The value of medical care in the United States: changes in lifetime spending and health-adjusted life-expectancy, 1996 to 2016

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Abstract

Introduction. We build on Cutler and colleagues research on the value of medical spending for the elderly using a period life-expectancy framework. We use the framework to track health-adjusted life-expectancy (HALE) and lifetime spending over years of the opioid epidemic, and show the value of improvements in medical care technology and practice for all ages.

Methods. We use population-level results on mortality and years lived with disability from the 2019 Global Burden of Disease, Injuries, and Risk Factor Study, and spending from the 2016 Disease Expenditure study to estimate 1996 HALE and lifetime spending by cause and age group. For 130 causes, we simulate improvements by replacing cause-specific outcomes per case and spending per case from 1996 with those measures for 2016. The effect is the difference between the 1996 estimate and simulation. Spending is reported in 2016 US dollars ($).

Findings. Effects across causes are heterogeneous; 79 of 130 causes have an increase in mean HALE and lifetime spending calculated at birth. For ischemic heart disease, HALE increases by 0.250 years and lifetime spending by $15,816 or $63,184 per HALE gained. Increases in HALE often occur at older ages than lifetime spending. For ischemic heart disease, one percent of the increase in HALE is for ages 0 to 64 years, compared to 20 percent in lifetime spending. The all-cause aggregate is substantially affected by drug use disorders, which reduce HALE gained from 1.62 to 1.29 years, and increase lifetime spending per HALE gained from $144,689 to $183,865.

Interpretation. Comprehensive measures show the value of medical care by cause.

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Introduction

Economists have a long-standing interest in developing methods to track the value of medical care by cause in the population,[1,2] where value is assessed by comparing medical care spending to health outcomes. The value of medical care in the US as a whole appears low, because of higher spending per capita and lower life expectancy, among other outcomes, relative to other high income countries.[3,4] However, disentangling population health from the value of medical care is challenging. Recent research that separates population health from the value of medical care finds that the value for specific causes, is heterogenous. Satellite health accounts for ages 65 or older,[5] and spending effectiveness for all ages[6] shows that spending on causes such as breast cancer, colon and rectum cancer, lung cancer, ischemic heart disease, and stroke yield good value, whereas spending on osteoarthritis and musculoskeletal disorders does not yield commensurate improvements in health outcomes. These measures are being developed to provide insights into the performance of the health sector, enable the formulation of better informed policies, and enhance the value of medical care.

In this article, we combine the period life-expectancy framework of the satellite health account research[5] with data sources on spending effectiveness.[6] Cutler et al (2006) used cause-replacement to estimate the effects of changes in cause-specific mortality on life expectancy, and changes in cause-specific spending on lifetime spending, thereby approximating the changes in health attributable to medical care.[7] In seminal work, Cutler et al (2022) account for the prevalence of health conditions in the population, allowing them to isolate the productivity of medical care from external factors affecting population health. Importantly, they also adjust life-expectancy for morbidity, a measure of average health-related quality of life of survivors at each age, in order to estimate changes in quality-adjusted life expectancy for the elderly and 80 conditions from 1999 to 2012.[5] Weaver et al (2022) also account for the prevalence or incidence of diseases and injuries in the population, and use the 2017 Global Burden of Diseases, Injuries and Risk Factor Study (GBD)[8] and 2016 Disease Expenditure Study (DEX)[9] results to estimate spending effectiveness for all 19 age groups and 139 causes from 1996 to 2016.[6] GBD results can be readily analyzed in a period life-expectancy framework that adjusts for morbidity, as demonstrated by health-adjusted life expectancy (HALE) estimates.[8,10,11]

Our objective is to estimate the value of medical care for the US by cause and age group using a period life-expectancy framework. For some medical care, spending occurs well before quality improvements, and lifetime measures account for this lag.[12] We use cause replacement to calculate the changes in HALE and lifetime spending between 1996 and 2016 that are attributable to medical care as measured by the change in spending per case and outcomes per case, respectively. We examine three sets of results: 1) the value of medical care measured as the ratio of change in lifetime spending to change in HALE calculated at birth for 130 causes, 2) HALE and lifetime spending effects calculated at each age group for selected causes, and 3) all-cause aggregate results that show the differences across age groups, and effect of the opioid epidemic.

Methods

Metrics

We use the period life-expectancy framework to simulate what HALE and lifetime spending in a base year cohort (1996) would be with the health technology from a comparison year (2016). In reporting an initial index of healthy life years, Sullivan (1971) explained, "They are the values which would occur if a birth cohort of a fixed size experienced age for age throughout life, the recent age-specific mortality and disability rates used in these life table calculations."[13] Just as period life-expectancy is an index of age-specific mortality rates, HALE is an index that combines age-specific mortality and disability rates, and lifetime spending is an index of age-specific spending rates. Life expectancy, e_x, is defined for a specific age *x* as the mean person-years lived above age *x* and calculated as the ratio of total person-years lived above age *x* to the number of people surviving to age *x.*

$HALE_x$ is defined for a specific age x as the mean health-adjusted person-years lived above age x.[14] Health adjusted person-years in the interval *x* to *x+n* are the product of person-years lived and the average health value in that interval, which is one minus years lived with disability (YLDs) per capita in the interval x to x+n.

Lifetime spending, $S_{x,}$, is an index of age-specific spending rates defined for a specific age x as the mean medical care spending for ages greater than age x. Similar to the health-adjusted person years lived, medical care spending for the interval *x* to *x+n* is the product of person-years lived and medical care spending per capita in the interval *x* to *x+n*.

Cause-replacement

We use cause-replacement to simulate the effects of changes in medical care technologies and practice for a specific cause. First, we hold the health of the population constant by holding cases constant at the number of cases in the base year. A rate such as deaths per population can be stated as the product of cases per population and deaths per case. We assume that cases per population control for population health, and outcomes per case and spending per case measure the effects of medical care technology and practice. The simulated new outcome (or spending) are the product of cases per population in the base year, and outcomes per case (or spending) per case in the comparison year. Equations for these calculations are in appendix pages 2-4. Therefore, our estimates are unaffected by changes in the number of cases over time and affected only by the change in outcomes per case and spending per case.

The effect of changes in medical care for cause k on HALE is the difference between the cause-replaced and base year HALE. A positive difference indicates that cause-specific changes in health technology and practice improve health. Given the causes are mutually exclusive, the sum of all the cause-specific effects on HALE are the total effects that are attributable to medical care. Similarly, the effect of changes in medical care for cause k on lifetime spending is the difference between the cause-replaced and base year life-time spending.

Similar to Cutler et al (2022),[5] we make two modifications to the period-life expectancy framework. First, we report the calculations with the mean of the number of cases in the base year and comparison year for each cause and age group. An explanation of both Cutler et al (2022)'s approach to this calculation and ours, and the proof that results of the two approaches are identical is in Appendix page 6.

Second, the age structure changes for the HALE calculation but not for lifetime spending. We use cause-replaced mortality rates in the HALE calculations, and the age structure of the population shifts with changes in mortality rates. For example, a lower infant mortality rate in the comparison year will lead to more children in older age groups relative to the base year. We use base year mortality rates in the lifetime spending calculations, and the age structure doesn't shift. This means that we do not account for increases in spending due to a change in the age structure, and consequently do not attribute that increase to medical care.

Data

We use GBD 2019 results on deaths, years lived with disability (YLDs), and cases by cause and age group for both sexes in 1996 and 2016. YLDs are calculated with the product of prevalence and disability weights for sequelae of diseases and injuries. For cases, we use incidence for communicable, maternal, neonatal, and nutritional diseases, neoplasms, and injuries, and prevalence for most non-communicable diseases other than neoplasms. We use results for 16 five-year age categories, two narrower categories for children 0-11 months, and 1-4 years, and one broader category for adults ages 85 or more. GBD deaths exceed cases for a few age groups and causes with a delay between diagnosis and death such as neoplasms. For details on these atypical age groups and causes, see appendix, pages 7-8.

We use DEX 2016 results on personal health care spending by condition for both sexes for the same age groups and years.[9] The term "condition" refers to spending on well-care, risk factors, and impairments, as well as causes of disease and injury. DEX results are based on 13 data sources, and the National Health Expenditure Accounts to reconcile total spending from multiple sources with them.[15] The GBD and DEX results were developed with the same disease classifications and age groups, which support comparing health outcomes to spending. Eleven DEX causes are less detailed GBD 2019 causes however, so we aggregate cases, mortality and YLDs for these GBD causes to match the DEX causes. See detailed methods and list in appendix, pages 8-9. All spending is converted to 2016 US dollars (US$) using the gross domestic product price index.[16]

Several adjustments are necessary to jointly analyze GBD and DEX results. Both GBD and DEX exclude age groups where cases are infrequent, such as ischemic heart disease among children 0-11 months. We exclude age groups when results are available from GBD but not DEX, and vice versa (appendix pages 9-10). DEX reports health spending on conditions that are outside of the GDB cause hierarchy. Spending on eight of them is allocated to DEX causes in proportion to their share of the GBD 2017 burden for those causes: four risk factors, three impairments, and well-dental care (appendix pages 10-11).[8,17]

Uncertainty

The GBD 2019 and DEX 2016 data incorporate uncertainty with distributions of 1,000 draws from the posterior distributions for each cause, age group and year, where each draw was a different realization of a mean. The changes in outcomes and lifetime spending attributable to health care are reported as the mean of the draws and the 95% uncertainty interval (UI). The ratio of lifetime spending effects to HALE effects is the ratio of those means.

Software

The datafile for the analysis was created in Python version 3.0 (Python Software Foundation, available at http://www.python.org). The analysis was performed using both Python version 3.0 and the open-source software R version 4.0.5 (Comprehensive R Archive Network, available at https://cran.r-project.org/bin/windows/base/).

Ethical approval

This analysis of secondary data did not require ethical approval.

Role of the funding source

Individuals at the United States Bureau of Economic Analysis contributed to the study design, data analysis, data interpretation, and manuscript development. All authors had full access to the data and had responsibility for final submission of the manuscript.

Results

To describe the sample, we report rates per 100,000 people per year that control for population size across years. The all-cause mortality rate increased from 846 deaths in 1996 to 849 deaths in 2016 (less than 1 %), YLDs increased from 13,676 to 15,445 (13%), and spending from $424 million to $788 million (85%). Descriptive statistics for each cause are in appendix pages 12-21.

For the cause-replacement calculations, the combined changes in HALE and lifetime spending calculated at birth could be in one of four quadrants (Table 1). Seventy-nine of 131 causes (60%) are in the northeast quadrant with an increase in both mean HALE and mean lifetime spending between 1996 and 2016, such as HIV/AIDs, ischemic heart disease, and diabetes. Improvements in medical care for ischemic heart disease increased HALE by 0.250 years and lifetime spending by $15,816. Nineteen causes (14%) are in the southeast quadrant with an increase in HALE and decrease in lifetime spending, such as breast cancer, and cardiomyopathy and myocarditis. Improvements in medical care for breast cancer increased HALE by 0.025 years and decreased lifetime spending by $669. Seven causes (5%) are in the southwest quadrant with decreases in both HALE and lifetime spending, such as alcohol use disorders with a 0.014 year decrease in HALE and $180 decrease in lifetime spending. Twenty-six causes (20%) are in the northwest quadrant with a decrease in HALE and increase in lifetime spending such as chronic kidney disease and drug use disorders.

The all-cause ratio of mean lifetime spending effect to mean hale effect is $182,201 (Table 1). Ratios are calculated for the 79 causes in the northeast quadrant with increases in HALE and lifetime spending.[18] The mean ratio for 46 (58%) causes is below the all-cause mean, of which 45 are fatal causes with a decrease in mortality rates between 1996 and 2016. The mean ratio is below $50,000 per HALE gained for 23 causes such as HIV/AIDS, 10 neoplasms, rheumatic heart disease, stroke, diabetes mellitus, and self-harm. The mean ratio is between $50,000 and $100,000 for 12 causes, such as ischemic heart disease, road injuries, and interpersonal violence. The mean ratio for 33 (42%) causes is above the all-cause mean, of which 11 are non-fatal such as anxiety disorders, osteoarthritis, and attention deficit/hyperactivity disorder.

The effects of changes in HALE and lifetime spending can be calculated for each age group. For example, the effect of improvements in medical care for ischemic heart disease on HALE at age 65 is about the same as at age 40, meaning that changes in mortality per case and YLDs per case between ages 40 and 65 are small (figure 2a). In contrast, the effect for lifetime spending at age 65 is lower than at 40 (figure 2b), meaning that spending per case increased between ages 40 and 65. The HALE effect of diabetes at age 65 is slightly lower than at 35, but the difference in the lifetime spending effect for this age range is proportionately much larger. The HALE effect of HIV/AIDS increases steeply between the ages of 60 and 25, reflecting large decreases in mortality per case, while the lifetime spending effect increases gradually for this age range. The HALE effects of drug use disorders are the opposite, reflecting large increases in mortality per case between the ages of 65 and 15.

In Figure 3, we focus on 39 causes that have the 25 largest increases in HALE calculated at age zero or 25 largest increases in lifetime spending calculated at age zero or both. We compare the effects calculated at age 65, with the effects for ages zero to 64; the latter are the effects calculated at age zero net of the effects calculated at age 65. For ischemic heart disease, 1% of the increase in HALE is for ages 0 to 64, compared to 20% of the increase in lifetime spending. For diabetes, 17% of the increase in HALE is for ages 0 to 64 compared to 90% of the increase in lifetime spending. For 25 causes, the share of the increase in HALE for ages 0 to 64 is smaller than the share of lifetime spending. HALE decreased for ages 0 to 64 for six of those 25 causes such as atrial fibrillation and flutter, chronic obstructive pulmonary disease, and low back and neck pain. For stroke and other cardiovascular and circulatory diseases, lifetime spending decreased for ages 65 or more years.

Spending per HALE gained for the all-cause aggregate is highest when calculated at birth and falls when calculated at older ages (Table 2). For example, lifetime spending increased by $92,085 per HALE gained when calculated at age 65, compared to $182,201 when calculated at birth. The mean HALE effect is 25% smaller at age 65 compared to birth, whereas the mean lifetime spending effect is 62% smaller at age 65 compared to birth.

The all-cause results in Table 2 are calculated as the sum across HALE effects and lifetime spending effects for each cause; it combines causes with results in all four quadrants. Note that the mean HALE effect is higher at age 30 when compared to age 15, whereas it is generally lower at older ages. This anomaly disappears when we remove drug use disorders from the calculation (not shown). There is a large decrease in HALE between the ages of 15 and 29 due to this cause without a commensurate increase from other causes. When we remove drug use disorders from calculation (column 4 of Table 2), the mean lifetime spending increases by $144,689 per HALE gained.

Discussion

In our estimates of changes in lifetime spending and HALE from 1996 to 2016, we find heterogeneity across causes in the directions of change, as well as the magnitude of those changes. When calculated at birth, some causes have lower lifetime spending and higher HALE in 2016 than in 1996 such as breast cancer, or a relatively low increase in lifetime spending per gain in HALE such as ischemic heart disease. Other causes would benefit from innovations that reduce spending or improve outcomes. To our knowledge, this is the first research to compare lifetime spending and HALE effects across causes and age groups.

An original contribution of this research is that HALE effects do not occur at the same ages as lifetime spending effects. When we compare changes calculated at each age group, increases in HALE occurred at older ages than increases in lifetime spending for the majority of causes with the largest increases in lifetime spending and/or HALE. Our finding could reflect that some medical care spending at younger ages is an investment that increases HALE at older ages. If this interpretation is correct, any calculations at age 65 that do not account for these investments, including Cutler et al (2022)'s aggregate estimate of $37,308 (adjusted to 2016 dollars) per quality-adjusted life-year gained,[5] and our estimate of $92,085 per HALE gained would be underestimates. Alternatively, the decrease in spending per HALE gained with age could reflect that medical care spending is more efficient for the elderly or lower prices for Medicare.[19] Further research is necessary to distinguish among these explanations. Calculations our calculations at birth or the spending effectiveness estimates for all ages[6] account for the lag between spending and health outcomes.

Our findings lend support to examining healthcare spending by cause, where each cause is analyzed as a separate industry that combines prevention, diagnosis, and treatment.[5] A striking finding is that drug use disorders increase all-cause life-time spending per HALE gained from $144,689 to $182,201. While numerous studies have examined the effects of the growth in opioid use, this is the first study to examine the implications for the value of medical care. These results suggest that concern about aggregate spending would be better directed to causes with large decreases in HALE such as drug use disorder or large increases in lifetime spending and relatively small increases in HALE such as osteoarthritis, and attention-deficit/hyperactivity disorder. More generally, this approach leads to improved measurement at the national level, providing unique insights about the real output and productivity of the health care sector.

Although we build on Cutler et al's period life-expectancy framework,[5] our data sources, methods, and results calculated at age 65 differ substantially from theirs. (See appendix 21-23 for a summary of the differences). A key similarity is that both research groups assume that medical care affects outcomes and spending per case, but not the number of cases. Two key differences are: 1) disease classifications, and 2) adjustment for risk factors. Our research uses the GBD cause hierarchy[8,11] whereas Cutler et al use the 80 conditions reported in Raghunathan et al.[12] We allocate spending from four risk factors (hypertension, hyperlipidemia, obesity, and tobacco use) to GBD causes in proportion to their share of the GBD 2017 burden.[8,17] In contrast, Cutler et al. (2022) adjust estimates for risk factors by allocating spending, prevalence, and health outcomes from seven conditions (cardiovascular disease, renal, dementia, accidents, frailty, infectious diseases, and cancer) to nine clinical risk factors.

Even though our data sources are similar, our methods and results also differ from Weaver et al (2022)'s[5] spending effectiveness research. Spending per HALE gained is 62% higher than spending per DALY averted over the same time period. We use GBD 2019 results, whereas Weaver et al (2022) used GBD 2017 results; the DEX results are the same. The change in life-expectancy from all causes between 1996 and 2016 is 2.46 years in GBD 2019 and 2.30 years in GBD 2016, which would make spending per HALE lower than spending per DALY. Concerning the methods, the size of the populations who benefit from improvements in medical care is smaller in the simulated population than in the actual population. In the period life-expectancy framework, the index is a summary of rates for all ages; the size of the simulated population decreases monotonically with the mortality rates in each age group. In contrast, the spending effectiveness research uses the actual population in each year and age group, and reflects for changes in birth rates over time. People born during the baby boom from 1946 to 1964 were ages 32 to 50 years in 1996 and ages 52 to 70 years in 2016, which are ages with large HALE effects. The spending effectiveness framework accounts for these improvements.

A limitation of this research is that we do not control for the changing effects of clinical risk factors, which we plan to address in the future. It would be possible to allocate a share of cases, health outcomes and spending of GBD causes to the four risk factors listed above, and potentially to the others in the GBD risk factor hierarchy. Another limitation is that the sequela distributions for estimating YLDs did not vary by location and year for many causes,[6] which may underestimate changes in the average health values, and consequently HALE effects, especially for non-fatal causes. Research on sequela distributions by location and year may be conducted in the future.[20] Finally, cases per population may not completely control for population health. Experiments with instrumental variables, such as the burden of breast cancer, may be incorporated in future research.

Conclusion

Medical spending accounted for 17 percent of gross domestic product in 2023,[21] but understanding the value of this spending is challenging as technologies and practices change. Building on prior work, we confirm that there is substantial heterogeneity in the value of spending across causes using a period life-expectancy framework. We also show potentially large dynamic effects across ages, demonstrating the advantages of analyzing the effects at the population-level and across age groups. Importantly, the findings suggest that healthcare investments made at younger ages can yield health benefits later in life. Furthermore, we measure large economic effects of drug use disorders that substantially decrease HALE for the working ages 15 to 65 and increase lifetime spending per HALE gained between 1996 and 2016.

Contributors

All authors read and approved the final version of the manuscript, had full access to all the data, and are responsible for the decision to submit for publication. CA, ED, and MRW directly accessed and verified the underlying data reported in the manuscript. Additional contributions of each author will be outlined based on author forms.

Data sharing

To download the data used in these analyses after publication, please visit the Global Health Data Exchange website at xx. Data from GBD 2019 are available at https://ghdx.healthdata.org/gbd-2019 and from DEX 2016 are available at xx.

Declarations of 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.

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Disclaimer

The views expressed in this manuscript are those of the authors. They do not necessarily represent those of the Bureau of Economic Analysis.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors did not use generative AI and AI assisted technologies in the writing process.

Figure and table legends

Table 1. Effects of changes in medical care on health-adjusted life-expectancy (HALE) and lifetime spending calculated at birth from 1996 to 2016, and value measured as the ratio of lifetime spending per HALE gained by cause

Legend: HALE=health-adjusted life-expectancy, HIV/AIDS=human immunodeficiency virus/acquired immunodeficiency syndrome. Underlined causes represent GBD 2019 level 2 aggregate causes. *The ratio is not calculated for results in the southeast, southwest, or northwest quadrants. The northeast quadrant means an increase in both mean HALE and mean lifetime spending between 1996 and 2016.

The southeast quadrant means an increase in HALE and decrease in lifetime spending. The southwest quadrant means decreases in both HALE and lifetime spending. The northwest quadrant means a decrease in HALE and increase in lifetime spending.

Table 2. All-cause aggregate effects of changes in medical care on health-adjusted life-expectancy (HALE) and lifetime spending from 1996 to 2016, and value measured as the ratio of lifetime spending per HALE gained calculated at selected ages, and with drug use disorders removed.

Figure 1. The effects of changes in medical care on health-adjusted life-expectancy (HALE) and lifetime spending from 1996 to 2016 calculated for 19 age groups and eight causes

Legend: HALE=health-adjusted life-expectancy, HIV/AIDS=human immunodeficiency virus/acquired immunodeficiency syndrome.

Figure 2. Share of the effects of changes in medical care on health-adjusted life-expectancy (HALE) and lifetime spending for ages 0 to 64, and 65 or more years for 39 selected causes

Legend: The 39 causes have the 25 largest increases in HALE calculated a birth or 25 largest increases in lifetime spending calculated at birth or both. HALE=health-adjusted life-expectancy, HIV/AIDS=human immunodeficiency virus/acquired immunodeficiency syndrome.

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Research in context

Evidence before this study

In seminal research, Cutler et al (2022) produced the first estimates of medical spending per quality-adjusted life-year gained in the United States for ages 65 and older using data on 80 conditions from 1999 to 2012. Estimates for all ages in this framework are not available.

We searched the Econlit and Pubmed databases for peer-reviewed publications through Oct 29, 2024. For Econlit, we used all combinations of four Journal of Economic Literature classification codes: Allocative Efficiency • Cost–Benefit Analysis (D61), Price Level • Inflation • Deflation (E31), Government Expenditures and Health (H51), and Analysis of Health Care Markets (I11). For the combinations of H51 and D61, and H51 and I11, we restricted the search to articles with the words “mortality” and “disease” in the text. For PubMed we conducted two searches, the first using the term “satellite account”. For the second, we used the MeSH term “healthy life expectancy” in seven searches with each one of the following MeSH terms: Cause of Death, Cost-Benefit Analysis, Health Care Costs, Health Expenditure, Health Policy/Economics, Health Services, and Quality of Health Care.

Added value of this study

Three key contributions of our research are:

1. Building on GBD and DEX research that synthesizes data from multiple sources, we report the first US estimates of the value of medical care in a life-expectancy framework by cause and by age group. In particular, we report the first estimates calculated at birth, which is the most comprehensive measure in the life-expectancy framework.

2. We calculate changes in HALE and lifetime spending by cause at each age to show that increases in HALE often occur at older ages than increases in lifetime spending. The all-cause aggregate increase in lifetime spending per HALE gained decreases with age at which it is calculated.

3. Our cause-specific results show the effect of drug use disorders over years impacted by the opioid epidemic. Drug use disorders reduce the all-cause aggregate HALE gained from 1.62 to 1.29 years, and increase lifetime spending per HALE gained from $144,689 to $183,865.

Implications of the available evidence

The effects of changes in medical technology and practice are heterogeneous. When calculated at birth, 19 of 130 causes (15%) such as breast cancer have an increase in HALE and decrease in lifetime spending, and 79 causes (60%) such as ischemic heart disease have an increase in both HALE and lifetime spending. Many causes would benefit from innovations that reduce spending or improve outcomes. Our finding that increases in HALE often occur at older ages than lifetime spending could reflect that some medical care spending at younger ages is an investment that increases HALE at older ages. Calculations of the value of medical care at age 65 that do not account for these investments would be underestimates. Alternatively, the decrease in spending per HALE gained with age could reflect that medical care spending is more efficient for the elderly or prices are lower for Medicare. Our findings lend support to examining the value of medical care by cause, where each cause combines the effects of prevention, diagnosis, and treatment. Concern about aggregate spending would be better directed to causes with large decreases in HALE such as drug use disorder or large increases in lifetime spending and relatively small increases in HALE such as osteoarthritis, and attention-deficit/hyperactivity disorder.

Cause	Fatal or non-fatal	Lifetime spending effect in 2016 US$	HALE effect in years	Lifetime spending per HALE gained	Quadrant
All cause		234111 (221395,242456)	1.285 (1.161,1.422)	182201	northeast
HIV/AIDS and sexually transmitted diseases					
HIV/AIDS	Fatal	2470 (1853,3334)	0.265 (0.225,0.302)	9315	northeast
Sexually transmitted infections excluding HIV	Fatal	-64 (-133,-2)	0.000 (-0.000,0.001)	*	southeast
Respiratory infections and tuberculosis					
Tuberculosis	Fatal	-48 (-71,-3)	0.005 (0.004,0.005)	*	southeast
Lower respiratory infections	Fatal	1492 (63,2724)	0.069 (0.056,0.083)	21738	northeast
Upper respiratory infections	Fatal	753 (333,1191)	0.000 (-0.000,0.001)	3536507	northeast
Otitis media	Fatal	620 (-310,1660)	0.000 (-0.001,0.002)	1727133	northeast
Enteric infections					
Diarrheal diseases	Fatal	810 (632,993)	-0.022 (-0.026,-0.017)	*	northwest
Intestinal infectious diseases	Fatal	-0 (-1,2)	0.000 (-0.000,0.000)	*	southeast
Other infectious diseases					
Meningitis	Fatal	683 (548,860)	-0.006 (-0.007,-0.005)	*	northwest
Encephalitis	Fatal	180 (146,214)	-0.002 (-0.002,-0.001)	*	northwest
Whooping cough	Fatal	-3 (-6,1)	-0.000 (-0.000,0.000)	*	southwest
Tetanus	Fatal	-0 (-0,0)	-0.000 (-0.000,0.000)	*	southwest
Measles	Fatal	-0 (-0,0)	0.000 (0.000,0.000)	*	southeast
Varicella and herpes zoster	Fatal	-50 (-85,-8)	0.000 (0.000,0.001)	*	southeast
Acute hepatitis	Fatal	1991 (1751,2323)	0.001 (0.001,0.001)	2019954	northeast
Other unspecified infectious diseases	Fatal	439 (-354,1233)	0.009 (0.002,0.016)	48468	northeast
Neglected tropical diseases and malaria	Fatal	19 (-1,39)	0.001 (-0.002,0.006)	12503	northeast
Maternal and neonatal disorders					

Cause	Fatal or non-fatal	Lifetime spending effect in 2016 US$	HALE effect in years	Lifetime spending per HALE gained	Quadrant
Maternal hemorrhage	Fatal	221 (144,329)	-0.000 (-0.000,0.000)	*	northwest
other maternal infections	Fatal	318 (255,381)	-0.000 (-0.000,0.000)	*	northwest
Maternal hypertensive disorders	Fatal	1046 (832,1281)	-0.000 (-0.001,-0.000)	*	northwest
labor and uterine rupture	Fatal	1044 (751,1402)	-0.000 (-0.000,-0.000)	*	northwest
miscarriage, and ectopic pregnancy	Fatal	368 (311,444)	-0.000 (-0.000,0.000)	*	northwest
Neonatal preterm birth	Fatal	4857 (3225,7119)	0.040 (0.029,0.052)	120890	northeast
encephalopathy due to birth asphyxia and trauma	Fatal	450 (282,672)	0.009 (0.004,0.013)	52765	northeast
other neonatal infections	Fatal	199 (102,313)	0.003 (0.001,0.005)	73347	northeast
Hemolytic disease and other neonatal jaundice	Fatal	137 (51,261)	0.000 (0.000,0.000)	722880	northeast
Nutritional deficiencies					
Protein-energy malnutrition	Fatal	101 (12,196)	-0.002 (-0.005,0.001)	*	northwest
Iodine deficiency	Non-fatal	0 (-0,1)	0.000 (-0.000,0.000)	16657	northeast
Vitamin A deficiency	Non-fatal	0 (-0,0)	-0.000 (-0.000,0.000)	*	northwest
Dietary iron deficiency	Non-fatal	1832 (1136,2993)	-0.000 (-0.003,0.003)	*	northwest
Neoplasms					
Esophageal cancer	Fatal	59 (2,111)	0.001 (0.000,0.001)	76833	northeast
Stomach cancer	Fatal	49 (-94,284)	0.006 (0.005,0.007)	7564	northeast
Liver cancer	Fatal	224 (166,279)	0.003 (0.003,0.004)	66756	northeast
Larynx cancer	Fatal	41 (-4,80)	0.002 (0.002,0.002)	21744	northeast
Tracheal, bronchus, and lung cancer	Fatal	860 (435,1231)	0.027 (0.022,0.033)	31711	northeast
Breast cancer	Fatal	-669 (-1384,-136)	0.025 (0.020,0.029)	*	southeast
Cervical cancer	Fatal	59 (18,102)	0.000 (-0.000,0.001)	147134	northeast

Cause	Fatal or non-fatal	Lifetime spending effect in 2016 US$	HALE effect in years	Lifetime spending per HALE gained	Quadrant
Uterine cancer	Fatal	-314 (-373,-246)	0.003 (0.002,0.003)	*	southeast
Prostate cancer	Fatal	-188 (-877,103)	0.014 (0.010,0.020)	*	southeast
Colon and rectum cancer	Fatal	4 (-468,440)	0.021 (0.018,0.024)	169	northeast
Lip and oral cavity cancer	Fatal	58 (-4,111)	0.002 (0.002,0.003)	27688	northeast
Nasopharynx cancer	Fatal	0 (-4,4)	0.001 (0.000,0.001)	461	northeast
Other pharynx cancer	Fatal	10 (-37,34)	0.001 (0.001,0.002)	7796	northeast
Gallbladder and biliary tract cancer	Fatal	-7 (-29,14)	0.001 (0.001,0.001)	*	southeast
Pancreatic cancer	Fatal	355 (254,443)	0.002 (0.001,0.002)	235946	northeast
Malignant skin melanoma	Fatal	26 (-24,60)	0.009 (0.006,0.011)	3029	northeast
Non-melanoma skin cancer	Fatal	2044 (915,3704)	0.020 (0.015,0.027)	101789	northeast
Ovarian cancer	Fatal	88 (-13,189)	-0.000 (-0.001,0.000)	*	northwest
Testicular cancer	Fatal	1 (-22,23)	0.001 (0.000,0.001)	1014	northeast
Kidney cancer	Fatal	472 (323,591)	0.006 (0.005,0.007)	74734	northeast
Bladder cancer	Fatal	48 (-63,146)	0.000 (-0.000,0.001)	114068	northeast
Brain and central nervous system cancer	Fatal	797 (577,1074)	0.004 (0.003,0.005)	189028	northeast
Thyroid cancer	Fatal	-10 (-64,29)	0.001 (0.001,0.001)	*	southeast
Hodgkin lymphoma	Fatal	99 (16,177)	0.002 (0.001,0.002)	57020	northeast
Non-Hodgkin lymphoma	Fatal	3031 (2563,3641)	0.006 (0.005,0.007)	493422	northeast
Multiple myeloma	Fatal	1199 (884,1363)	0.004 (0.003,0.005)	317682	northeast
Leukemia	Fatal	2687 (2262,3094)	0.003 (0.002,0.007)	856597	northeast
Other neoplasms	Fatal	437 (-248,1060)	0.023 (0.014,0.032)	19035	northeast
Cardiovascular diseases					
Rheumatic heart disease	Fatal	270 (-129,570)	0.016 (0.013,0.019)	16973	northeast

Cause	Fatal or non-fatal	Lifetime spending effect in 2016 US$	HALE effect in years	Lifetime spending per HALE gained	Quadrant
Ischemic heart disease	Fatal	15816 (11450,19110)	0.250 (0.175,0.334)	63184	northeast
Stroke	Fatal	89 (-1697,1633)	0.197 (0.164,0.232)	451	northeast
Hypertensive heart disease	Fatal	352 (-203,976)	-0.027 (-0.044,0.014)	*	northwest
Cardiomyopathy and myocarditis	Fatal	-1568 (-2109,-986)	0.053 (0.013,0.072)	*	southeast
Atrial fibrillation and flutter	Fatal	2269 (798,3906)	0.018 (0.009,0.029)	126760	northeast
Peripheral artery disease	Fatal	-317 (-1282,153)	-0.007 (-0.018,-0.000)	*	southwest
Endocarditis	Fatal	2181 (30,8109)	-0.010 (-0.017,0.003)	*	northwest
Other cardiovascular and circulatory diseases	Fatal	786 (-312,2040)	0.025 (0.019,0.032)	30883	northeast
<u>Chronic respiratory diseases</u>					
Chronic obstructive pulmonary disease	Fatal	3422 (2213,4572)	0.009 (-0.029,0.076)	383162	northeast
Pneumoconiosis	Fatal	38 (-7,85)	0.001 (0.001,0.001)	40410	northeast
Asthma	Fatal	1522 (768,2256)	0.025 (0.021,0.028)	61894	northeast
Interstitial lung disease and pulmonary sarcoidosis	Fatal	64 (-51,175)	-0.002 (-0.016,0.017)	*	northwest
<u>Digestive diseases</u>					
Cirrhosis and other chronic liver diseases	Fatal	2171 (324,4145)	0.018 (0.012,0.024)	119069	northeast
Peptic ulcer disease	Fatal	-707 (-1118,-393)	0.018 (0.015,0.021)	*	southeast
Gastritis and duodenitis	Fatal	66 (-613,224)	0.000 (-0.001,0.001)	248252	northeast
Appendicitis	Fatal	921 (555,1310)	0.001 (0.000,0.001)	1405232	northeast
Paralytic ileus and intestinal obstruction	Fatal	723 (457,1215)	-0.005 (-0.007,-0.000)	*	northwest
Inguinal, femoral, and abdominal hernia	Fatal	533 (-98,1184)	-0.000 (-0.001,0.000)	*	northwest
Inflammatory bowel disease	Fatal	5537 (4568,6461)	-0.008 (-0.010,-0.003)	*	northwest
Vascular intestinal disorders	Fatal	187 (83,295)	0.004 (0.002,0.007)	45766	northeast

Cause	Fatal or non-fatal	Lifetime spending effect in 2016 US$	HALE effect in years	Lifetime spending per HALE gained	Quadrant
Gallbladder and biliary diseases	Fatal	-83 (-786,540)	0.007 (0.003,0.012)	*	southeast
Pancreatitis	Fatal	893 (466,1435)	-0.002 (-0.004,-0.001)	*	northwest
Other digestive diseases	Non-fatal	2912 (1709,4287)	0.008 (-0.000,0.019)	347471	northeast
<u>Neurological disorders</u>					
Alzheimer's disease and other dementias	Fatal	7564 (2366,12987)	0.041 (0.007,0.128)	185623	northeast
Parkinson's disease	Fatal	-455 (-825,-112)	-0.007 (-0.016,0.003)	*	southwest
Idiopathic epilepsy	Fatal	1002 (581,1417)	0.002 (-0.008,0.012)	580822	northeast
Multiple sclerosis	Fatal	2645 (2397,2925)	0.000 (-0.001,0.003)	9566428	northeast
Migraine	Non-fatal	1695 (1163,2346)	0.002 (-0.003,0.009)	787135	northeast
Tension-type headache	Non-fatal	-13 (-43,7)	-0.001 (-0.003,0.001)	*	southwest
Other neurological disorders	Fatal	4036 (2439,5645)	0.017 (0.012,0.023)	232093	northeast
<u>Mental disorders</u>					
Schizophrenia	Non-fatal	-784 (-1293,-355)	0.001 (-0.001,0.004)	*	southeast
Depressive disorders	Non-fatal	5332 (3985,6717)	-0.008 (-0.015,-0.003)	*	northwest
Bipolar disorder	Non-fatal	1350 (1025,1670)	0.000 (-0.001,0.002)	2833465	northeast
Anxiety disorders	Non-fatal	7629 (6424,8894)	0.002 (-0.001,0.005)	4250811	northeast
Eating disorders	Fatal	17 (-14,47)	0.000 (-0.000,0.000)	612478	northeast
Autism spectrum disorders	Non-fatal	403 (280,517)	0.000 (-0.000,0.001)	1828078	northeast
deficit/hyperactivity disorder	Non-fatal	2751 (2108,3428)	0.000 (-0.000,0.000)	343770047	northeast
Conduct disorder	Non-fatal	-80 (-130,-32)	0.000 (-0.001,0.001)	*	southeast
developmental intellectual disability	Non-fatal	-193 (-276,-115)	0.000 (-0.000,0.001)	*	southeast
Other mental disorders	Non-fatal	-126 (-195,-55)	0.001 (-0.000,0.002)	*	southeast
<u>Substance use disorders</u>					

Cause	Fatal or non-fatal	Lifetime spending effect in 2016 US$	HALE effect in years	Lifetime spending per HALE gained	Quadrant
Alcohol use disorders	Fatal	-180 (-584,150)	-0.014 (-0.018,-0.011)	*	southwest
Drug use disorders	Fatal	331 (-130,790)	-0.331 (-0.370,-0.296)	*	northwest
Diabetes and chronic kidney diseases					
Diabetes mellitus	Fatal	6880 (4989,8474)	0.234 (0.202,0.266)	29355	northeast
Acute glomerulonephritis	Fatal	-1 (-5,2)	-0.000 (-0.001,-0.000)	*	southwest
Chronic kidney disease	Fatal	6234 (5017,7382)	-0.126 (-0.143,-0.110)	*	northwest
Musculoskeletal disorders					
Rheumatoid arthritis	Fatal	6098 (5063,6937)	0.002 (0.001,0.003)	2747596	northeast
Osteoarthritis	Non-fatal	13325 (11119,15063)	0.001 (-0.003,0.007)	16271496	northeast
Low back and neck pain	Non-fatal	22849 (19697,26693)	0.009 (-0.000,0.019)	2655003	northeast
Gout	Non-fatal	138 (-200,1065)	0.001 (-0.000,0.001)	263070	northeast
Other musculoskeletal disorders	Fatal	8351 (-3736,16120)	0.025 (0.012,0.049)	340216	northeast
Skin and subcutaneous diseases	Fatal	11204 (10065,12774)	0.016 (0.009,0.024)	714267	northeast
Sense organ diseases	Non-fatal	3085 (703,4969)	0.012 (0.003,0.024)	247338	northeast
Other non-communicable diseases					
Congenital birth defects	Fatal	1623 (521,2752)	0.024 (0.010,0.035)	67052	northeast
Urinary diseases and male infertility	Fatal	9237 (6108,12453)	0.012 (0.008,0.015)	781027	northeast
Gynecological diseases	Fatal	1818 (723,3130)	0.035 (0.016,0.057)	52663	northeast
Hemoglobinopathies and hemolytic anemias	Fatal	2079 (1829,2358)	0.003 (0.000,0.005)	729208	northeast
blood, and immune disorders	Fatal	4678 (3752,5616)	-0.048 (-0.059,-0.027)	*	northwest
Oral disorders	Non-fatal	12790 (12221,13291)	0.022 (0.010,0.037)	576283	northeast
Transport injuries					
Road injuries	Fatal	6183 (2929,9976)	0.069 (0.056,0.086)	89064	northeast

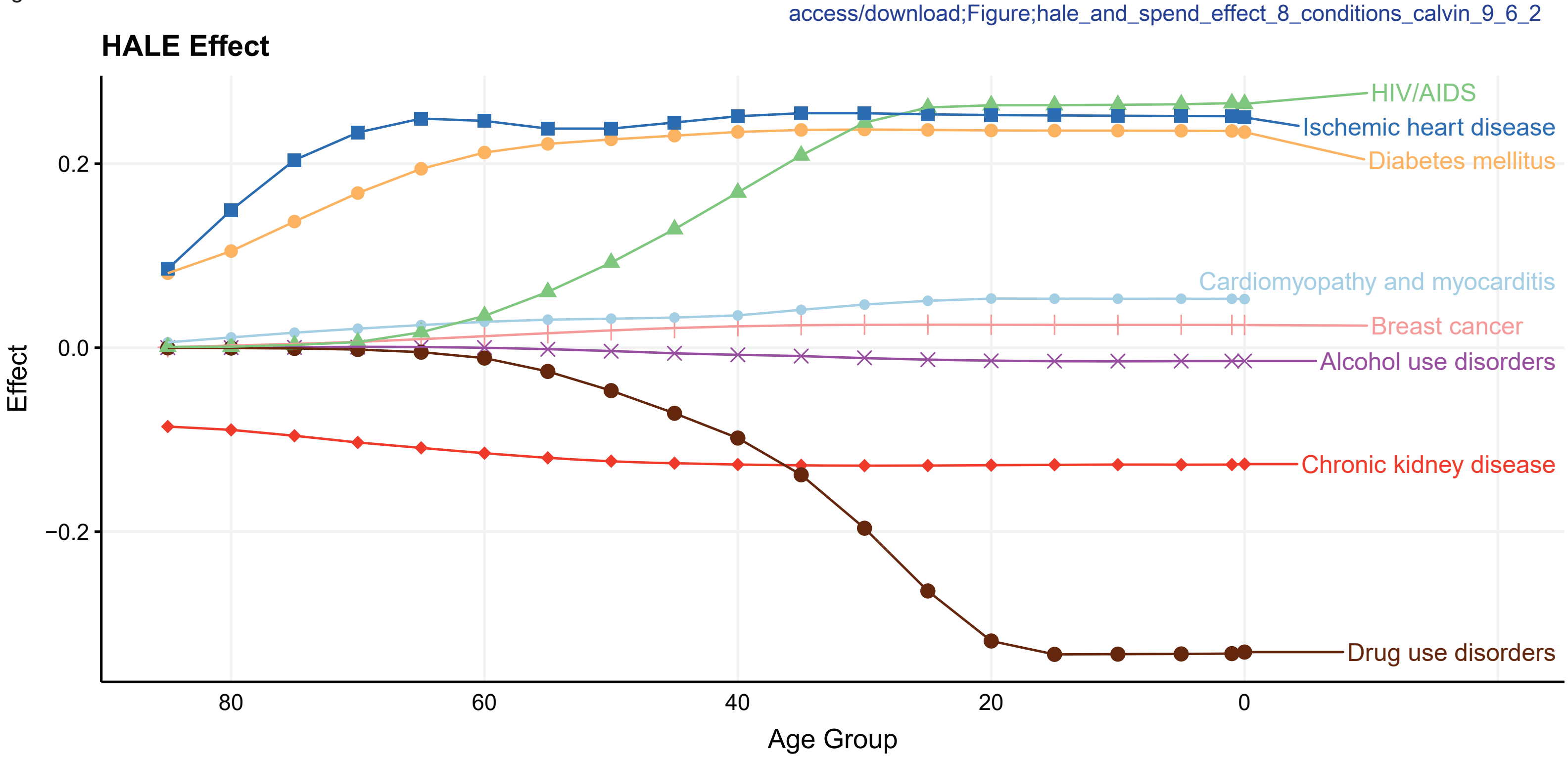
Cause	Fatal or non-fatal	Lifetime spending effect in 2016 US$	HALE effect in years	Lifetime spending per HALE gained	Quadrant
Other transport injuries	Fatal	170 (118,221)	-0.013 (-0.016,-0.009)	*	northwest
Unintentional injuries					
Falls	Fatal	5382 (390,9475)	0.046 (0.025,0.075)	115988	northeast
Drowning	Fatal	-8 (-13,-2)	0.007 (0.004,0.009)	*	southeast
Fire, heat, and hot substances	Fatal	143 (58,224)	0.012 (0.009,0.018)	11427	northeast
Poisonings	Fatal	901 (701,1137)	0.005 (0.002,0.008)	180134	northeast
Exposure to mechanical forces	Fatal	4478 (2928,6203)	0.037 (0.024,0.054)	122345	northeast
Animal contact	Fatal	365 (70,714)	0.002 (0.001,0.003)	182024	northeast
Foreign body	Fatal	91 (-0,193)	-0.016 (-0.019,-0.013)	*	northwest
Other unintentional injuries	Fatal	2181 (559,3942)	0.020 (0.015,0.025)	111130	northeast
Exposure to forces of nature	Fatal	0 (-0,1)	-0.000 (-0.000,-0.000)	*	northwest
Self-harm and interpersonal violence					
Self-harm	Fatal	151 (3,302)	0.019 (0.011,0.026)	8103	northeast
Interpersonal violence	Fatal	1367 (724,2030)	0.023 (0.016,0.031)	59572	northeast
Collective violence and legal intervention	Fatal	-7 (-22,-2)	0.002 (0.001,0.003)	*	southeast

Table 2. All-cause aggregate effects of changes in medical care on health-adjusted life-expectancy (HALE) and lifetime spending from 1996 to 2016, and value measured as the ratio of lifetime spending per HALE gained calculated at selected ages, and with drug use disorders removed

Age of calculation	Mean lifetime spending effect in 2016 US$	Mean HALE effect in years	Mean lifetime spending per mean HALE gained in 2016 US$	Mean lifetime spending per mean HALE gained net of drug use in 2016 US$
0	234,111	1.28	182,201	144,689
15	210,276	1.22	171,732	134,764
30	188,047	1.29	146,163	126,769
45	161,557	1.18	136,892	129,135
55	133,770	1.08	123,615	120,884
65	89,733	0.97	92,085	91,843

Figure 1

Click here to access/download;Figure;hale_and_spend_effect_8_conditions_calvin_9_6_2



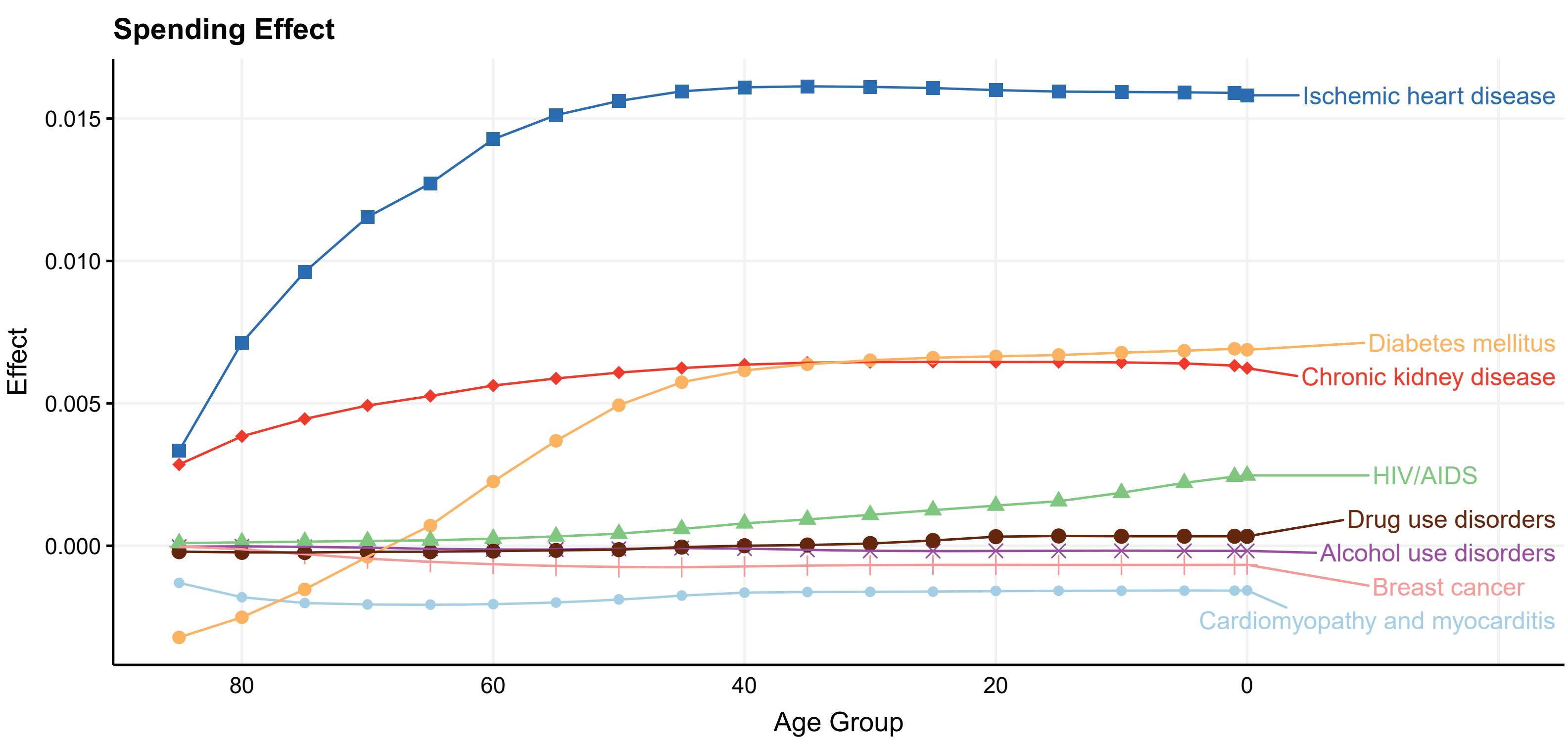
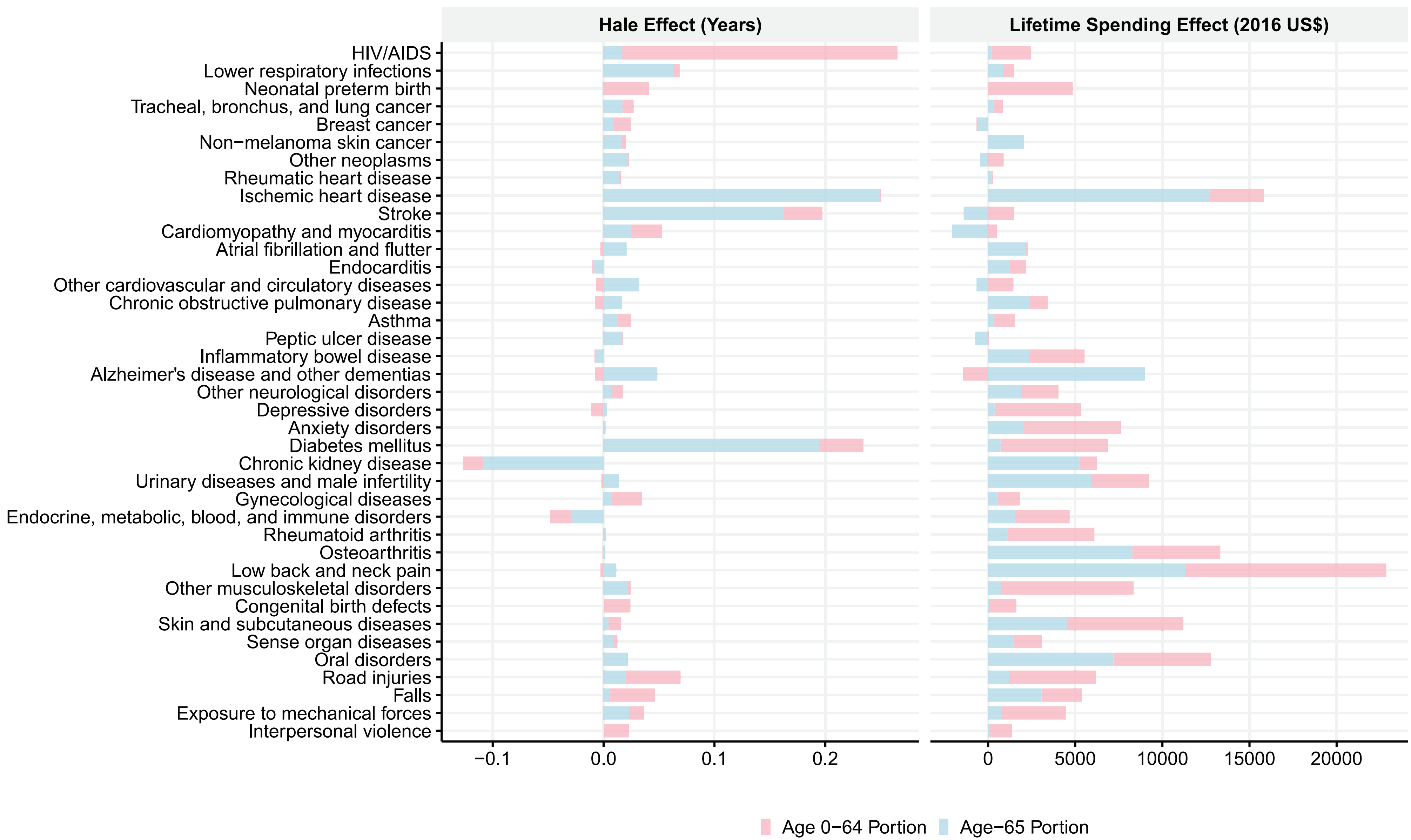


Figure 2



Hale Effect (Years)
Lifetime Spending Effect (2016 US$)
HIV/AIDS
Lower respiratory infections
Neonatal preterm birth
Tracheal, bronchus, and lung cancer
Breast cancer
Non−melanoma skin cancer
Other neoplasms
Rheumatic heart disease
Ischemic heart disease
Stroke
Cardiomyopathy and myocarditis
Atrial fibrillation and flutter
Endocarditis
Other cardiovascular and circulatory diseases
Chronic obstructive pulmonary disease
Asthma
Peptic ulcer disease
Inflammatory bowel disease
Alzheimer's disease and other dementias
Other neurological disorders
Depressive disorders
Anxiety disorders
Diabetes mellitus
Chronic kidney disease
Urinary diseases and male infertility
Gynecological diseases
Endocrine, metabolic, blood, and immune disorders
Rheumatoid arthritis
Osteoarthritis
Low back and neck pain
Other musculoskeletal disorders
Congenital birth defects
Skin and subcutaneous diseases
Sense organ diseases
Oral disorders
Road injuries
Falls
Exposure to mechanical forces
Interpersonal violence
−0.1
0.0
0.1
0.2
0
5000
10000
15000
20000
Age 0−64 Portion
Age−65 Portion