Los Angeles, CA 90024.

Email: yymeng@ucla.edu.

Dahai Yue, Ph.D.

Department of Health Policy and Management, University of Maryland, College Park, MD, USA. 4200 Valley Dr, College Park, MD 20742. Email: dhyue@umd.edu.

John Molitor, Ph.D.

College of Public Health and Human Sciences, Oregon State University, Corvallis, OR, USA

Xiao Chen, Ph.D.

Center for Health Policy Research, University of California at Los Angeles, Los Angeles, CA, USA.

Jason G. Su, Ph.D.

School of Public Health, University of California, Berkeley, CA, United States

Michael Jerrett, Ph.D. (Full Professor)

Department of Environmental Health Science, University of California at Los Angeles, Los Angeles, CA, USA.

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Data Sharing Statement

We used Medicaid claims data from the California Department of Health Care Services (DHCS). We are not legally permitted to share the data used for this study. For the exposure (e.g., air pollutant) data, we obtained them from various sources including US Geological Survey, California Irrigation Management Information System (CIMIS), and US Environment Protection Agency. Some of these exposure data can be shared upon request to authors.

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Reductions in NO_2 and Emergency Room Visits Associated with California's Goods Movement Policies: A Quasi-Experimental Study

Abstract

Introduction

This study examines whether the "Emission Reduction Plan for Ports and Goods Movement" in California reduced air pollution exposures and emergency room visits among California Medicaid enrollees with asthma and/or chronic obstructive pulmonary disease.

Method

We created a retrospective cohort of 5,608 Medicaid enrollees from ten counties in California with data from 2004 and 2010. We grouped the patients into two groups: those living within 500 m of goods movement corridors (ports and truck-permitted freeways), and control areas (away from the busy truck or car permitted highways). We created annual air pollution surfaces for nitrogen dioxide and assigned them to enrollees' home addresses. We used a quasi-experimental design with a difference-in-differences method to examine changes before and after the policy for cohort beneficiaries in the two groups.

Results

The reductions in nitrogen dioxide exposures and emergency room visits were greater for enrollees in goods movement corridors than those in control areas in post-policy years. We found that the goods movement actions were associated with 14.8% (95% CI, -24.0% to -4.4%; P = 0.006) and 11.8% (95% CI, -21.2% to -1.2%; P = 0.030) greater reduction in emergency room visits for the beneficiaries with asthma and chronic obstructive pulmonary disease, respectively, in the third year after California's emission reduction plan.

Conclusion

These findings indicate remarkable health benefits via reduced emergency room visits from the significantly improved air quality due to public policy interventions for disadvantaged and susceptible populations.

Keywords

Air pollution; Emergency Room Visits; Asthma; COPD

Highlights

- This is the first study, to the best of our knowledge, to assess this specific long-term, large-scale, and complex regulatory action on air quality and health.
- Our findings suggest that the California Goods Movement interventions led to substantial reductions in NO_2 exposures and ER visits among low-income people with respiratory diseases.
- This paper contributed to scientific methods for assessing the health effects of regulatory actions with routinely collected pollutants and medical claims data.
- Our study adds to the small but emerging evidence base that indicated that air pollution control actions reduced pollution exposures.

1. Introduction

Air pollution imposes substantial health tolls, including disease onset and exacerbations, and even death. Previous studies have well established the links between adverse health effects and traffic-related pollutant exposures among individuals with chronic respiratory diseases, such as asthma and chronic obstructive pulmonary disease (COPD) (Bowatte et al. 2017; Cirera et al. 2012; Hesterberg et al. 2009; Hsu et al. 2021). Only a few studies have directly assessed whether regulatory interventions lead to improvements in air quality and subsequently health (Boogaard et al. 2017; Burns et al. 2019; Henneman et al. 2017; Rich 2017). There are considerable challenges inherent in such impact research, most studies were based on "natural experiments," not on actual targeted policies and programs, or the consequences of shorter-term or relatively small-scale actions. It thus limits inference on whether a policy or a type of policy is effective.

Due to the aggressive pollution control measures, air quality has improved substantially in California, the U.S., and other developed countries. Emerging studies have attempted to show how air quality improvements are associated with improved child lung health in California (Gilliland et al.,2017), reduced emergency room (ER) visits (Russell et al. 2018), and lower mortality in the Medicare population (Di et al. 2017). These studies, however, do not link a particular pollutant emission reduction regulation to improvements in air quality and health, thus limiting causality inference on what type of policy is effective.

California has four of the major ports in the U.S. The adjacent Los Angeles and Long Beach Ports are the two busiest container ports in the U.S. and the fifth busiest in the world, moving more than $260 billion in goods each year. Transporting these goods to and from the ports to their ultimate destinations across the U.S. and the world involves diesel-powered vehicles and equipment. In 2006, the California Air Resources Board (CARB) and local air quality management districts implemented the "Emission Reduction Plan for Ports and Goods Movement (ERPPGM)" (CARB 2006). The ERPPGM is comprised of approximately 200 actions with an estimated investment of $6 to $10 billion. These actions targeted the major sources and polluters related to goods movements, such as highways, ports and rail yard trucks, ship fuel and shore power, cargo equipment, and locomotives. The emission reduction plan proposed to reduce total statewide international and domestic goods movement emission back to 2001 levels or lower by the year 2010. These measures were implemented immediately and achieved the expected emission reduction (CARB 2006). Based on Long Beach Port NOx emission reduction inventory between 2005 and 2010, the measures on trucks have achieved the largest emission reduction: 78%; followed by rail: 43%; cargo handling equipment: 38%, ships: 26%, and harbor craft: 24% (Starcrest Consulting Group July 2011).

Previous studies have demonstrated that these goods movement regulatory actions resulted in significant declines in air pollutants (e.g., NO_2, and NOx) and exposures of NO_2 among Medicaid enrollees near goods movement corridors and port facilities compared to control areas after controlling for likely confounders such as census-track level socioeconomic status (Su et al. 2020; Su et al. 2016). Yet the health impacts of improvements in air quality due to this action plan remain unexplored. To address this gap, this study aims to examine whether ERPPGM in California leads to reduced ambient air pollution exposures and ER visits among Medicaid enrollees with asthma and/or COPD.

2. Methods

2.1. Study design

We defined three study domains (Figure A1): the goods movement corridors (GMCs) – locations within 500 m of truck-permitted freeways and ports,(HEI Panel on the Health Effects of Traffic-Related Air Pollution 2010) non-goods movement corridors (NGMCs) –locations within a 500 m buffer of a truck-prohibited (mainly car dominant) roadway or 300 m of connecting roadways, and control areas (CTRLs), i.e. outside the other two corridors. We based the definition of Goods Movement Corridor on an extensive review by a panel of leading experts assembled by the Health Effects Institute Boston, U.S.A. This review examined distance decay gradient studies and other emission and atmospheric chemistry studies aired at characterizing the impact of traffic-related air pollution adjacent areas. The spatial dispersion of emissions on major highways was found to be approximately 500 m from the line source in the vast majority of studies. At distances of 500 m or greater, the traffic-related air pollution tended to blend with the urban background atmosphere, which the traffic contribution became indistinguishable from other source contributions (Greenbaum 2010). For connecting major roadways, the impact of traffic diminished to background levels at approximately 300 m or less from the source (Greenbaum 2010). We thus defined locations within 500 m of a truck-prohibited roadway or within 300 m of connecting roadways or those where trucks were prohibited as NGMC. GMC helped us understand the policy effects on reductions of air pollution from diesel-operating machines/vehicles. NGMC provided measurements on roadways that had high impact from traffic other than trucks. CTRL mainly measured background concentrations because they were outside the impact zones of the GMC and NGMC areas. These CTRL areas were used for comparing changes in air pollutant concentrations and related health effects. Using the GMCs as the proxy of the impact of ERPPGM, this study sought to evaluate whether the policy intervention reduces beneficiaries' pollutant exposures, and also ER visits for patients with asthma or COPD, given patients with respiratory diseases are more sensitive to changes in air quality (Kurt et al. 2016). To examine the extent to which those living close to ports or truck-permitted highways benefited more than those living farther away from those emission sources, we reported the results comparing GMCs with CTRLs and excluded the comparison with NGMCs, which is more likely affected by car-related emission reductions.

We used a quasi-experimental design to evaluate the impacts of the ERPPGM by comparing changes in NO_2 exposures and emergency room visits among patients residing in GMCs versus those living in CTRLs before and after the emission reduction plan. Due to time lags between the promulgation of air quality regulations and subsequent impacts on health effects, we used the end of 2007 as a cutoff point for policy intervention. Our study period included three years before and three years after the action. We estimated the policy effects at the first, second, and third years after the ERPPGM.

2.2. Health data

Using six years of medical and pharmacy claim data of California Medicaid Fee-for-Services adult enrollees we constructed a retrospective cohort to include those being 22 years of age or older under certain aid codes (e.g. excluding Medicare eligible) and having at least one paid claim between March 1, 2004 and October 2010 for any of the six following conditions: asthma, COPD, diabetes, atherosclerotic heart disease, coronary artery disease, and congestive heart failure (the latter three were grouped into heart disease). To identify those with Asthma or COPD at the baseline, we used any appearance of the respective diagnostic codes in the encounter data in the first three years (pre-policy period). The beneficiaries resided in Los Angeles, Riverside, San Bernardino, Alameda, San Francisco, Santa Clara, San Joaquin, Fresno, Sacramento, and San Diego Counties. These ten counties cover the state's four "port-to-border" goods movement corridors (Los Angeles-Long Beach/Inland Empire, San Francisco Bay Area, San Diego/Border, and Central Valley), which were most likely to be affected by the emission reduction plan. We focused on a Medicaid population with chronic disease conditions because they are more susceptible to air pollution exposures, have worse symptoms, and therefore are more likely to need urgent treatment.

We normalized the time so that Year 1 was from September 1, 2004, to August 31, 2005, based on the availability of the claim data. Similar patterns were followed for other study years through the whole study period. Year 1 (09/2004 – 08/2005), Year 2 (09/2005 – 08/2006), and Year 3 (09/2006 – 08/2007) are before the policy implementation. Year 4 (09/2007 – 08/31/2008), Year 5 (09/2008 – 08/2009), and Year 6 (09/2009 – 08/2010) are after the policy implementation. To assure data completeness for the study cohort, we included patients with six years of continuous Medi-Cal enrollments between 2004 and 2010, which was defined to be at least 11 months enrolled plus at least one record in the claims data each year. For this study, we further restricted our study subjects to those who (1) had a valid home address (e.g., not a PO Box or zipcode only); (2) had pollutant assignments (i.e., with an address in California). and (3) was diagnosed with Asthma or COPD, in the first three years (baseline years). Based on those conditions, we created a cohort of 5,608 enrollees for the study. The biggest drop in the sample sizes happened when the 6-year continuous enrollment requirement was imposed. We decided to use a cohort instead of the whole study population since the evidence suggests that a sizable number of people in Medi-Cal programs are unable to maintain their coverage over a period of time, despite remaining eligible for the program (Seifert et al. 2010; Sommers et al. 2013). Prior studies have shown that interruptions in Medicaid coverage can result in greater emergency department use as well as significant increases in hospitalization for conditions that can be managed on an ambulatory basis (Bindman et al. 2008; Hall et al. 2008; Kasper et al. 2000; Ku et al. 2009; Paradise and Garfield 2013). If we include churning beneficiaries, it may be difficult for us to differentiate weather the changes in utilizations were policy-related or generated by disruptions in coverage. This study has received Institutional Review Board (IRB) approvals from both the California Health and Human Services Agency and the University of California, Los Angeles.

We calculated the annual number of ER visits for all causes per beneficiary using Current Procedural Terminology (CPT) codes, claim type (e.g., outpatient, inpatient, pharmacy, medical/physician, and dental), place of service (e.g., emergency room, doctor office, outpatient/inpatient hospital) and date of service to define each measure. Based on Medi-Cal enrollment and claims data, we constructed individual-level socio-demographic variables, which include age, sex, race/ethnicity, and English speaking. We also created measures for baseline comorbidities as follows: any claim record with more than one diagnosis of the diseases (up to two ICD-9 codes for each encounter), —asthma, heart disease, COPD, and diabetes—in baseline years (from September 2004–August 2007) was defined as the presence of comorbidity and actual counts were used to indicate the number of comorbidities. Given the data we had obtained, we thought these comorbidities might influence the changes in outcomes. Additionally, we constructed measures of other time-varying confounding factors that include year-specific

Chronic Illness and Disability Payment System (CDPS) scores (Kronick et al. 2000) for disease severity, depression status (yes/no), smoking behavior (yes/no), and the number of doctor visits as a proxy for access to primary care (see Appendix Section 1.1).

2.3. Pollutant and neighborhood data

We developed a machine learning land-use regression (LUR) model and created annual air pollution surfaces for nitrogen dioxide (NO_2) across California for the years 2004 through 2010 at a spatial resolution of 30 m. The details for the developing LUR models could be found in Appendix Section 1.2 and elsewhere (Su et al. 2020; Su et al. 2016). NO_2 was used as a marker for traffic-related air pollution for health effect studies in California (Andersen et al. 2011; Jerrett et al. 2013; Organization 2013). The rationale for doing that is that the regulatory policy implemented by CARB significantly reduced NO_2 emission from roadway traffic and directly resulted in the overall reductions in regional NO_x levels (Appendix Section 1.2 provides more details). We used SAS/GRAPH® 9.2 software to convert enrollees' home addresses into geocodes and assigned the appropriate annual exposures.

Moreover, we used the census tract level Social Vulnerability Index (SVI) data developed by the U.S. Centers for Disease Control and Prevention (CDC) to control for socioeconomic changes at the neighborhood level (Flanagan et al. 2011). We used the 2000 SVI for the pre-policy period and the 2010 SVI for the post-policy period.

2.4. Statistical analysis

To examine whether the emission reduction plan led to decreases in NO_2 exposures, we estimated a difference-in-differences (DiD) type model using a linear mixed model with random intercepts for beneficiaries to examine temporal changes in outcomes by comparing GMCs with CTRLs before and after the ERPPGM. The model controls for potential differential pre-trends between the two groups and allows the health impact to evolve over time. The coefficients (γ_k) on interactions between year dummy variables and the group dummy variables during the post-policy years indicate DiD estimates in year k (Appendix Section 2.1).

In order to evaluate the effect of the emission reduction plan on ER visits, we applied a similar approach but with a nonlinear model due to the skewed distribution of ER visits. Specifically, we adopted a multilevel generalized linear model with a log link function and a negative binomial distribution. Random intercepts for beneficiaries were used to accommodate within-patient correlation. Notice that the parallel assumption has been imposed on the transformed log-linear scale, and the coefficients (γ_k) on the interaction terms capture changes on a log scale. To ease interpretation, we computed a new estimate as $100(e^{\gamma_k} - 1)$, which indicates the % change in the expected number of ER visits due to intervention of policy (Appendix Section 2.2). We conducted several tests to assess the adequacy of the parallel-trends assumption. (See Appendix Section 2 for more details).

The model adjusted for sex, English speaking (yes/no), age groups (21-45, 46-55, and 56+), race/ethnicity (White, Black, Asian/Pacific Islander, Latino, Other or Unknown), number of comorbidities in three baseline years (0, 1 or 2, 3+), the county as fixed effects, and year-specific variables including smoking status, depression status, number of doctor visits, and log-transformed CDPS scores. We also controlled for several census track-level SVI variables: census track level proportion of unemployed (age 16+), the proportion of persons below poverty estimates, proportion of minority, proportion of households with no vehicle available.

3. Results

3.1. Characteristics of the study sample

The retrospective cohort included 5,608 Medi-Cal beneficiaries residing in the 10 California counties in the baseline year with 33,648 person-years of follow-up. Table 1 reports baseline sample characteristics. There were 3,718 (66.3%) enrollees with asthma and 3,727 (66.5%) enrollees with COPD. Approximately 53% of the patients lived in GMCs.

In general, patients living in GMCs have similar demographics and health status compared to those living in the CTRLs (Table 1). There were fewer females (62.9% versus 65.9%), and more African Americans (20.3% versus 15.7%) and Latinos (13.6% versus 10.1%) living in GMCs than CTRLs. Those residing in GMCs were also more likely to smoke (5.3% versus 4.2%). Differences in neighborhood-level socioeconomic status between the two areas were generally more pronounced. The GMCs areas had slightly higher unemployment rates (10.6% versus 9.3%), higher poverty rates (24.2% versus 18.5%), a higher proportion of minority (67.5% versus 59.6%), and a higher proportion of households with no available vehicle (18.9% versus 10.2%). Characteristics of patients included in the subgroup (e.g., asthma patients only and COPD patients only) analyses follow a similar pattern.

3.2. Air pollution exposure improvements

Panel A of Figure 1 presents the trends of NO_2 (ppb, parts per billion) exposure levels by study areas and subsamples. We observed reductions in NO_2 exposures for enrollees in 10 counties. The results showed that the emission reduction plan led to measurable changes in NO_2 exposures among beneficiaries living in GMCs from 24 ppb in 2005 to 19.3 ppb in 2010. For $PM_{2.5}$, reductions in $\mu g/m^3$ were seen from 13.9 to 11.8, from 12.9 to 10.9, and from 12.3 to 10.4 in GMC, NGMC, and CTRL areas, respectively. However, the O_3 exposures showed an opposite trend with relatively low concentration in GMCs, and trends are identical among the three study domains (Data not shown). The NO_2 (ppb) reductions for beneficiaries living in GMCs were greater than those living in CTRLs in the post-policy years (1-year DiD=-2.3, 95% CI, -2.3 to -2.2; $p < 0.001$), including all beneficiaries with Asthma and COPD (Table 2). We found statistically significant reductions in NO_2 (Table A1) comparing GMCs versus NGMCs.

3.3. ER visits reductions

Panel B of Figure 1 shows greater reductions in ER visits for those with asthma or COPD in the GMCs than those in the CTRLs in post-policy years. The red line with triangle markers represents the adjusted average number of ER visits for the control group, the blue line with square markers is for the GMCs group, and the black line with point markers indicated the counterfactual (the expected rates if the parallel increases were assumed based on increases in the CTRLs). Specifically, the number of ER visits for those with asthma living in GMCs reduced 11.8% (95% CI, -21.4% to -1.1%; p = 0.032) more than those with those living in CTRLs in the second year, and 14.8% in the third year (95% CI, -24.05% to -4.4%; p = 0.006) after the policy (Table 3). The ER visits for those with COPD in GMCs also reduced more than those living in CTRLs in the third year (Percent change = -11.8, 95% CI, -21.2% to -1.2%; p = 0.030). Results without adjusting for covariates are also similar (Table A2). We didn't find statistically significant reductions in ER visits comparing GMCs versus NGMCs (Table A3).

Sensitivity analyses found that the required "parallel trends" assumption is reasonable for our analyses. As shown in Table A4, the parallel trends assumption is plausible during the baseline years. We also found similar results from a model including interaction terms between the GMCs and CTRLs and time dummy variables in the pre-policy period (Table A5). In addition, results from the propensity score matching method yield consistent DiD estimates (Table A6-A7). All these sensitivity analyses corroborate our findings that the ERPPGM was associated with significant reductions in air pollutant concentrations and emergency room visits.

4. Discussion

This is the first study, to the best of our knowledge, to assess this specific long-term, large-scale, and complex regulatory action on health. Our findings suggest that improvements in air quality due to the California goods movement actions led to substantial reductions in NO_2 exposures and ER visits among Medicaid beneficiaries with respiratory diseases. Most impact studies were based on "natural experiments", not on actual targeted policies and programs. Also, these studies have mostly focused on the consequences of shorter-term or relatively small-scale actions, such as the Dublin coal ban; and traffic and pollution controls implemented during the Atlanta and Beijing Olympic Games (van Erp and Cohen 2009).

Our investigation joined a small number of other studies that assess the longer-term, large scale, and more complex regulatory actions (Boldo et al. 2014; Schikowski et al. 2013; van Erp and

Cohen 2009). Structuring our analyses within three well-defined study areas (e.g. GMCs, NGMCs and CTRLs) allows us to compare concentration differences along goods movement corridors that are mostly attributable to goods movement policies versus changes in concentrations that have occurred on non-truck freeways (those prohibited to trucks) that would be most likely attributable to broader mobile emission reduction policies versus changes in concentrations that have occurred in control areas likely due to regional emissions reductions policies.

Although numerous studies have established links between adverse health effects and traffic-related pollutant exposures among individuals with chronic respiratory diseases (e.g., asthma and COPD) (Bowatte et al. 2017; Cirera et al. 2012; Hesterberg et al. 2009; Hsu et al. 2021), few previous studies evaluated whether reductions in air pollution concentrations led to improved health, such as reductions in ER visits or hospitalizations. More importantly, unlike other studies that use administrative data at the ZIP code resolution, we were able to use the residential home address, which allowed us to group the study populations into two groups: those living within 500 m of goods movement corridors (GMCs, ports and truck-permitted freeways), and control areas (CTRLs, away from the busy truck or car permitted highways). For the 10 counties used in our research, the size of the zip codes is 22 Km^2 (3 km^2 - 513 km^2) for median and 95% confidence intervals. Our results demonstrate a remarkable impact of environmental regulations on the reduction of ER visits. Specifically, for the third year after the implementation of the policy, we estimated that regulation was associated with a 14.8 percent and 11.8 percent decrease in ER visits for asthma patients and COPD patients, respectively. Given the baseline average number of ER visits is around 1.0, it amounts to approximately 148 more decreases in ER per

1,000 beneficiaries per year among asthma patients, and a similar greater reduction of about 118 ER visits per 1000 patients among the beneficiaries with COPD. It is expected to see a stronger finding in the 3rd year when the policy gradually took effect. Given that all participants were Medi-Cal beneficiaries we can assume any Medi-Cal-related policy changes or public health interventions may affect those in intervention and control areas equally. If there are any county-level interventions, the inclusion of county as a fixed effect may help adjust for unmeasured exogenous factors at the county level. We also controlled for neighborhood SES (e.g., economic downturn using unemployment rates and percentages of populations below poverty). With all these efforts, we may still not be able to control all other exogenous factors. There might be potential unmeasured confounding remaining, especially at the neighborhood or household level (e.g., installing air filters for the public housings near freeways), which might distort the results by violating the parallel trends assumption though we are not aware of these kinds of interventions.

These findings are important in demonstrating that addressing environmental determinants of health, such as air quality, is a plausibly effective way to improve health and reduce expensive health care utilizations. Moreover, understanding the independent contribution of air pollution exposures compared to other patient-level risk factors will be crucial for managing high-risk populations through better risk management. This study provides pertinent information which health care programs such as Medicaid program and their providers can leverage. To translate the findings into policy and practices, clinical guidelines can be developed for health plans and their providers to add pollution exposure profiles (geography) in the care of beneficiaries at high risk of adverse outcomes. This will lead to better risk assessments and management for potential

"ER frequent users" or "hot spots" of utilization, such as areas with higher ER visits or hospitalization.

These findings also showed that reducing air pollution might have an additional beneficial effect on reducing health inequalities among the less-advantaged groups. While all of our study subjects were of low income as they were all Medicaid beneficiaries, those living in the CTRLs generally had lower exposures and lower rates of ER visits at the beginning of the study than those subjects living in the GMCs. As the effects of the policy persisted into years 2 and 3 of the post-intervention period, the disparities in both exposures and ER visits between the control groups and the GMC intervention group tended to decrease. These observed phenomena are promising to shed light on eliminating health inequities by reducing unequal exposures to environmental hazards. Our study population is also more susceptible to air pollution due to chronic disease conditions, and their low SES also made them more affected by pollutants due to greater vulnerability (Bravo et al. 2016; Hajat et al. 2015; Morello-Frosch et al. 2011; Ostro et al. 2001; Ou et al. 2008; Su et al. 2012). Given the study populations are adults with chronic conditions, it is expected that they might have increased the need for health services due to aging and the natural course of development of their conditions as we observed in the CTRL groups (Agarwal et al. 2017). More importantly, Medicaid patients experienced significantly greater increases in ER visits after the great recession due to the 2008 financial crisis in the United States (Watts et al. 2015). However, for those in GMCs, we observed significant relative reductions instead. The findings of this study indicate that those more exposed and susceptible or vulnerable also potentially benefited the most from the exposure reductions. As a corollary, goods movement regulations may serve to reduce persistent health disparities among different social groups, which result in part from the unequal distribution of exposures to air pollution and other environmental stressors.

Our study had several strengths. One notable strength is that we built annual Land Use Regression models and associated surfaces to coincide with the annual health outcomes. Another strength is that we leveraged the goods movement actions as a quasi-experimental design with well-defined intervention and control groups. Estimates from the difference-in-differences analysis are robust to many threats to internal validity. The third strength is that we used longitudinal claims data to create a study cohort. Medicaid rich enrollment and claims data allowed us to account for common confounders when examining associations between air quality improvement and the decrease in adverse health outcomes.

This study was subject to some limitations. First, we mainly relied on residence-based air pollution exposure estimates, which allowed us to conduct the area-specific analyses, but we lacked information on personal exposures in other potentially important micro-environments because the claim data did not collect information on beneficiaries' work locations or time spent in other environments. Thus, our exposure measures did not consider individual variability in exposures for a specific year due to personal mobility, indoor, commuting, and occupational exposures. Previous cohort studies that included multiple communities with assigned exposure using community-average pollution concentrations have shown that the long-term health effects are relatively unaffected by a lack of personal exposure measures (Berhane et al. 2004). Study also suggested that ignoring daily mobility patterns can contribute to bias toward the null hypothesis in epidemiological studies using individual-level exposure estimates (Setton et al.

2011). Second, we used the diagnostic codes (up to two codes for each encounter) to identify the cases and comorbidities and we don't know at what age their disease was diagnosed.. Nevertheless, that limitation may have affected those in the GMCs and CTRLs in similar ways. Third, we had the beneficiaries' addresses only at the beginning of the study. Based on data from the California Health Interview Survey 2009, 54% of Medi-Cal respondents have lived at their current residence for 5 years or more in our study counties. It is unknown whether they moved within the corridors or out of the corridors, so the impact on our results is unknown. Forth, we excluded the beneficiaries without continuous enrollment (about 60% of the total) to ensure the individuals were followed throughout the study period and eliminated the uncertainties in outcomes created due to drop-out or churning. The comparisons of the demographic characteristics of those included and excluded showed that the study population had about 16% less enrollees above 56 years old, 5% less males, about 4% less Latinos and 2% less African Americans. Currently, it is unclear whether results from this study suggesting that goods movement policies improve health outcomes would apply to the Medi-Cal population with chronic conditions, but dropped out or churned, even though some pollutants (e.g., NO_x, NO_2, and $PM_{2.5}$) will likely have similar effects across populations. Lastly, there might be other temporal changes in health care or air quality measures that may confound the findings. Although we might assume that may affect people in the different study domains equally, it is unclear if some external secular changes such as the 2006 diesel fuel standard changes may have affected the results.

In summary, our study concludes that environmental policies that aim to improve air quality also had notable health benefits, especially for patients with chronic respiratory diseases. This paper also contributed to scientific methods for assessing the health effects of regulatory actions with routinely collected pollutants and medical claims data, which can apply to other studies in the era of electronic medical records.

REFERENCES

Agarwal, P.; Bias, T.K.; Sambamoorthi, U. Longitudinal Patterns of Emergency Department Visits: A Multistate Analysis of Medicaid Beneficiaries. Health Serv Res 2017;52:2121-2136

Andersen, Z.J.; Hvidberg, M.; Jensen, S.S.; Ketzel, M.; Loft, S.; Sorensen, M.; Tjonneland, A.; Overvad, K.; Raaschou-Nielsen, O. Chronic obstructive pulmonary disease and long-term exposure to traffic-related air pollution: a cohort study. Am J Respir Crit Care Med 2011;183:455-461

Berhane, K.; Gauderman, W.J.; Stram, D.O.; Thomas, D.C. Statistical issues in studies of the long-term effects of air pollution: The Southern California Children's Health Study. Statistical Science 2004;19:414-449

Bindman, A.B.; Chattopadhyay, A.; Auerback, G.M. Interruptions in Medicaid coverage and risk for hospitalization for ambulatory care–sensitive conditions. Ann Intern Med 2008;149:854-860

Boldo, E.; Linares, C.; Aragones, N.; Lumbreras, J.; Borge, R.; de la Paz, D.; Perez-Gomez, B.; Fernandez-Navarro, P.; Garcia-Perez, J.; Pollan, M.; Ramis, R.; Moreno, T.; Karanasiou, A.; Lopez-Abente, G. Air quality modeling and mortality impact of fine particles reduction policies in Spain. Environmental Research 2014;128:15-26

Boogaard, H.; van Erp, A.M.; Walker, K.D.; Shaikh, R. Accountability Studies on Air Pollution and Health: the HEI Experience. Curr Environ Health Rep 2017;4:514-522

Bowatte, G.; Erbas, B.; Lodge, C.J.; Knibbs, L.D.; Gurrin, L.C.; Marks, G.B.; Thomas, P.S.; Johns, D.P.; Giles, G.G.; Hui, J.; Dennekamp, M.; Perret, J.L.; Abramson, M.J.; Walters, E.H.; Matheson, M.C.; Dharmage, S.C. Traffic-related air pollution exposure over a 5-

year period is associated with increased risk of asthma and poor lung function in middle age. Eur Respir J 2017;50:1602357

Bravo, M.A.; Anthopolos, R.; Bell, M.L.; Miranda, M.L. Racial isolation and exposure to airborne particulate matter and ozone in understudied US populations: Environmental justice applications of downscaled numerical model output. Environ Int 2016;92-93:247-255

Burns, J.; Boogaard, H.; Polus, S.; Pfadenhauer, L.M.; Rohwer, A.C.; van Erp, A.M.; Turley, R.; Rehfuess, E. Interventions to reduce ambient particulate matter air pollution and their effect on health. Cochrane Database Syst Rev 2019;

CARB. Emission Reduction Plan for Ports and Goods Movement in California. Resolution 06-14. Accessed August 2nd, 2011 @ http://www.arb.ca.gov/planning/gmerp/plan/final_plan.pdf.; 2006

Cirera, L.; Garcia-Marcos, L.; Gimenez, J.; Moreno-Grau, S.; Tobias, A.; Perez-Fernandez, V.; Elvira-Rendeles, B.; Guillen, J.J.; Navarro, C. Daily effects of air pollutants and pollen types on asthma and COPD hospital emergency visits in the industrial and Mediterranean Spanish city of Cartagena. Allergol Immunopathol (Madr) 2012;40:231-237

Di, Q.; Dominici, F.; Schwartz, J.D. Air Pollution and Mortality in the Medicare Population. The New England journal of medicine 2017;377:1498-1499

Flanagan, B.E.; Gregory, E.W.; Hallisey, E.J.; Heitgerd, J.L.; Lewis, B. A Social Vulnerability Index for Disaster Management. Journal of Homeland Security and Emergency Management 2011;8

Gilliland, F.; Avol, E.; McConndell, R.; Berhane, K.; Gauderman, W.; Lurmann, F.e.a. The Effects of Policy-Driven Air Quality Improvements on Children's Respiratory Health. Health Effects Institute,2017;

Greenbaum, D. HEI Panel on the Health Effects of Traffic-Related Air Pollution. Traffic-related air pollution: a critical review of the literature on emissions, exposure, and health effects HEI Special Report 2010;17

Hajat, A.; Hsia, C.; O'Neill, M.S. Socioeconomic Disparities and Air Pollution Exposure: a Global Review. Curr Environ Health Rep 2015;2:440-450

Hall, A.G.; Harman, J.S.; Zhang, J. Lapses in Medicaid coverage: impact on cost and utilization among individuals with diabetes enrolled in Medicaid. Med Care 2008:1219-1225

HEI Panel on the Health Effects of Traffic-Related Air Pollution. Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects. in: 17, ed. Special Report. Boston, Massachusetts: Health Effects Institute; 2010

Henneman, L.R.; Liu, C.; Mulholland, J.A.; Russell, A.G. Evaluating the effectiveness of air quality regulations: A review of accountability studies and frameworks. J Air Waste Manag Assoc 2017;67:144-172

Hesterberg, T.W.; Bunn, W.B.; McClellan, R.O.; Hamade, A.K.; Long, C.M.; Valberg, P.A. Critical review of the human data on short-term nitrogen dioxide (NO2) exposures: evidence for NO2 no-effect levels. Crit Rev Toxicol 2009;39:743-781

Hsu, H.-T.; Wu, C.-D.; Chung, M.-C.; Shen, T.-C.; Lai, T.-J.; Chen, C.-Y.; Wang, R.-Y.; Chung, C.-J. The effects of traffic-related air pollutants on chronic obstructive pulmonary disease in the community-based general population. Respir Res 2021;22:217

Jerrett, M.; Burnett, R.T.; Beckerman, B.S.; Turner, M.C.; Krewski, D.; Thurston, G.; Martin, R.V.; van Donkelaar, A.; Hughes, E.; Shi, Y. Spatial analysis of air pollution and mortality in California. Am J Respir Crit Care Med 2013;188:593-599

Kasper, J.D.; Giovannini, T.A.; Hoffman, C. Gaining and losing health insurance: strengthening the evidence for effects on access to care and health outcomes. Med Care Res Rev 2000;57:298-318

Kronick, R.; Gilmer, T.; Dreyfus, T.; Lee, L. Improving health-based payment for Medicaid beneficiaries: CDPS. Health Care Financ Rev 2000;21:29-64

Ku, L.C.; MacTaggart, P.; Pervez, F.; Rosenbaum, S.J. Improving Medicaid's continuity of coverage and quality of care. 2009;

Kurt, O.K.; Zhang, J.; Pinkerton, K.E. Pulmonary health effects of air pollution. Curr Opin Pulm Med 2016;22:138-143

Morello-Frosch, R.; Zuk, M.; Jerrett, M.; Shamasunder, B.; Kyle, A.D. Understanding the cumulative impacts of inequalities in environmental health: implications for policy. Health Aff (Millwood) 2011;30:879-887

Organization, W.H. Review of evidence on health aspects of air pollution—REVIHAAP project: technical report. Copenhagen, Denmark: WHO Regional Office for Europe 2013;

Ostro, B.; Lipsett, M.; Mann, J.; Braxton-Owens, H.; White, M. Air pollution and exacerbation of asthma in African-American children in Los Angeles. Epidemiology 2001;12:200-208

Ou, C.Q.; Hedley, A.J.; Chung, R.Y.; Thach, T.Q.; Chau, Y.K.; Chan, K.P.; Yang, L.; Ho, S.Y.; Wong, C.M.; Lam, T.H. Socioeconomic disparities in air pollution-associated mortality. Environ Res 2008;107:237-244

Paradise, J.; Garfield, R. What is Medicaid's impact on access to care, health outcomes, and quality of care? Setting the record straight on the evidence. Kaiser Family Foundation, August 2013;

Rich, D.Q. Accountability studies of air pollution and health effects: lessons learned and recommendations for future natural experiment opportunities. Environ Int 2017;100:62-78

Russell, A.; Tolbert, P.; Henneman, L.; Abrams, J.; Liu, C.; Klein M, e.a. Impacts of Regulations on Air Quality and Emergency Department Visits in the Atlanta Metropolitan Area. Health Effects Institute 2018;Research Report 195

Schikowski, T.; Schaffner, E.; Meier, F.; Phuleria, H.C.; Vierkotter, A.; Schindler, C.; Kriemler, S.; Zemp, E.; Kramer, U.; Bridevaux, P.O.; Rochat, T.; Schwartz, J.; Kunzli, N.; Probst-Hensch, N. Improved Air Quality and Attenuated Lung Function Decline: Modification by Obesity in the SAPALDIA Cohort. Environ Health Persp 2013;121:1034-1039

Seifert, R.; Kirk, G.; Oakes, M. Enrollment and disenrollment in MassHealth and Commonwealth Care ed^eds: Massachusetts Medicaid Policy Institute Boston (MA); 2010

Setton, E.; Marshall, J.D.; Brauer, M.; Lundquist, K.R.; Hystad, P.; Keller, P.; Cloutier-Fisher, D. The impact of daily mobility on exposure to traffic-related air pollution and health effect estimates. J Expo Sci Environ Epidemiol 2011;21:42-48

Sommers, B.D.; Buchmueller, T.; Decker, S.L.; Carey, C.; Kronick, R. The Affordable Care Act has led to significant gains in health insurance and access to care for young adults. Health Aff (Millwood) 2013;32:165-174

Starcrest Consulting Group, L. PORT OF LONG BEACH AIR EMISSIONS INVENTORY – 2010, . https://polb.com/environment/air/#emissions-inventory) July 2011

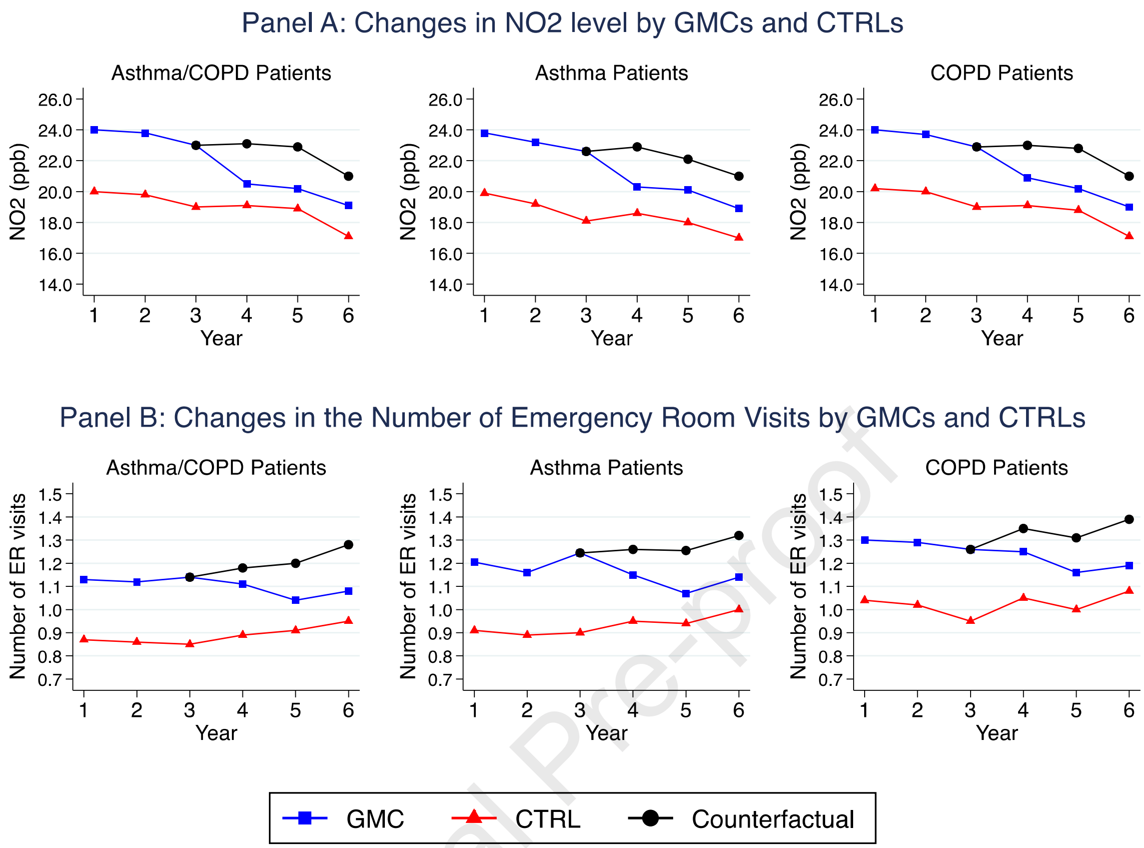
Su, J.G.; Jerrett, M.; Morello-Frosch, R.; Jesdale, B.M.; Kyle, A.D. Inequalities in cumulative environmental burdens among three urbanized counties in California. Environ Int 2012;40:79-87

Su, J.G.; Meng, Y.Y.; Chen, X.; Molitor, J.; Yue, D.; Jerrett, M. Predicting differential improvements in annual pollutant concentrations and exposures for regulatory policy assessment. Environ Int 2020;143:105942

Su, J.G.; Meng, Y.Y.; Pickett, M.; Seto, E.; Ritz, B.; Jerrett, M. Identification of Effects of Regulatory Actions on Air Quality in Goods Movement Corridors in California. Environ Sci Technol 2016;50:8687-8696

van Erp, A.M.; Cohen, A.J. HEI's research program on the impact of actions to improve air quality: Interim evaluation and future directions. Health Effects Institue Communication 14. Accessed August 13 @ http://pubs.healtheffects.org/getfile.php?u=511. 2009;

Watts, S.H.; David Bryan, E.; Tarwater, P.M. Changes in insurance status and emergency department visits after the 2008 economic downturn. Acad Emerg Med 2015;22:73-80



Notes: The above figures were based on average predicted values from difference-in-differences models. The red line with triangle markers represents the adjusted NO_2 or ER visits for the control group, the blue line with square markers is for the GMCs group, and the black line with point markers indicates the counterfactual (the expected rates if the parallel increases were assumed based on increases in the CTRLs). Patients were followed for six consecutive years: Year 1 (09/2004 – 08/2005), Year 2 (09/2005 – 08/2006), and Year 3 (09/2006 – 08/2007) are before the policy implementation. Year 4 (09/2007 – 08/31/2008), Year 5 (09/2008 – 08/2009), and Year 6 (09/2009 – 08/2010).

Figure 1. Temporal Changes in NO2 and the Number of ER Visits

Table 1. Baseline Characteristics of Included Patients by Residential Areas and Patient Types.

	Patients with Asthma or COPD		Patients with Asthma		Patients with COPD	
	GMCs	CTRLs	GMCs	CTRLs	GMCs	CTRLs
Number of ER visits	1.1	1.0	1.2	1.2	1.3	1.1
NO_2 (ppb)	23.9	22.3	23.8	22.0	24.1	22.6
Female (%)	62.9	65.9	68.8	71.3	59.4	62.5
English (%)	39.0	37.6	40.9	39.3	39.6	40.1
Age categories (%)						
21-45	26.9	26.6	29.8	30.1	22.9	22.1
46-55	40.7	40.9	40.8	40.2	42.2	43.3
56+	32.4	32.5	29.4	29.7	35.0	34.6
Race/ethnicity (%)						
White	39.2	40.2	36.5	36.0	42.6	46.7
African American	20.3	15.7	21.2	16.5	20.2	15.5
Asian/Pacific Island	16.0	20.7	17.7	24.2	13.2	15.5
Latino	13.6	10.1	14.1	9.6	13.2	10.1
Other or Unknown	10.9	13.3	10.5	13.7	10.8	12.1
No. of comorbidities in baseline years (%)						
None	29.3	29.1	26.8	28.9	17.6	14.5
One or Two	64.8	64.9	64.0	62.3	73.7	76.1
Three or more	5.9	6.0	9.2	8.8	8.7	9.3
Smoking (%)	5.3	4.2	4.2	3.9	6.9	5.6
Depression (%)	13.9	12.7	13.7	12.8	14.7	13.2
Total no. of doctor visits this year	6.6	7.2	6.9	7.5	6.8	7.6
CDPS score	1.2	1.2	1.2	1.2	1.3	1.3
Proportion of unemployed (16+) (%)	10.6	9.3	10.9	9.5	10.5	9.3
Proportion of persons below poverty estimates (%)	24.2	18.5	25.1	19.0	24.0	18.3
Proportion of minority (%)	67.5	59.6	68.5	59.9	66.7	59.3
Proportion of households with no vehicle available (%)	18.9	10.2	19.0	10.3	19.1	10.4
N (persons)	2,996	2,612	1,931	1,787	2,047	1,680
N*T (person years)	17,976	15,672	11,586	10,722	12,282	10,080

Notes: Estimates are descriptive statistics based on the first baseline year, which corresponds to the period from September 1, 2004 to August 31, 2005. N denotes the number of patients, and N*T represents person years.

Table 2. Difference-in-Differences Estimates for NO_2 (ppb) between GMCs and CTRLs

	DiD estimates	95% Confidence Intervals	P value
Patients with Asthma or COPD			
Third year effect	-1.8	(-1.9, -1.7)	<0.001
Second year effect	-2.1	(-2.2, -2.0)	<0.001
First year effect	-2.3	(-2.3, -2.2)	<0.001
Patients with Asthma			
Third year effect	-1.9	(-1.9, -1.8)	<0.001
Second year effect	-2.1	(-2.2, -2.0)	<0.001
First year effect	-2.3	(-2.4, -2.2)	<0.001
Patients with COPD			
Third year effect	-1.7	(-1.8, -1.6)	<0.001
Second year effect	-2.2	(-2.3, -2.1)	<0.001
First year effect	-2.3	(-2.3, -2.2)	<0.001

Notes: Numbers are difference-in-differences (DiD) estimates comparing NO_2 levels between GMCs and CTRLs before and after California's Emission Reduction Plan for Ports and Goods Movement (ERPPGM). NO_2 is measured in parts per billion (ppb). First, second, and third year effect denote the policy effect one, two, and three years after ERPPGM, respectively.

Table 3 Percentage Change for ER Visits between GMCs and CTRLs

	Percent Change %	95% Confidence Intervals	P value
Patients with Asthma or COPD			
Third year effect	-13.1	(-21.0, -4.3)	0.004
Second year effect	-10.2	(-18.4, -1.1)	0.029
First year effect	-4.6	(-13.3, 5.0)	0.34
Patients with Asthma			
Third year effect	-14.8	(-24.0, -4.4)	0.006
Second year effect	-11.8	(-21.4, -1.1)	0.032
First year effect	-7.8	(-17.8, 3.3)	0.16
Patients with COPD			
Third year effect	-11.8	(-21.2, -1.2)	0.030
Second year effect	-6.9	(-16.9, 4.3)	0.22
First year effect	-5.5	(-15.5, 5.7)	0.32

Notes: Numbers are percentage changes comparing the number of ER visits between GMCs and CTRLs before and after California's Emission Reduction Plan for Ports and Goods Movement (ERPPGM). First, second, and third year effect denote the policy effect one, two, and three years after ERPPGM, respectively.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.