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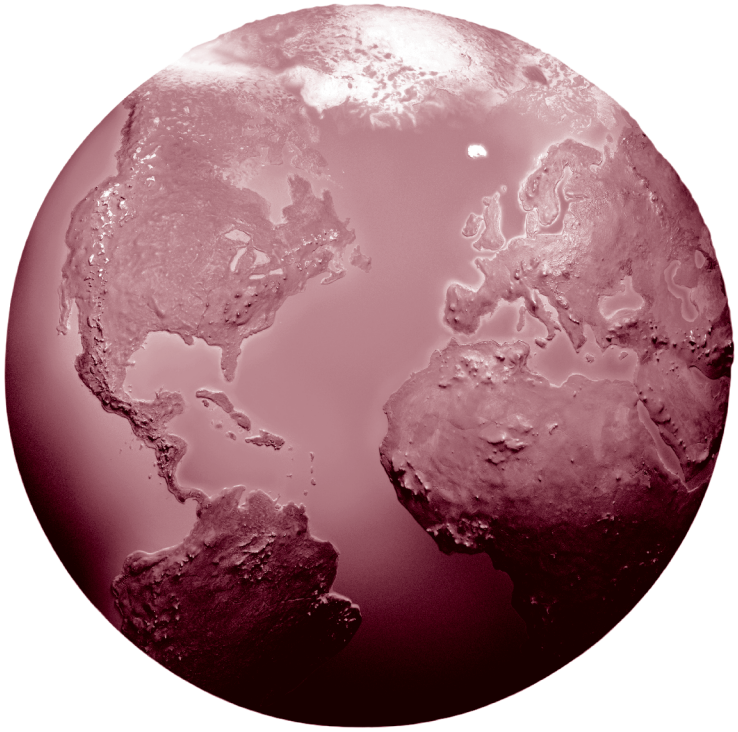

COMMENTARY BY THE HEI REVIEW COMMITTEE SUMMARIZING AND EVALUATING THE INVESTIGATORS' REPORT:

Improvements in Air Quality and Health Outcomes Among California Medicaid Enrollees Due to Goods Movement Actions

Meng et al.

Health Effects Institute

Commentary by the HEI Review Committee Summarizing and Evaluating the Investigators' Report:

Improvements in Air Quality and Health Outcomes Among California Medicaid Enrollees Due to Goods Movement Actions

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

Research Report 205

Health Effects Institute

Boston, Massachusetts

Trusted Science • Cleaner Air • Better Health

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ABOUT HEI

The Health Effects Institute is a nonprofit corporation chartered in 1980 as an independent research organization to provide high-quality, impartial, and relevant science on the effects of air pollution on health. To accomplish its mission, the institute

- Identifies the highest-priority areas for health effects research;
- Competitively funds and oversees research projects;
- Provides intensive independent review of HEI-supported studies and related research;
- Integrates HEI's research results with those of other institutions into broader evaluations; and
- Communicates the results of HEI's research and analyses to public and private decision makers.

HEI typically receives balanced funding from the U.S. Environmental Protection Agency and the worldwide motor vehicle industry. Frequently, other public and private organizations in the United States and around the world also support major projects or research programs. HEI has funded more than 340 research projects in North America, Europe, Asia, and Latin America, the results of which have informed decisions regarding carbon monoxide, air toxics, nitrogen oxides, diesel exhaust, ozone, particulate matter, and other pollutants. These results have appeared in more than 260 comprehensive reports published by HEI, as well as in more than 2,500 articles in the peer-reviewed literature.

HEI's independent Board of Directors consists of leaders in science and policy who are committed to fostering the public–private partnership that is central to the organization. The Research Committee solicits input from HEI sponsors and other stakeholders and works with scientific staff to develop a Five-Year Strategic Plan, select research projects for funding, and oversee their conduct. The Review Committee, which has no role in selecting or overseeing studies, works with staff to evaluate and interpret the results of funded studies and related research.

All project results and accompanying comments by the Review Committee are widely disseminated through HEI's website (*www.healtheffects.org*), printed reports, newsletters and other publications, annual conferences, and presentations to legislative bodies and public agencies.

COMMENTARY

Review Committee

HEI

Research Report 205, *Improvements in Air Quality and Health Outcomes among California Medicaid Enrollees Due to Goods Movement Actions*, Y-Y Meng et al.

INTRODUCTION

Governmental regulation is essential for protecting environmental quality and human health, but also typically incurs an economic cost. For example, the U.S. Clean Air Act and its amendments are credited with the drastic improvements in ambient air quality over the last four decades, including large reductions in lead, particulate matter, and carbon monoxide. Yet the U.S. Environmental Protection Agency (U.S. EPA*) estimates that implementation and compliance costs totaled $588 billion between 1970 and 2010 (U.S. EPA 1997, 2011). It is therefore essential to understand whether environmental policies result in the intended improvements, comparing the predicted benefits to air quality and health with those that are actually achieved. This area of research is known as accountability, and it evaluates the extent to which environmental regulations yield improved air quality and public health.

Over the past two decades the Health Effects Institute (HEI) has emerged as a leader in air pollution accountability research, contributing to research design, funding, and study oversight. In 2003, an HEI working group developed a conceptual framework for conducting air pollution accountability research and outlined methods and opportunities for future research (HEI Accountability Working Group 2003). More details on HEI's involvement in accountability research is reviewed in the Preface. Through a series of Requests for Applications (RFAs) over the past two decades, HEI has now funded over a dozen studies that assessed a wide variety of regulations targeting both point and mobile sources of air pollution. For practical reasons, earlier studies tended to focus on local-level actions that were implemented over a relatively short time frame. HEI later solicited research that evaluated actions with a larger geographical scope and were implemented over longer periods of time.

In its 2011 RFA 11-1, "Assessing the Health Outcomes of Air Quality Actions," HEI aimed to fund research studies that would (1) evaluate regulatory and other actions at the national or regional level that were implemented over multiple years; (2) evaluate complex sets of actions aimed at improving air quality in large urban areas, including those in the vicinity of major ports; or (3) develop methods to support such health outcomes research. In response, Meng and colleagues proposed to study the impact of the 2006 Emission Reduction Plan for Ports and Goods Movement in California on air pollution exposures and healthcare utilization among more than 20,000 low-income residents of port-adjacent communities. They would first estimate changes before and after the implementation of the plan in individual-level exposures to three pollutants primarily emitted from diesel engines by leveraging existing governmental air quality monitoring data and additional sampling in cities near California's largest ports. Then they would evaluate whether emergency room visits and hospitalizations decreased after implementation of the plan to a greater extent for people living near ports and major highways in comparison with people living in areas further away and less likely to be impacted by the plan.

The HEI Research Committee recommended the proposal by Meng and colleagues for funding due to its strong focus on disadvantaged communities living near ports and major roadways, because this was an area of great interest to HEI's industry and governmental sponsors and yet the subject of limited existing research. A key strength of the proposed study design was the comparison of different areas based on proximity to major goods movement transportation routes (i.e., ports and highways leading to ports), which would help differentiate the goods movement policy actions under study versus other regulations that may affect pollution from other forms of road traffic. The Research Committee also appreciated the substantial sample size and focus on large urban regions, as well as the air pollution modeling expertise among the investigators. The study was conducted in two phases, with air pollutant

Dr. Meng's 4-year study, "Improvements in Air Quality and Health Outcomes among California Medicaid Enrollees Due to Goods Movement Actions," began in September 2012. Total expenditures were $750,867. The draft Investigators' Report from Meng and colleagues was received for review in January 2020. A revised report, received in October 2020, was accepted for publication in December 2020. During the review process, the HEI Review Committee and the investigators had the opportunity to exchange comments and to clarify issues in both the Investigators' Report and the Review Committee's Commentary. As a co-investigator of the Meng report, Dr. Michael Jerrett was not involved in its evaluation by the Review Committee.

* A list of abbreviations and other terms appears at the end of this volume.

and health outcome assessments commencing in 2012 and 2015, respectively.

This Commentary provides the HEI Review Committee's evaluation of the study. It is intended to aid the sponsors of HEI and the public by highlighting both the strengths and limitations of the study and by placing the Investigators' Report into scientific and regulatory context.

SCIENTIFIC AND REGULATORY BACKGROUND

The U.S. economy relies heavily on international trade, with approximately $4 trillion worth of goods imported and exported annually, including raw materials, agricultural supplies, and consumer products (U.S. Census Bureau and U.S. Bureau of Economic Analysis 2021). Three-quarters of these goods by weight are transported into and out of the United States via oceangoing vessels, largely funneled through only a handful of ports (Tomer and Kane 2015). These ports are vital to U.S. economic prosperity, accounting for a quarter of gross domestic product and generating more than 30 million jobs (Martin Associates 2019). Yet just 4% of traded goods start or end their journey within local port communities — instead they travel an average of 1,000 miles, mainly via truck or rail, to their final destinations across the country (Tomer and Kane 2015). This goods movement transport network is operated by a sequence of ships, cargo-handling machinery, locomotives, and trucks that are primarily powered by diesel engines.

However, goods movement–related diesel emissions, especially from older diesel engines, can contribute to locally elevated air pollution, exposing the nearly 40 million Americans who live near ports, and the 11 million who live near major highways, to harmful contaminants such as particulate matter and nitrogen oxides (Boehmer et al. 2013; U.S. EPA 2016). The International Agency for Research on Cancer classifies diesel emissions as carcinogenic to humans (Benbrahim-Tallaa et al. 2012), and exposure has been associated with increased risks of adverse respiratory symptoms, hospitalizations related to heart and lung illnesses, and premature death (U.S. EPA 2016). In addition, the people that live near ports and thus have higher exposure to diesel emissions tend to consist of low-income and racial- and ethnic-minority households (Rosenbaum et al. 2011). Compared with those from higher socioeconomic backgrounds, these households may be more susceptible to air pollution-related health effects due to higher rates of comorbidities and less access to primary medical care (Daw 2017; National Association of Community Health Centers 2007).

California represents a microcosm of these issues. The state has the largest economy of any state (U.S. Census Bureau and U.S. Bureau of Economic Analysis 2021), and its eleven ports connect U.S. trade with countries across the Pacific Ocean. The Port of Los Angeles is the busiest container port in the Western Hemisphere, moving $276 billion in goods per year. Together with the adjacent Port of Long Beach, the port complex handles 30% of national cargo volumes (Port of Los Angeles 2019). In residential neighborhoods surrounding the port complex and nearby roadways, diesel-related pollutant exposures were previously estimated to be five times greater than non-impacted locations (Kozawa et al. 2009), with higher exposures disproportionately impacting communities of color (Houston et al. 2014). Further, research undertaken by the California Environmental Protection Agency's Air Resource Board (CARB) had found that people living in those communities were likely to suffer pollution-related economic loss, including restricted activity and missed work, and poorer health, including increased risk of asthma attacks, cancer, and premature death (Di 2006).

Recognizing that goods movement–related emissions were the primary contributor to transportation emissions in the State of California (Di 2006) and that controlling those emissions was critical to protecting public health, CARB and local air quality management districts implemented the Emission Reduction Plan for Ports and Goods Movement in California (herein referred to as Goods Movement Plan) in 2006 (CARB 2006). The plan had five major goals:

1. Decrease California's overall emissions from international and domestic goods movement to 2001 levels or lower by year 2010.
2. Achieve an 85% reduction in CARB-estimated statewide health effects due to diesel particulate matter emissions from international and domestic goods movement by 2020.
3. Reduce nitrogen oxide emissions from international goods movement within four counties surrounding the Los Angeles–Long Beach port complex to prescribed levels by 2020, putting the region on track for meeting state and federal air quality standards.
4. Implement a comprehensive set of emission-reduction strategies for ports and goods movement across the state to help all regions achieve state and federal air quality standards.
5. Prioritize implementation of all feasible strategies to reduce health risks to communities adjacent to goods movement facilities.

The Goods Movement Plan consisted of a multi-year rollout of emission reduction strategies targeting five modes of goods movement transport including ships, commercial harbor craft, cargo handling equipment, heavy duty trucks, and locomotives. Strategies comprised state and federal regulations, international agreements, and voluntary incentive programs primarily designed to reduce diesel particulate matter and nitrogen oxide pollution. The Commentary Table summarizes selected strategies from the Goods Movement Plan by transportation mode and approximate period of implementation. Note that there were numerous previously and concurrently implemented strategies not shown in the Commentary Table, including certain emissions standards, fuel rules, and violation reporting; those additional strategies were expected to have an ongoing contribution to emission reductions.

Implementation of the Goods Movement Plan provided an unprecedented natural experiment in which a well-defined network of goods movement-related roads and freeways would undergo immediate and ongoing interventions to reduce emissions. Research was also essential to evaluate whether the estimated $6–10 billion investment required to implement the plan was effective in reducing ambient air pollution and improving public health, particularly within communities adjacent to ports and other goods movement transportation corridors. However, major challenges of this research would be to assemble a cohort representative of the population residing in near-port communities and to identify any air quality and public health improvements that were attributable to the Goods Movement Plan versus other regulations that may have similar effects.

In their research report, *Improvements in Air Quality and Health Outcomes Among California Medicaid Enrollees Due to Goods Movement Actions*, Meng and colleagues describe a study designed to meet these challenges. The investigators assessed changes in air pollutant concentrations and healthcare utilization before and after the 2006 Goods Movement Plan implementation within ten counties surrounding California's major ports. They set out to investigate potential health benefits in an existing cohort of racially diverse adults enrolled in Medi-Cal, a medical care program for low-income individuals. To help differentiate potential improvements attributable to the Goods Moment Plan versus other regulations impacting vehicle emissions, investigators compared three exposure groups defined by their proximity to goods movement transportation routes and other high vehicle traffic areas. Their findings will help inform future regulations to control goods movement emissions across the country.

SUMMARY OF THE STUDY

OBJECTIVES

Meng and colleagues studied the effects of the 2006 California Goods Movement Plan on air quality and health outcomes by focusing on vulnerable populations living in three areas: neighborhoods close to the ports and major highways with heavy-duty truck traffic driving to and from the ports (referred to as "goods movement corridors"), neighborhoods close to highways where truck traffic was banned ("non-goods movement corridors"), and neighborhoods located away from the ports and highways ("control areas"). They evaluated whether air quality had changed more in the areas where the Goods Movement Plan was expected to have greater effects and whether any observed air quality improvements had led to improved health outcomes. By comparing the three areas they hoped to tease out the specific effects of the Goods Movement Plan as compared with other regional and national regulations aimed at traffic-related pollution from cars or other factors that also lead to reduced emissions of pollutants. The investigators studied three criteria pollutants directly and indirectly targeted by the plan — nitrogen dioxide (NO_2), fine particulate matter ($PM_{2.5}$), and ozone (O_3) — in relation to health outcome data for Medi-Cal beneficiaries (California's Medicaid program) with chronic health conditions. They focused their analyses on comparing air quality and healthcare utilization before and after the plan went into effect and on comparing the results among people living in those three areas. Specific study objectives included the following:

1. Develop annual land use regression models and associated surfaces for pollutants NO_2, $PM_{2.5}$, and O_3 for years 2004–2010 across California at a spatial resolution of 30 m.
2. Assess reductions in air pollution exposure measures among Medi-Cal enrollees living in goods movement, non–goods movement, and control areas by assigning the annual pollutant concentrations to their home addresses and comparing their reductions among the three location categories from the pre- to the post-policy period.
3. Develop and evaluate measures for health effects (e.g., emergency room visits and hospitalization) and time-varying confounding factors (e.g., change in disease severity) to support the analysis.
4. Identify whether improvements in air quality were greater in goods movement and non–goods movement

areas than those in control areas from the pre- to the post-policy period.

5. Examine whether changes in exposure resulted in improvements in health outcomes, including reductions in the number of emergency room visits and hospitalizations among Medi-Cal beneficiaries with asthma, heart disease, chronic obstructive pulmonary disease (COPD), and diabetes by estimating the difference-in-differences using generalized linear multilevel models.
6. Conduct sensitivity analyses (e.g., propensity score methods) and analyses using a multilevel mediation model to examine whether improvements in health outcomes were due to the effect of regulatory policies on reductions in air pollution.

Meng and colleagues first estimated annual NO_2, $PM_{2.5}$, and O_3 concentrations across California for each year from 2004 to 2012. These pollutant estimates were then assigned to the home addresses of the Medi-Cal beneficiaries with at least one of the following chronic conditions: asthma, COPD, diabetes, and heart disease. Each address was further assigned to one of three location categories based on proximity to specific traffic zones: goods movement corridors — areas within 500 m of a port or freeway where trucks were allowed; non–goods movement corridors — areas within 500 m of truck-prohibited freeways or within 300 m of freeway-connecting roads; and control areas, which included all areas other than goods movement and non-goods movement corridors. Changes in pollutant exposure among those living in the three zones were compared between the pre- and post-policy periods. Although the Goods Movement Plan was approved in 2006, rollout was slow. Therefore, Meng and colleagues defined 2004–2007 as the pre-policy period and 2008–2010 as the post-policy period. Finally, the investigators examined subsequent changes in healthcare utilization among these Medi-Cal beneficiaries to assess whether the policy-related air quality improvements were effective in improving health. The investigators hypothesized that compared with control areas, reductions in the selected air pollutants and healthcare utilization would be greatest in goods movement corridors that were targeted by the policy actions, followed by non–goods movement corridors, which may show improvements due to more general statewide and national air pollution regulations.

STUDY DESIGN AND METHODS

Design

This study implemented a quasi-experimental design among a previously established cohort of Medi-Cal enrollees to identify whether 2006 goods movement policy actions were effective in improving ambient air pollution and health outcomes among disadvantaged populations living near California ports or freeways where trucks were permitted. Meng and colleagues compared reductions in pollutant exposure levels and healthcare utilization from the pre-policy (2004–2007) to early post-policy (2008–2010) periods among people residing in areas designated as goods movement, non–goods movement, and control areas (see sidebar) to identify whether policies had a greater impact in goods movement corridors compared with other high and low traffic areas. The post-policy

ABOUT GOODS MOVEMENT CORRIDORS

Meng and colleagues focused on evaluating changes in post-policy air pollution and healthcare utilization among zones classified by proximity to goods movement transport routes to identify changes attributable to the Goods Movement Plan versus other regulations and unrelated secular trends.

Goods Movement Corridors were areas within 500 m of ports or freeways where trucks are permitted. This zone was expected to experience the greatest benefit from the Goods Movement Plan because it included the policy-targeted transportation modes involved in the international and domestic goods movement through ports, such as drayage trucks, transport refrigerator units, and tractor trailers.

Non–Goods Movement Corridors were areas within 500 m of truck-prohibited freeways or within 300 m of freeway-connecting roads. This zone was expected to benefit from ongoing air pollution policy changes implemented at the regional and national level that imposed emissions limits on passenger cars and light-duty vehicles, but to a lesser extent than goods movement corridors given the exclusion of major goods movement transportation modes.

Control Areas, located away from the ports and freeways, served as the comparison group. Post-policy changes here were considered background shifts related to other policies affecting traffic-related emissions, but less likely to be affected by the Goods Movement Plan.

study period was meant to capture goods movement actions that were implemented immediately and during the first three years of the Goods Movement Plan multiyear rollout (see Commentary Table).

Study Population

The cohort was assembled with Medi-Cal fee-for-service claims data from the California Department of Health Care Services. Medi-Cal is California's Medicaid system, a needs-based healthcare program for low income and disabled persons. The cohort was part of a disease management program evaluation conducted by the University of California, Los Angeles Center for Health Policy from 2004–2010. The claims data included both inpatient (e.g., hospitalization) and outpatient (e.g., emergency room visit, doctor visit, and pharmacy) medical service encounters,

Commentary Table. Summary of the Goods Movement Plan Strategies to Reduce Emissions from Ports and Goods Movement by Transport Mode and Estimated Implementation Timeline

Goods Transport Mode	Strategy	Implementation Timeline		
		2006–2010	2011–2015	2016–2020
Ships Commercial and passenger oceangoing vessels	Use cleaner marine and auxiliary engine fuels			
	Expand vessel speed reduction program			
	Require cleaner engines in new vessels and retrofit old engines			
	Dedicate cleanest vessels to California service			
	Switch to electric shore power			
Commercial Harbor Craft Tow/tugboats, ferries, barges	Cleaner engine incentives			
	Require low-sulfur fuel			
	Switch to electric shore power			
	New engine emission standards			
Cargo Handling Equipment Machinery used to load/unload goods in ports and railyards	Require low-sulfur fuel			
	Cleaner fuel incentives			
	Higher emission standards for diesel and gas engines/equipment			
	Upgrade equipment with better diesel particulate matter control			
	Achieve near zero emissions for all equipment			
Heavy Duty Trucks Trucks and transport refrigeration units that move goods across California	International trucks must meet U.S. emissions standards			
	Enhanced enforcement of truck idling limits			
	Retrofit, repower, and replace truck fleets			
Locomotives Used to move goods within railyards and across California	Upgrade switcher locomotive engines			
	Retrofit particulate matter control devices on existing engines			
	Switch to cleaner fuels			
	Achieve new idling and control standards			
	Concentrate the cleanest locomotives in California railways			

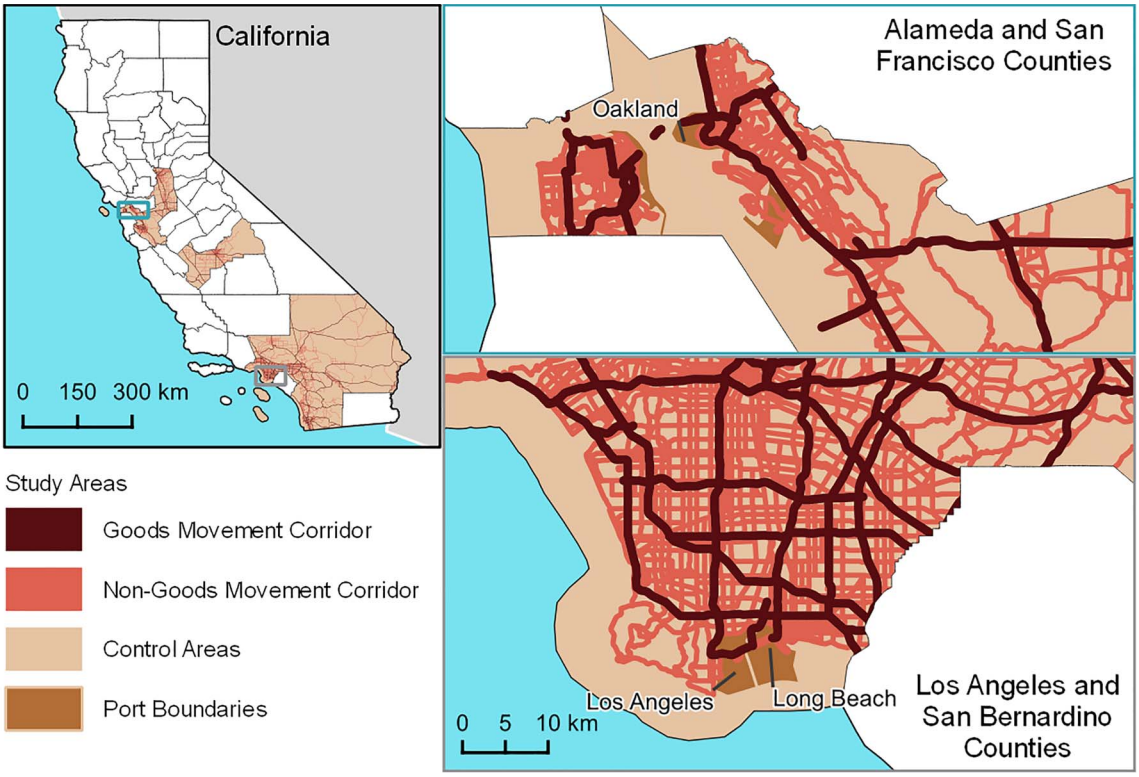
Adapted from CARB 2006, Table 3.

with up to two diagnoses listed per encounter. Beneficiaries resided in 10 California counties including Los Angeles, Riverside, San Bernardino, San Diego, Alameda, San Francisco, Santa Clara, San Joaquin, Fresno, and Sacramento (Commentary Figure 1). Original inclusion criteria for the disease management program limited the cohort to adults 22 years and older who were Medicare ineligible, and had at least one paid Medi-Cal claim for one of four chronic conditions. These conditions included asthma, COPD, diabetes, and heart disease (which included atherosclerotic heart disease, coronary artery disease, and congestive heart failure). Most beneficiaries in the source Medi-Cal claims dataset were middle-aged because persons who are 65 and older typically enroll in Medicare, the national medical program for elderly individuals.

Dr. Meng limited the study population to beneficiaries in the healthcare program evaluation with continuous Medi-Cal enrollment over the 2004–2010 study period and at least one claim per year. Enrollees were excluded if they had been diagnosed with human immunodeficiency virus or cancer, were long-term care patients, or they did not have a valid home address that could be linked with pollution data. Of the approximately 172,000 enrollees in the original claims dataset, about 23,000 remained after exclusions.

Approach

The project was conducted in two phases. In Phase I, Meng and colleagues estimated annual levels of pollutants NO_2, $PM_{2.5}$, and O_3 across the state of California by developing land use regression model surfaces for calendar years 2004 to 2012. In Phase II of the study, home addresses for each Medi-Cal beneficiary were assigned NO_2, $PM_{2.5}$, and O_3 exposure levels and categorized into the goods movement, non–goods movement, and control areas (see sidebar and Commentary Figure 1). Health outcome measures included annual number of all-cause emergency



Commentary Figure 1. Map of Southern California, with the goods movement corridors, non–goods movement corridors, control areas, and ports shown. Data sources: goods movement corridors courtesy of Jason Su; California county and state boundaries from the California OpenData Portal based on the U.S. Census Bureau's 2016 MAF/TIGER Database (*https://data.ca.gov/dataset/ca-geographic-boundaries* [accessed 26 January 2021]); port boundaries from California Department of Transportation (*www.arcgis.com/home/item.html?id=ca25a3a15fa2448c801499638300780e* [accessed 12 March 2021]); U.S. boundary from the Census Bureau's MAF/TIGER geographic database *www.census.gov/geographies/mapping-files/time-series/geo/carto-boundary-file.html* [accessed 12 March 2021]).

room visits and hospitalizations per beneficiary from September 1, 2004, to August 31, 2010. To detect potential incremental improvements over time, the pollutant exposure levels and healthcare utilization for each year in the early post-policy period (2008, 2009, and 2010) were compared with the average annual utilization during the pre-policy period (2004–2007).

Statistical Analysis

Estimating Pollutant Levels Across California Meng and colleagues estimated annual levels of pollutants NO_2, $PM_{2.5}$, and O_3 at a 30-m resolution across the state by developing mixed-effects land use regression models for every year of the study period. Air pollution data were merged from two sources. Continuous pollutant concentrations were monitored at more than 100 sites across California by the U.S. EPA for all study years, with approximately 38% of sites located within the 10 counties under study. The investigators conducted additional NO_2 monitoring in Alameda and Los Angeles counties because they are home to California's three largest ports and are part of the two largest urban regions in the state. These NO_2 monitoring data were collected in 2004–2005 for Alameda and 2006–2007 for Los Angeles counties. Additional sampling was conducted in 2012–2013 for Alameda and Los Angeles in order to improve land use regression modeling, although this occurred after the time frame when Medi-Cal data were available. The more than 600 NO_2 samples were distributed evenly across the goods movement, non–goods movement, and control areas. The statewide data allowed Meng and colleagues to reduce the uncertainty of pollutant exposure estimates in the outer regions of the study areas, while supplemental monitoring in Alameda and Los Angeles counties increased the precision and accuracy of NO_2 exposure estimates in key areas.

The optimal land use regression model was chosen using a deletion/substitution/addition algorithm paired with cross-validation. Predictors included numerous variables related to road traffic, distance to ports and coastline, land elevation and use, atmospheric conditions, and the gridded ozone concentrations from the U.S. EPA's ozone Downscaler (U.S. EPA 2020). The investigators intended for vehicle-kilometers-traveled variables to serve as proxies for changes in economic conditions, including the 2008 economic recession. Phase I of this study culminated with annual NO_2, $PM_{2.5}$, and O_3 concentrations predicted at a 30-m spatial resolution across California.

Analysis of Health Data To test whether goods movement policy actions improved air quality and health outcomes, the investigators applied a difference-in-differences model in Phase II. This method is commonly used in observational research on policy-related interventions to mimic experimental designs and compares the change of an outcome over time in an intervention group to a change in outcome over time in a control (no intervention) group (Dimick and Ryan 2014). In the absence of confounding, if the policy has no effect, then baseline differences between these two groups will remain unchanged over time. But if a policy impacts the intervention group, then the differences between groups may become larger or smaller over time.

Meng and colleagues used the difference-in-differences analysis to compare changes in pollutant exposure levels and healthcare utilization, including both emergency room visits and hospitalizations, among those living in the goods movement, non–goods movement, and control areas. Changes in each of the areas were compared. They analyzed these changes for each of the three post-policy years (2008, 2009, and 2010), evaluating the entire cohort together and among those with each of the four chronic conditions separately. If the Goods Movement Plan had the intended effects, in the absence of confounding investigators would expect to observe greater reductions in pollutant exposure levels and healthcare utilization in the goods movement corridor compared with other areas. Analyses were adjusted for numerous risk factors to control for individual- and neighborhood-level variables that could bias results. To control for differences across the three traffic areas, beneficiary-level variables included age, sex, language spoken, race and ethnicity, number of comorbidities in pre-policy years, and county of residence. To control for changes over time, they also adjusted for annually recorded smoking status, depression, number of doctor visits, and severity of health status using the Chronic Illness and Disability Payment System risk scores. Neighborhood-level factors were derived from the 2000 and 2010 U.S. Census (representing the pre- and post-policy periods, respectively) and included percent minority, unemployed, living in poverty, and households with no vehicle. Results were considered statistically significant at $\alpha = 0.05$ and reported with both 95% confidence intervals (CI) and *P* values.

Supplemental Analyses Investigators conducted additional sensitivity analyses to evaluate the robustness of their findings. To account for the fact that individuals could not be randomized to the goods movement corridor, difference-in-differences analyses with inverse probability weighting was also conducted. This method first uses logistic regression to estimate the predicted probability of each Medi-Cal beneficiary living in the goods movement compared with control areas, given key demographic characteristics. In their report, investigators chose age, sex, number of comorbidities, and severity of health status as

their key characteristics. The inverse of these probabilities is then used to create weights for each individual. Thus, individuals living in goods movement areas with characteristics similar to their neighbors will be downweighted, while those with characteristics more similar to those living in control areas will be upweighted. Compared to an experimental design where the distribution of characteristics is equal across groups due randomization, this method attempts to distribute characteristics equally across groups by re-weighting them (Rosenbaum and Rubin 1983).

Finally, investigators conducted a multi-level mediation analysis to test whether the way in which the Goods Movement Plan reduced healthcare utilization was through reduced air pollution. This is important because the policy intervention could improve health outcomes directly, but be due to outside influences. In their modeling approach, investigators tested whether the policy-related reductions in both NO_2 and $PM_{2.5}$ mediated the reduction in emergency visits among those living in goods movement corridors compared with controls. Only NO_2 and $PM_{2.5}$ were included in the mediation analysis because preliminary results showed these pollutants, but not O_3, were related to the intervention.

SUMMARY OF KEY RESULTS

Population Characteristics

In this study population of Medi-Cal beneficiaries, 13,337 (57%) had been diagnosed with diabetes, 8,900 (38%) with COPD, 8,636 (37%) with asthma, and 8,684 (37%) with heart disease. Beneficiaries were not evenly distributed across the three areas, with most residing in non–goods movement corridors (57%), followed by goods movement (22%), and control areas (20%). Demographic characteristics were similar across zones; however, those residing in goods and non–goods movement areas were more likely to be African American and Latino compared with control areas. At the neighborhood-level higher rates of unemployment, poverty, and households without vehicles were observed in goods movement corridors, followed by non–goods movement corridors, compared with control areas.

Air Quality Improvements

Compared with the pre-policy period, Meng and colleagues reported statistically significant reductions in NO_2 and $PM_{2.5}$ concentrations across all 10 counties in the post-policy period. Results from the difference-in-differences analyses showed the greatest reductions in NO_2 and $PM_{2.5}$ when comparing goods movement to control areas for all Medi-Cal beneficiaries together and when stratifying by beneficiaries with each of the four chronic conditions. For example, the average annual estimated exposures to NO_2 and $PM_{2.5}$ were 2.43 ppb (95% CI = −2.51, −2.34) and 1.58 μg/m^3 (95% CI = −1.63, −1.52) lower, respectively, among beneficiaries with asthma living in the goods movement corridor versus the control area during the first-year post-policy compared with average levels in pre-policy years. Commentary Figure 2(A) shows the decreasing NO_2 exposure levels among all beneficiaries, and beneficiaries with asthma and COPD, across the study period with greater reductions for those living in goods movement corridors compared to control areas during the post-policy period. The investigators reported that the higher NO_2 concentrations in goods movement corridors during the pre-policy period decreased by 19.5% and approached the lower concentrations observed in non–goods movement and control areas during the post-policy period.

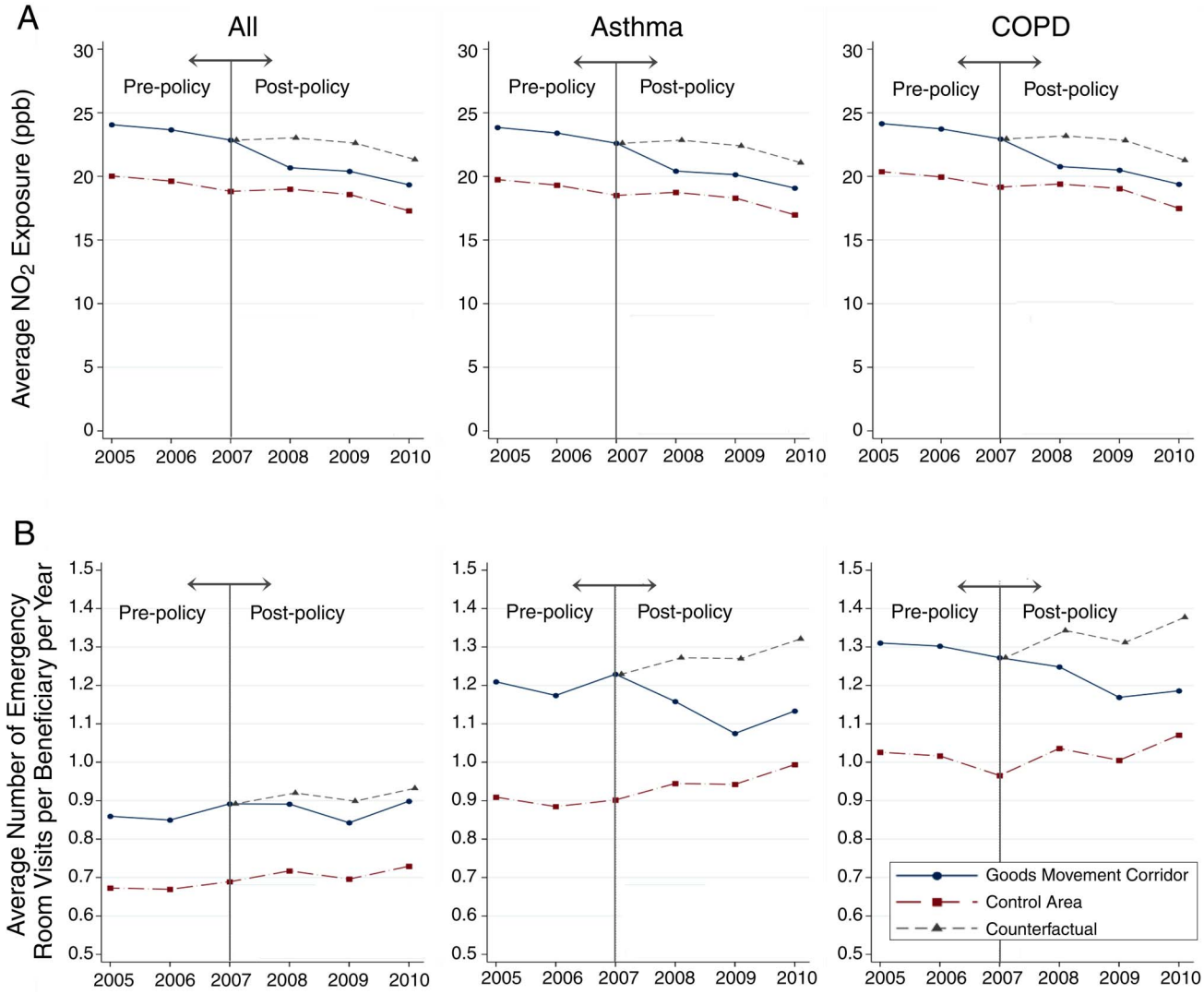
Similar, but smaller reductions in NO_2 and $PM_{2.5}$ were observed when comparing non–goods movement to control areas, with the smallest reductions observed when comparing goods movement areas to non–goods movement areas. For example, among beneficiaries with asthma, during the first-year post-policy average annual estimated exposure to NO_2 and $PM_{2.5}$ was 1.31 ppb (95% CI = −1.39, −1.24) and 0.90 μg/m^3 (95% CI = −0.95, −0.86) lower, respectively, among beneficiaries living in the non-goods movement corridor versus control, and 1.11 ppb (95% CI = −1.18, −1.05) and 0.68 μg/m^3 (95% CI = −0.72, −0.63) lower, respectively, among beneficiaries living in the goods movement versus non-goods movement corridors. Reductions in NO_2 and $PM_{2.5}$ were generally largest in the first year following policy changes, with smaller reductions in years two and three. For example, the average annual exposures among all beneficiaries living in the goods movement corridor versus control areas during the first, second, and third years post-policy were 2.35, 2.21, and 1.98 ppb lower, respectively, for NO_2, and 1.49, 1.34, and 1.37 μg/m^3 lower, respectively, for $PM_{2.5}$.

In contrast, O_3 concentrations demonstrated the opposite trend during the post-policy period, where greater increases were observed for goods and non–goods movement corridors when compared with controls. This finding is consistent with the known inverse relationship between O_3 and NO_2. O_3 concentrations showed similar changes across the study period in goods and non–goods movement corridors.

Health Outcome Improvements

Investigators reported statistically significantly greater improvements in health outcomes for Medi-Cal beneficiaries suffering from respiratory-related chronic conditions

who were living in goods and non–goods movement corridors when compared with controls in the second and third years post-policy. For example, difference-in-differences estimates indicated that in year three following the goods movement policy actions, an additional 170 (95% CI = −290, −50) emergency visits among those with asthma, and an additional 180 (95% CI = −300, −50) emergency visits among those with COPD, were avoided annually for every 1,000 beneficiaries in the goods movement areas compared with control areas. Estimates were smaller when comparing non-goods movement corridors with control areas. For example, in post-policy year three, an additional 160 (95% CI = −260, −60) emergency visits among those with asthma, and an additional 90 (95% CI = −200, −10) emergency visits among those with COPD, were avoided annually for every 1,000 beneficiaries in the non-goods movement compared with control areas. There were no significant differences between goods and non-goods movement corridors. Commentary Figure 2(B) shows the emergency room visits among all beneficiaries, as well as those



Commentary Figure 2. Average NO_2 exposure levels (A) and emergency room visits (B) among all beneficiaries, those with asthma, and those with COPD from the pre-policy (2005–2007) to post-policy (2008–2010) study periods. After 2007 policy implementation, reductions were greater for goods movement corridors (solid blue line) compared with control areas (long-dashed red line). The counterfactual (gray short-dashed line) indicates the expected trend for the goods movement corridor if the Goods Movement Plan had not been implemented. (Adapted from Figure 5 in Investigators' Report.)

suffering from asthma and COPD, across the study period. Although emergency visits decreased for beneficiaries living in goods movement corridors, they increased for those living in control areas during the post-policy period.

Results from the mediation analysis indicated that the reductions in emergency room visits among beneficiaries with asthma in goods movement compared with control areas were mediated through reductions in NO_2 and $PM_{2.5}$ in the post-policy period. This suggests that reductions in emergency room visits among those with asthma were at least partially a downstream effect of the policy-related air quality improvements.

Post-policy reductions in emergency room visits among all beneficiaries and those with diabetes and heart disease were not significantly different for goods and non–goods movement corridors when compared with controls, and post-policy reductions among each beneficiary group was not significantly different for goods compared with non–goods movement corridors. Investigators posited that the observed ER reductions in asthma and COPD, but not diabetes and heart disease, were due to an increased biological susceptibility when air pollutants are deposited in the lungs of persons with chronic respiratory diseases.

Investigators reported that the difference-in-differences estimates for hospitalizations showed a downward trend in the post-policy period but were not significantly different for those living in goods and non–goods movement corridors versus controls or for goods movement versus non–goods movement corridors. Similar results were observed in supplemental difference-in-differences analyses of health outcomes with inverse probability weighting.

HEI REVIEW COMMITTEE EVALUATION

In its independent evaluation of the study, the Review Committee appreciated that this study used a quasi-experimental design to assess the effectiveness of the 2006 California Goods Movement Plan on air pollution and health outcomes near major ports. In the absence of confounding, this study design enabled investigators to establish cause and effect from observational data (Dominici et al. 2014). They generally agreed with the interpretation of results as reported by the investigators. First, there were greater reductions in NO_2 and $PM_{2.5}$ levels during the post-policy period in goods movement areas compared with control areas (for a description of the goods movement areas, see the sidebar). Furthermore, the post-policy reductions in air pollution subsequently led to lower emergency healthcare utilization among Medi-Cal beneficiaries with respiratory-related chronic conditions, but not among those beneficiaries with diabetes or heart disease. Finally, smaller reductions were observed when comparing non–goods movement with control areas, and the smallest reductions were observed when comparing goods movement with non–goods movement areas.

Overall, the Committee found the study results to be useful and clearly presented and considered them to be of particular interest to policymakers who are planning goods movement policy interventions in other jurisdictions. However, the Committee thought that the conclusions were too strong because the changes in health outcomes could not be definitively linked to the policy actions due to various other regulations and economic changes that happened during the same time frame. Below, we highlight strengths and limitations of the study.

STUDY DESIGN

The Committee noted that the robust study design enabled assessment of regulatory impacts on public health and was applied to unique datasets linking detailed air quality measurements and models with longitudinal Medi-Cal claims. In addition, the investigators were able to obtain individual home addresses, allowing them to estimate finer variation in pollution exposure by small-scale proximity to goods movement areas. However, the observational nature of this study design meant that it was not possible to randomly assign people to goods movement corridors and therefore inherent differences between beneficiaries living in the three areas at baseline and over time may have influenced the results. To account for this, investigators used a difference-in-differences model and inverse probability weighting to control for dissimilar socioeconomic and health characteristics between Medi-Cal beneficiaries in the goods movement and control areas. They reported that trajectories in pollutant exposures and healthcare utilization for the goods movement and control areas were parallel over time, indicating that potential biases due to unobserved confounding should be minimized, and similar results were obtained with and without inverse-probability weighting. Although these methods aim to replicate randomized experimental trials by balancing characteristics of the intervention and control groups at baseline and over time, residual and unmeasured differences cannot be completely ruled out.

Another major strength of this study was that the analysis was structured within three goods movement traffic zones. In particular, the Committee appreciated the inclusion of an intermediate non–goods movement area. This allowed the investigators to tease out effects attributable to the Goods Movement Plan from the effects of other regional and national regulations affecting vehicle emissions that would impact both the goods movement

and non–goods movement corridors, but were expected to affect the control areas to a much smaller extent. The difference-in-differences estimates comparing these three areas were suggestive of a gradation in responses, with goods movement corridors showing the greatest improvement in air quality and healthcare utilization, a smaller improvement shown for non–goods movement corridors, and minimal or no improvement in control areas.

Finally, the Committee appreciated that the investigators evaluated three air pollutants and were therefore able to compare results for a traffic-related air pollutant (i.e., NO_2); a pollutant largely related to traffic, regional transport, and shipping emissions (i.e., $PM_{2.5}$); and a secondary air pollutant (i.e., O_3). Meng and colleagues reported that goods movement actions reduced concentrations of NO_2, with smaller reductions in concentrations of $PM_{2.5}$. Consistent with the known inverse relationship between NO_2 and O_3, O_3 concentrations increased during the post-policy period. Therefore, the results from this study can be built upon so that future regulations can better target specific pollutants that are most likely to be affected by the goods movement sector.

STUDY POPULATION

Investigators limited the cohort to beneficiaries with six years of continuous Medi-Cal enrollment. Enrollment interruptions, known as churning, are common due to intermittent eligibility changes (e.g., inconsistent income level). They justified this choice because those with disrupted coverage generally have higher emergency-care utilization that may be difficult to differentiate from policy-related utilization changes. The Review Committee noted that characterization of those excluded from this cohort, including demographic information and which traffic corridor or control area they resided in, would have been helpful to include in the Investigators' Report to identify potential selection bias affecting the results and aid our understanding of how the results may be generalized. Currently it is unclear whether results from this study suggesting that goods movement policies improve health outcomes would apply to the overall Medi-Cal population with chronic conditions. The Committee acknowledged that including churning beneficiaries may have made the results more difficult to interpret, but would have preferred additional sensitivity analysis.

Another limitation was the time frame of available Medi-Cal data. The study period was limited to only three years post-policy because in 2010 the Medi-Cal fee-for-service reimbursement system, where healthcare providers are paid for each service performed, transitioned to a managed-care system, where providers are regularly paid a predetermined amount to monitor and manage a patient's health. This transition can alter healthcare utilization (Kern et al. 2019; Toseef et al. 2019, 2020; Yamaki et al. 2019) and providers' claim submission behaviors, with uncertain changes to this Medi-Cal population with chronic conditions. Although the transition to managed care was gradually implemented beginning in 2003, the investigators state that all members of the cohort were fee-per-service patients and that the changes would not affect the inclusion of participants in the cohort. The Committee thought that it was unfortunate that the study population could not be followed for a longer period, but agreed that the change in the data due to the change in reimbursement system would have been too large for reasonable comparisons after 2010. Overall, the Committee appreciated that the study targeted people who may be more vulnerable to the health effects of air pollution, a population that is often inadequately included in many other studies.

ALTERNATIVE EXPLANATIONS FOR THE RESULTS

Although the results suggested that the Goods Movement Plan improved some aspects of air quality and health, the Review Committee acknowledged the possibility that other factors may have contributed to the observed results due to inherent limitations to the design. However, they felt these limitations were not adequately addressed in the discussion. Although the investigators controlled for numerous confounding variables in their analysis, some bias may nonetheless persist. Population changes, additional public health interventions, and secular trends occurring over the study period may have influenced the results if they disproportionately affected some locations or population subgroups, but not others. The investigators argued that such changes would be accounted for using the difference-in-differences model; Medi-Cal policy changes would impact the entire study population equally; and local interventions would be partially controlled for by adjusting for county and neighborhood poverty levels in the regression models. However, these assumptions cannot be comprehensively tested.

Of particular concern, it is unclear whether a 2006 diesel fuel standard change or the 2008 global economic recession affected the goods movement, non–goods movement, and control areas differently. In 2006 the U.S. EPA began phasing in regulations requiring all highway vehicles, locomotives, and marine engines and equipment to transition to ultra-low-sulfur diesel fuel, which reduces both nitrogen oxide and particulate matter emissions (Zhu et al. 2010). The economic recession also severely impacted port and road traffic. For example, between 2007 and 2009, the number of shipping containers moving through the Ports

of Los Angeles and Oakland declined 19% and 14%, respectively (Port of Los Angeles; Port of Oakland). Although annual traffic and cargo volumes were included in the statistical analyses of pollutant exposures, the investigators reported that this information could not be meaningfully assigned to beneficiaries and therefore could not be included in the health outcome models. Alternatively, the investigators adjusted for pre- and post- intervention census-tract-level unemployment, poverty, and vehicle ownership to help control for the economic downturn. Notably, results showed that NO2 levels and emergency room visits markedly decreased in 2008. Therefore, the Committee thought that the decline could not be fully attributed to the Goods Movement Plan.

Another result that was not discussed in the report was that NO_2 and $PM_{2.5}$ levels showed the greatest improvement in the first year post-policy, with incrementally smaller improvements in the second and third years. However, the Goods Movement Plan included many rules, such as electrification of ships and drayage vehicles in the ports that took time to implement, as did rules that affected vehicle emissions that happen over several years due to slow fleet turnover (see the Commentary Table for summary of Goods Movement Plan strategies and timelines). Thus, changes in air quality due to the Goods Movement Plan were expected to accumulate over time and extend well beyond the study period. If the policy intervention were directly and primarily responsible for greater reductions in NO_2 and $PM_{2.5}$ levels in the goods movement corridor compared with the control area, the Committee would have expected to observe greater improvements in the second and third years.

The Committee concluded that the results were consistent with the investigators' interpretation that changing air pollution was responsible for the changes in health outcomes, but not sufficient to prove there was a causal relationship given the uncertain influence of extrinsic factors. In addition, the investigators were not able to fully tease apart air quality changes that could be attributed to the goods movement regulations from those resulting from other regulations to reduce emissions or other changes in society that happened over the same time period. Given the infeasibility of exploring all possible alternative explanations, the Review Committee believed that the investigators may have been too strong in their conclusions without completely acknowledging the limitations.

SUMMARY AND CONCLUSIONS

Meng and colleagues assessed the effectiveness of the 2006 California Goods Movement Plan on air quality and healthcare utilization among Medi-Cal beneficiaries with chronic conditions living near ports or freeways over a 6-year period. They classified neighborhoods into three zones based on proximity to goods movement transportation routes: goods movement corridors were adjacent to ports or freeways, non–goods movement corridors with high levels of non–truck traffic, and control areas with comparably low traffic. Using a difference-in-differences analysis, they compared changes in ambient NO_2, $PM_{2.5}$, and O_3 exposure, and changes in emergency room visits and hospitalizations, from the pre-policy (2004–2007) to post-policy (2008–2010) periods among the three zones.

The investigators hypothesized that goods movement corridors would receive the greatest benefit because the Goods Movement Plan targeted the major transportation modes within and through ports. They reported greater reductions in NO_2 and $PM_{2.5}$ concentrations during the three-year post-policy period among those living in the goods movement areas compared with those living outside of those areas. Furthermore, the post-policy reductions in air pollution were associated with fewer emergency room visits among Medi-Cal beneficiaries with asthma and COPD. However, there was no improvement in O_3 exposures, hospitalizations, or emergency room visits among beneficiaries with diabetes and heart disease.

The Review Committee commented on the strong quasi-experimental study design addressing an important research topic of great interest to policymakers. They agreed with the investigators that the evidence supported the conclusions that the Goods Movement Plan was related to greater reductions in NO_2 and $PM_{2.5}$ exposures and greater reduction in emergency care utilization among beneficiaries with asthma and COPD living in goods movement corridors compared with other areas. Yet they thought some study limitations were not fully addressed. The Committee would have preferred additional results demonstrating similarities and differences between the current cohort and those excluded so that selection bias and generalizability could be adequately evaluated. They would have also preferred a more detailed discussion of alternative explanations, including other regulations and secular trends, that may have contributed to observed findings.

Overall, this study provided evidence that regulatory actions to limit emissions from goods movements in and around major ports and freeways may decrease emergency care utilization among disadvantaged people who live close to those locations and also suffer from respiratory-related chronic conditions. Further research is needed to understand whether continued improvements are seen during the decade(s) following the start of the implementation of the Goods Movement Plan in 2006, given that it takes many years to implement such an ambitious program

and that vehicle turnover is generally slow. It will also be useful to evaluate whether similar improvements are observed elsewhere when goods movements actions are implemented, targeting ports and other major distribution hubs. The most difficult and pressing challenge remains to disentangle the effects on emissions, air quality, and health of individual regulations. Whereas it is useful to study the effectiveness of a broad program of regulations, such as the Goods Movement Plan, governing authorities would ultimately like to know which of the individual actions have been most effective. Further research and development of statistical approaches is needed to provide further insight into these issues.

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ABBREVIATIONS AND OTHER TERMS

CARB	California Air Resources Board
CI	confidence interval
COPD	chronic obstructive pulmonary disease
ER	emergency room
HEI	Health Effects Institutes
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O_3	ozone
$PM_{2.5}$	particulate matter ≤ 2.5 µm in aerodynamic diameter
RFA	Requests for Applications
TIGER	Topologically Integrated Geographic Encoding and Referencing database
U.S. EPA	U.S. Environmental Protection Agency

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