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Measuring The Impact Of Air Pollution On Health Care Costs

ABSTRACT **Air pollution contributes to the development of numerous adverse human health outcomes. The Environmental Protection Agency's Environmental Benefits Mapping and Analysis Program–Community Edition (BenMAP-CE) tool is widely used in estimating the health care costs of air pollution and in the development of federal and state regulations and policy. Its default features consider only the costs of hospital and emergency department admissions. A more complete accounting of the chain of costs would include ambulatory and other care. In this article we use employer health insurance claims data to infer additional costs that accompany hospitalizations but are not included in BenMAP-CE. Including additional categories increases BenMAP-CE health care cost estimates by approximately 40 percent for respiratory and cardiovascular patients. That is, for each dollar of health care costs captured by BenMAP-CE, a more complete accounting would include an additional 40 cents. These results suggest that because such air pollution costs are underestimated, the health care benefits associated with reducing air pollution may be much larger than previously estimated.**

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S hort- and long-term air pollution exposure exacerbates and contributes to the development of numerous adverse health outcomes.[1–9] For example, air pollutants such as particulate matter and ground-level ozone can exacerbate preexisting conditions and also contribute to increased incidence of disease, particularly respiratory (such as chronic bronchitis and asthma) and cardiovascular conditions.[1] In turn, greater incidence of illness can increase mortality, health care use, and costs.[1,10]

The Environmental Benefits Mapping and Analysis Program–Community Edition (BenMAP-CE) is a tool historically used by the Environmental Protection Agency (EPA) to estimate the economic impact of a range of clinical outcomes due to air pollution, including the cost of a subset of impacts (hospital admissions and emergency department [ED] visits). Both morbidity and mortality outcomes are considered.[11–13] BenMAP-CE includes concentration-response parameters and unit economic values to quantify the air pollution–attributable cases of premature death. BenMAP-CE is preloaded with geographic-specific data on ground-level ozone and particulate matter. Users can also import data on the geographic values for other air pollutants.

BenMAP-CE is often used in the US to conduct various types of analyses in support of air quality regulations, such as the Regulatory Impact Analysis for Light-Duty Vehicle Greenhouse Gas Emission Standards[14] and the Regulatory Impact Analysis for the Final Mercury and Air Toxics Standards.[15] In addition to its extensive use by the EPA, BenMAP-CE is used widely by other agencies in analyses conducted both domestically and internationally.[16–19] In these analyses BenMAP-CE's default configuration, described here, is often used.

Mortality is an important health outcome measure of the burden of air pollution. From an economic outcome perspective, lives lost matter greatly to the future productivity and growth of the economy. BenMAP-CE uses the value of a statistical life approach to estimate mortality costs.[12] This approach measures the willingness of a group of people to pay to reduce the risk for premature death.[12] Although previous research has shown the large mortality burden associated with air pollution,[5,6,12] it is also important to quantify accurately the costs of health care associated with air pollution because they add to the financial burden of care paid by patients as well as by private and public insurers.

Based on air quality and population data, baseline rates of mortality and morbidity, concentration-response parameters, and unit economic values, BenMAP-CE quantifies the number and value of air pollution–attributable cases of premature death and disease (for example, hospital admissions for respiratory and cardiovascular conditions).[13] To estimate health care costs, BenMAP-CE multiplies the estimated number of hospitalizations and ED visits attributed to an air pollutant by unit cost estimates. It also uses the same hospitalization data in its calculation of work loss as it does for health care costs (that is, hospital length-of-stay).[12,20]

The default BenMAP-CE configuration estimates the costs of the health outcome examined (that is, the hospital admission or ED visit), but not other health care costs that could be incurred before or after entry into the hospital. Therefore, absent from BenMAP-CE's default calculations are the costs attributable to ambulatory care (including physician and clinic visits, prescription drugs, supplies, and home health care) that may also increase as a result of increased air pollution. The literature does not offer ways that meet BenMAP-CE standards to quantify the impact of air pollution on ambulatory visits. Nevertheless, a hospitalization (assuming patient survival) typically will necessitate additional follow-up outpatient visits regardless of the initiating event, whether or not it is related to air pollution.[21,22] Although patients with severe symptoms may be hospitalized on bad air pollution days, on such days patients with mild respiratory symptoms may just seek ambulatory care.[21–23]

The cost of such ambulatory care can be substantial. For instance, an analysis of the effect of asthma exacerbations using an employer claims database found that ambulatory care costs exceed hospital costs for patients with at least one asthma exacerbation.[24] Analysis of data from the Medical Expenditure Panel Survey found that hospitalization costs from asthma are a small fraction of total health care costs.[25] Simi-

larly, analyses of Kaiser Permanente data found that inpatient costs among patients with cardiovascular disease account for less than half of their total costs.[26] This literature suggests that by not accounting for the full chain of potential related ambulatory outcomes, BenMAP-CE computations may underestimate the morbidity costs of air pollution.

In a similar vein, although the BenMAP-CE configuration considers only hospitalizations with cardiovascular or respiratory disease coded as a primary diagnosis, recent research has found that air pollution is also associated with hospitalizations in addition to those considered in BenMAP-CE. This is because air pollution can cause harm beyond these acute conditions to affect chronic conditions, "potentially affecting every organ in the body. It can cause, complicate, or exacerbate many adverse health conditions."[27] Similarly, there is evidence air pollution is a carcinogen linked to lung cancer.[28,29] Another study found that many conditions that are neither respiratory nor cardiovascular related (for example, septicemia and anemia) are also exacerbated by air pollution.[30]

The objective of this article is to provide a more complete estimate of the health care costs associated with morbidity resulting from air pollution. Specifically, the analysis here makes no changes to the inner workings of BenMAP-CE. Rather, this study more completely estimates the economic impact of air pollution on morbidity outcomes. Specifically, it considers the increased costs of both ambulatory care and "other hospitalizations" (with a secondary diagnosis code of cardiovascular or respiratory disease or with diagnosis codes for any non-respiratory- or non-cardiovascular-related condition).

Study Data And Methods

To demonstrate the effect of including additional categories of health care resource use (that is, ambulatory care and other hospitalizations) on the monetary costs of air pollution, this analysis considers the two main disease categories for adults in the default BenMAP-CE configuration: all respiratory (ages 65–99) and all cardiovascular (ages 18–64 and 65–99) patients. To estimate costs of additional outcomes not included in BenMAP-CE, we compared the use of health care resources and costs of patients in a year in which they had a respiratory or cardiovascular hospitalization (2016) with those in the preceding year (2015), during which the same patients did not have any such hospitalizations. The ratio of the cost of care components (for example, ambulatory care) not included in BenMAP-CE to the cost of hospital care that was included

in BenMAP-CE is an estimate of the extent of the additional costs relative to included costs. The cost per event of air pollution and non–air pollution health care are assumed to be the same.

DATA SOURCE We analyzed data from the OptumHealth Reporting and Insights Administrative Claims Database, which contains administrative claims for approximately twenty million privately insured people covered by eighty-four large US employers from 1999 through the first quarter of 2017. This is an opportunistic database of participating employers. Although not representative of the US population, it and other commercial claims databases have been used extensively in health outcomes analyses.[31,32] As described here (see Study Results), hospital lengths-of-stay and unit cost data measures in the employer database are similar to those used in BenMAP-CE analyses. The study database contains complete medical and pharmaceutical claims, along with enrollment information, for beneficiaries younger than age sixty-five as well as those ages sixty-five and older who have employer-paid Medicare supplemental insurance. The study database is deidentified and is fully compliant with the requirements of the Health Insurance Portability and Accountability Act.

STUDY POPULATION Patients with at least one 2016 inpatient stay or ED claim with a primary diagnosis of a respiratory or cardiovascular condition considered by BenMAP-CE (as defined by *International Classification of Diseases,* Ninth Revision, or *Statistical Classification of Diseases and Related Health Problems*, Tenth Revision, diagnosis codes, henceforth termed BenMAP-CE-specified conditions) were identified in the study database. Inclusion criteria specified that patients in the respiratory and cardiovascular cohorts must not have had a hospitalization for these conditions in 2015 (the baseline period). All patients were also required to have continuous non–health maintenance organization insurance coverage during the full calendar years of 2015 through 2016, to ensure the completeness of the cost information. Online appendix exhibit A1 illustrates the selection of patients in the analytic sample.[33] The final sample of patients having a hospitalization for these conditions in 2016 but not 2015 included 11,694 patients in the respiratory cohort, 19,191 patients in the cardiovascular cohort ages 18–64, and 14,354 patients in the cardiovascular cohort ages 65 and older.

ANALYSIS The analysis first considered the comparability of the mean length of hospital stay and mean unit cost of hospitalization between BenMAP-CE results and those using the study database. Then the analysis measured increases in care (and costs) that occurred when patients went from having no hospitalizations in 2015 for respiratory or cardiovascular care to having such a hospitalization in 2016. This methodology allows patients to serve as their own controls to determine the impact of a hospitalization on ambulatory care costs.

To compute the costs of health care included by BenMAP-CE, we summed annual costs (that is, total charges of providers, following BenMAP-CE's approach) for hospitalizations in 2016 that had a primary diagnosis of cardiovascular or respiratory disease for each cohort. All costs during these hospitalizations were attributed to the given condition. This definition is consistent with BenMAP-CE's methodology and represents those costs included in BenMAP-CE analyses.

Total annual costs were then summed for 2015 and 2016 for each cohort. These costs included all-cause ambulatory care (outpatient visits, home health care, other care, and prescription medications for any reason). The study also included other hospitalizations with cardiovascular or respiratory disease coded as a secondary diagnosis, as well as any non-respiratory- or non-cardiovascular-related conditions. These other hospitalizations are important to consider because air pollution can exacerbate many non-respiratory- or non-cardiovascular-related conditions, as mentioned above. The difference in costs between 2016 and 2015 represents the added costs that patients had in a year in which they had a hospitalization with a primary diagnosis for a cardiovascular or respiratory condition relative to a year in which they did not. These incremental (additional) costs are not included in the default BenMAP-CE configuration.

For each of the three cohorts, the ratio of incremental costs relative to health care costs included by BenMAP-CE was calculated. For patients with cardiovascular disease, a single weighted cost ratio was also calculated using the two cardiovascular cohort sizes as weights.

WORK-LOSS AND UTILIZATION ANALYSES Work-loss costs were calculated by cohort, following the EPA's methodology of estimating work-loss days using BenMAP-CE, as the product of median daily wage and mean length of hospitalization stay as reported in BenMAP-CE. The analysis estimated the total number of added work-loss days in 2016 that were due to incremental ambulatory care and other hospitalizations. As in work-loss analyses elsewhere, each day of incremental hospitalization accounted for one day of work loss.[31,32] Each ambulatory visit accounted for one day of work loss per visit. Additional work-loss costs were estimated as the number of added days of hospital/ambulatory use multiplied by the BenMAP-CE reported median daily wage. Similar to the health care

cost analysis, the ratio of incremental work-loss costs relative to BenMAP-CE-included costs were calculated for each cohort.

In addition to cost measures, health care use constitutes a substantial patient outcome that imposes a large emotional and time burden on patients. Therefore, results are reported on the number of visits and days for which patients received health care that are not included in BenMAP-CE.

LIMITATIONS A limitation of this research is the absence of measures of health care costs associated with actual, local changes in particulate matter. It would be useful to extend the research of Yaguang Wei and colleagues regarding the roles of geography, patient demographics, treatment patterns, and timing of air pollution events on the use and cost of both hospital and ambulatory care.[30] Wei and colleagues' research found that air pollution leads to cost increases in inpatient and postacute care costs and mortality;[30] similar findings are reported by Tatyana Deryugina and colleagues.[8] Other temporal factors such as recent increases in air pollution associated with changes in climate and outbreaks of new diseases (for example, coronavirus disease 2019 [COVID-19])[34] also should be considered. Because this study is based on administrative claims data for a commercially insured population, results might not be generalizable to other groups (for example, Medicare and Medicaid patients). Work-loss costs are another area where the chain of costs could be broadened from that in BenMAP-CE; for example, days missed from work while recuperating from a hospitalization were not accounted for in the tool.

Study Results

Because the analysis here relies on an employer-sponsored claims database, not the Healthcare Cost and Utilization Project (hospital discharge abstract database) used in BenMAP-CE,[35] hospital lengths-of-stay and unit cost data for the research sample were compared with BenMAP-CE estimates. Appendix exhibit A2 shows that measures in the employer database are similar to those used in BenMAP-CE analyses.[33] For example, average lengths-of-stay for cardiovascular patients younger than age sixty-five were 4.12 days in BenMAP-CE[12] and 3.97 days in the study data (appendix exhibit A2).[33] Average hospital costs were $45,659[12] and $43,337 (in 2015 dollars), respectively.

COST OF ADDITIONAL CARE The extent and cost of additional ambulatory care use was substantial. Among patients with no hospitalization in 2015 and a respiratory hospitalization in 2016, the average number of ambulatory care visits increased from 20.7 visits in 2015 to 26.0 visits in 2016 (exhibit 1). That is, for respiratory patients there was an increase of 25.6 percent in the average number of ambulatory care visits associated with a hospitalization. An even larger increase in the average number of ambulatory care visits occurred for cardiovascular patients (44.0 percent for patients younger than age sixty-five and 33.0 percent for patients ages sixty-five and older). Likewise, other hospitalizations not included in the BenMAP-CE calculation also increased substantially (76.0 percent for respiratory patients, 64.3 percent for cardiovascular patients younger than age sixty-five, and 118.8 percent for cardiovascular patients ages sixty-five and older).

For respiratory patients, the annual per patient costs (in 2016 dollars) of BenMAP-CE-included care averaged $52,336; the total cost of the additional services was $22,621 (exhibit 2). The calculation implies that including the costs of additional services would increase the health care costs measured by BenMAP-CE by 43.2 percent for respiratory patients. Similar

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EXHIBIT 1

Annual and incremental health care resource use: respiratory and cardiovascular patients in the US with no condition-specific hospitalizations in 2015 and with at least one condition-specific hospitalization in 2016

	All-cause health care resource use per patient-year								
	Respiratory patients ages 65+ (*n* = 11,694)			Cardiovascular patients ages <65 (*n* = 19,191)			Cardiovascular patients ages 65+ (*n* = 14,354)		
	2015	**2016**	**Incremental**	**2015**	**2016**	**Incremental**	**2015**	**2016**	**Incremental**
Ambulatory visits[a]	20.7	26.0	5.3	13.4	19.3	5.9	20.6	27.4	6.8
Other hospitalization days[b]	2.5	4.4	1.9	1.4	2.3	0.9	1.6	3.5	1.9

SOURCE Authors' analysis of data from the OptumHealth Reporting and Insights Administrative Claims Database. **NOTES** To be included, all patients were required to have continuous health plan eligibility during the entirety of 2015 and 2016. [a]Includes all-cause medical encounters not in an inpatient or emergency department setting (for example, outpatient, home health agency). [b]Includes medical encounters in an inpatient or emergency department setting without a primary diagnosis code for the given condition.

Annual and incremental health care costs: respiratory and cardiovascular patients in the US with no condition-specific hospitalizations in 2015 and with at least one condition-specific hospitalization in 2016

	Health care costs per patient-year (2016 US $)								
	Respiratory patients ages 65+			Cardiovascular patients ages <65			Cardiovascular patients ages 65+		
	2015	2016	Incremental	2015	2016	Incremental	2015	2016	Incremental
[A1] Condition hospitalization (primary)	0	52,336	52,336	0	55,170	55,170	0	61,282	61,282
[A2] Condition hospitalization (secondary)[a]	1,282	2,785	1,503	2,015	4,015	2,000	2,539	5,461	2,922
[A3] Other hospitalization	10,690	17,927	7,238	6,616	11,532	4,916	4,680	8,756	4,077
[B] All-cause ambulatory[b]	27,323	41,203	13,880	24,836	40,912	16,075	24,190	38,728	14,538
Total	39,295	114,251	74,957	33,467	111,629	78,161	31,408	114,226	82,819

source Authors' analysis of data from the OptumHealth Reporting and Insights Administrative Claims Database. **notes** Sample sizes are in exhibit 1. Hospitalizations for a given condition were defined as an inpatient or emergency department visit with a primary diagnosis code for the given condition. All costs during these hospitalizations were attributed to the given condition. To be included, all patients were required to have continuous health plan eligibility during the entirety of 2015 and 2016. The percentage of additional costs in the Environmental Benefits Mapping and Analysis Program–Community Edition (BenMAP-CE) relative to costs included for respiratory patients was 43.2 percent; for cardiovascular patients younger than age 65, 41.7 percent; and for cardiovascular patients ages 65 and older, 35.1 percent. This was calculated by dividing the sum of A2, A3, and B by A1 from the "Incremental" column. For example, for respiratory patients ages sixty-five and older, ($1,503 + $7,238 + $13,880)/$52,336 = 43.2%. [a]Hospitalizations with a diagnosis code for the given condition in the secondary position. [b]Ambulatory costs include all medical costs not in an inpatient or emergency department setting (for example, outpatient, home health agency), as well as costs of all prescription medications.

calculations for cardiovascular patients found that including the additional services would increase the cost of health care by 41.7 percent for patients younger than age sixty-five and 35.1 percent for patients ages sixty-five and older relative to what BenMAP-CE includes.

work loss A similar analysis conducted for work loss, shown in appendix exhibit A3,[33] found that costs not included in BenMAP-CE were 85 percent of included costs for the BenMAP-CE categories for respiratory patients, 138 percent for cardiovascular patients younger than age sixty-five, and 119 percent for cardiovascular patients ages sixty-five and older. Although the added work-loss costs were proportionally much larger than for additional health care costs, on a dollar basis the added work-loss costs were much smaller.

With these additional health care and work-loss costs combined into a total cost measure, shown in appendix exhibit A4,[33] the additional total costs would exceed included BenMAP-CE costs by more than 40 percent (44.4 percent for respiratory patients, 43.1 percent for cardiovascular patients younger than age sixty-five, and 36.8 percent cardiovascular patients ages sixty-five and older. Exhibit 3 shows these differences in dollar terms.

sensitivity analyses Several sensitivity analyses were conducted. One sensitivity analysis, shown in appendix exhibit A5,[33] considered the impact of excluding hospitalizations with a secondary diagnosis of cardiovascular or respiratory disease from the analysis. After the exclusion of such hospitalizations, BenMAP-CE health

Incremental per patient annual health care and work-loss costs in the US, by condition
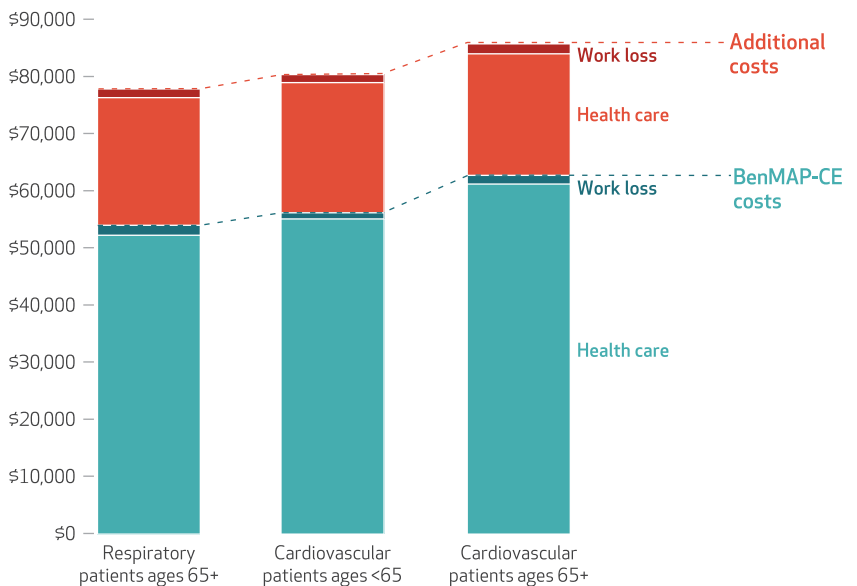
sources Environmental Protection Agency. BenMAP-CE user's manual (see note 12 in text); authors' analysis of data from the OptumHealth Reporting and Insights Administrative Claims Database. **notes** Annual costs include both Environmental Benefits Mapping and Analysis Program–Community Edition (BenMAP-CE) included costs and additional costs, accounting for both health care and work-loss costs. BenMAP-CE health care and work loss includes inpatient or emergency department visits with a primary diagnosis code for the given condition, as well as associated work loss. Additional health care and work loss includes incremental hospitalization visits without a primary diagnosis code for the given condition and other all-cause ambulatory care (for example, outpatient, home health agency), as well as associated work loss and incremental costs of all prescription medications. Calculations are in exhibit 2 and appendix exhibit A3 (see note 33 in text).

care costs still would increase by approximately 36 percent (that is, 36 cents added for every dollar included in BenMAP-CE estimates). Similarly, this study included other hospitalizations (nonrespiratory and noncardiovascular) that were not directly attributable to cardiovascular or respiratory disease; after the removal of such hospitalizations, BenMAP-CE health care costs would increase by up to 31 percent.

Because not every ambulatory visit is associated with a full day missed from work as computed earlier, a sensitivity analysis also was conducted counting the visit as a half-day (rather than a full-day) loss. This calculation still yields additional work-loss costs of 54 percent of BenMAP-CE costs for respiratory patients, 78 percent for cardiovascular patients younger than age sixty-five, and 72 percent for cardiovascular patients ages sixty-five and older (appendix exhibit A6).[33] Because work-loss cost as measured here is small relative to health care costs, the change in additional total (work-loss plus health care) costs is approximately 1 percentage point, as computed from appendix exhibit A7.[33]

Discussion

For each dollar of health care costs captured by the BenMAP-CE tool that the EPA has used to calculate the outcomes of air pollution, a more complete accounting described here would include approximately 40 additional cents. These results suggest that because air pollution costs are underestimated, the health care benefits associated with reducing air pollution may be substantially larger than previously estimated.

These results also suggest that policy analyses using the BenMAP-CE model may substantially underestimate the health care benefits of reductions in air pollution. For instance, in the Regulatory Impact Analysis for the Final Mercury and Air Toxics Standards, the EPA used BenMAP-CE to estimate the annual benefits associated with the reductions in respiratory and cardiovascular hospitalizations due to the Final Mercury and Air Toxics Standards and found these benefits to be

$10 million for respiratory and $30 million for cardiovascular (in 2007 dollars).[15] Results estimated here suggest that these benefits would be approximately 40 percent higher after ambulatory and other care was considered. Another EPA study of the Clean Air Act[36] found that a more complete accounting of health care costs would lead to greater reductions in the annual costs of respiratory and cardiovascular hospitalizations by up to $488 million for respiratory and $809 million for cardiovascular hospitalizations (in 2006 dollars). Similarly, BenMAP-CE-based analyses conducted both domestically and internationally have not considered the potential full chain of costs.[16–19]

Beyond economic considerations, avoided air pollution–related physician visits and hospitalizations are desirable patient outcomes. In addition to the health care costs of ambulatory care, there is a burden to the patient and family members (in time, emotional stress, and so on) from additional visits. For example, every patient hospitalized for respiratory care, as noted earlier, also averages five additional ambulatory care visits not included in the BenMAP-CE tool. Extrapolating this analysis suggests that consideration of the full chain of outcomes in the Regulatory Impact Analysis for the Final Mercury and Air Toxics Standards could result in 3,142 avoided respiratory and 8,491 avoided cardiovascular ambulatory care visits.

Conclusion

Although the estimates reported here can be refined, this research finds that the health care cost benefits associated with reducing air pollution may be much larger than previously estimated. Further improvements in methods and data will yield more complete measures of the economic impacts and patient outcomes of air pollution at both the patient and payer levels. In today's environment, where current health care costs are a focus of much debate and individual concern, further research on the full range of air pollution–induced health care costs is warranted. ∎

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