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Economic Evaluation

The Impact of Funding Inpatient Treatments for COVID-19 on Health Equity in the United States: A Distributional Cost-Effectiveness Analysis

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ABSTRACT

Objectives: We conducted a distributional cost-effectiveness analysis (DCEA) to evaluate how Medicare funding of inpatient COVID-19 treatments affected health equity in the United States.

Methods: A DCEA, based on an existing cost-effectiveness analysis model, was conducted from the perspective of a single US payer, Medicare. The US population was divided based on race and ethnicity (Hispanic, non-Hispanic black, and non-Hispanic white) and county-level social vulnerability index (5 quintile groups) into 15 equity-relevant subgroups. The baseline distribution of quality-adjusted life expectancy was estimated across the equity subgroups. Opportunity costs were estimated by converting total spend on COVID-19 inpatient treatments into health losses, expressed as quality-adjusted life-years (QALYs), using base-case assumptions of an opportunity cost threshold of $150 000 per QALY gained and an equal distribution of opportunity costs across equity-relevant subgroups.

Results: More socially vulnerable populations received larger per capita health benefits due to higher COVID-19 incidence and baseline in-hospital mortality. The total direct medical cost of inpatient COVID-19 interventions in the United States in 2020 was estimated at $25.83 billion with an estimated net benefit of 735 569 QALYs after adjusting for opportunity costs. Funding inpatient COVID-19 treatment reduced the population-level burden of health inequality by 0.234%. Conclusions remained robust across scenario and sensitivity analyses.

Conclusions: To the best of our knowledge, this is the first DCEA to quantify the equity implications of funding COVID-19 treatments in the United States. Medicare funding of COVID-19 treatments in the United States could improve overall health while reducing existing health inequalities.

Keywords: cost-effectiveness, COVID-19, health equity, United States

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Introduction

The burden of COVID-19 is far reaching and ubiquitous across communities and countries; nevertheless, the burden has not been equitable across the US population.[1] Minority, low income, and socially vulnerable individuals/communities faced a disproportionate burden of COVID-19 cases, hospitalizations, and deaths.[2-6] The disproportionate impact of COVID-19 on vulnerable communities has accelerated interest in understanding what steps can be taken to effectively mitigate disparities in health between more and less socially disadvantaged groups.[7]

To promote efficient resource allocation when budgets are limited, cost-effectiveness analysis (CEA) is being leveraged to inform decision making on funding and reimbursement for COVID-19 treatments in the United States.[8-14] CEA focuses on the total costs and health effects across the whole population eligible for treatment. Nevertheless, CEAs rarely provide information on the distribution of costs and effects—that is, who gains and who loses—which depends on differences among people at various steps in the “inequality staircase” including differences in health risks (eg, who is at the highest risk), access (eg, who is most likely to receive treatment), capacity to benefit (eg, who benefits most from treatment), and who bears the opportunity costs of diverting scarce resources from other uses.[15] Distributional CEA (DCEA) is an extension of CEA that provides information about these distributional questions, as well as the conventional question of cost-effectiveness.[15]

The equity impact of funding COVID-19 interventions in the United States has not yet been established.[8,14] Given the disproportionate impact of COVID-19 on disadvantaged populations, it is essential to understand how decisions on the funding of treatments may affect health disparities. Building on previous work to outline a framework for estimating the cost-effectiveness of COVID-19 inpatient treatments,[13] we conducted the first application of DCEA to evaluate how US Medicare funding of inpatient COVID-19 treatments for hospitalized patients might affect health equity in the United States.

Methods

The Original CEA Model

We adapted a published CEA model, described by Sheinson et al.[13] This model was chosen for convenience and aligned with other COVID-19 CEAs developed in the United States in 2021.[9,10] The model compared various treatments for hospitalized COVID-19 patients with standard of care as defined in clinical trials in 2020,[16,17] including treatments with varying levels of impact on reducing mortality, use of mechanical ventilation, and length of hospital stay.

Treatment effectiveness parameters remained unchanged from the published CEA model given that clinical data were not reported based on equity-relevant subgroups. In brief, effects were based on trials of inpatient treatments available at the time of model development (RECOVERY, ACTT-1).[16,17] The intervention of interest was a hypothetical treatment with an impact on reducing mortality (relative risk [RR] 0.89 and 0.67 for patients on mechanical ventilation and oxygen support, respectively) and reducing progression to mechanical ventilation (RR 0.77), with an assumed treatment cost of $2500 (similar to the cost of monoclonal antibodies funded in 2021).[10] Incremental cost-effectiveness ratio per quality-adjusted life-year (QALY) was used as a measure of cost-effectiveness. Base-case results for the healthcare payer perspective—when COVID-19 treatment was funded on top of the bundled episode-based care payments made to hospitals—found treatments to be cost-effective: incremental cost-effectiveness ratio of $28 651 per QALY gained (0.437 incremental QALYs, $12 527 incremental costs).

DCEA Framework: Estimation Tasks, Equity-Relevant Variables, and Perspective

Extending a standard CEA to conduct DCEA requires the estimation of 3 main distributional breakdowns, in addition to the information provided by standard CEA:

1. the baseline distribution of health in terms of quality-adjusted life expectancy (QALE);
2. the distribution of health effects; and
3. the distribution of opportunity costs.

All involve disaggregating an overall whole-population outcome by the same equity-relevant variables of interest. We focused on 2 equity-relevant variables: race and ethnicity (3 groups: Hispanic [H], non-Hispanic black [B], non-Hispanic white [W]) and county-level social vulnerability (5 quintile groups), yielding 15 equity subgroups for each distributional breakdown—as described later.

The perspective of our DCEA analysis is that of a single US payer: Medicare. We assumed that Medicare operates under a quasi-fixed budget whereby allocating funds to cover inpatient COVID-19 treatments would result in health opportunity costs from forgone health improving activities funded by either Medicare or other federal health programs. Although we recognize that the US landscape consists of many fragmented payers with limited continuous enrollment, Medicare perspective was adopted for this study because the vast majority of patients hospitalized in the United States for COVID-19 in 2020 were 65 years of age or older and covered by Medicare.[18]

Creation of Equity-Relevant Subgroups

Conventional CEA focuses on effects among the intervention recipient population only. DCEA considers the entire general population, including individuals who are not eligible for the intervention but could face opportunity costs from funding a cost-increasing alternative. To inform the creation of the subgroups and inputs for the DCEA, a targeted literature review was conducted to gather information on key risk factors for COVID-19 and COVID-19-related health outcomes of hospitalization and inpatient mortality (see Appendix in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010) available through February 28, 2021. Our race and ethnicity subgroups were chosen for inclusion based on the availability of data and review findings. The review identified many studies reporting increased risks of COVID-19 and death for Hispanic and non-Hispanic black communities relative to non-Hispanic white communities, although the magnitude and significance of race and ethnicity as a predictor of increased COVID-19 risks varied notably across geographies and analyses.[5,6,19-21] Information on additional racial and ethnic subgroups beyond these 3 categories was not identified in the literature. We also used a deprivation index as a second equity-relevant variable, which interacts with some of the underlying causes of COVID-19 disparities across racial and ethnic groups.[15,22] The social vulnerability index (SVI), a percentile-based measure routinely collected at the US census tract level to estimate the resilience of communities during times of public health emergencies, was used to group the populations into 5 quintile groups (from Q1 [least vulnerable] to Q5 [most vulnerable]).[3,23] This resulted in 15 subgroups capturing important differences in COVID-19 risks and outcomes according to race and ethnicity and level of social vulnerability[24] (see Fig. 1 and Appendix Table 1 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010). To align with available literature and mortality data available at the county level, these 15 subgroups represented approximately 80% of the US population, but not include individuals beyond those identified as Hispanic, non-Hispanic black, or non-Hispanic white (see Appendix Figure 1 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010).

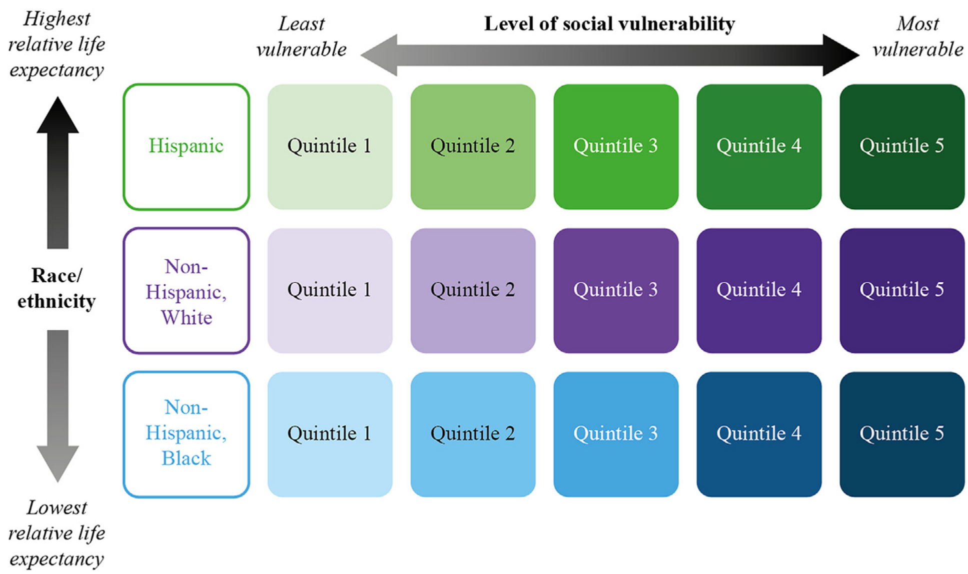
Establishing Baseline QALE Across the Subgroups

Suitable baseline data on QALE at birth across the whole US general population based on both social vulnerability and race and ethnicity were not available, and hence, we conducted a substantial de novo estimation exercise, which is reported in detail in the Appendix in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010. Using population, mortality,[25] and disability data (extracted from Centers for Disease Control and Prevention Wonder, American Community Survey, and County Health Rankings and Roadmaps program[26]), we first estimated disability-free life expectancy (DFLE) for each subgroup. DFLE was then converted to QALE, using a previously published mapping process outlined by Asaria et al[22] where the ratio of DFLE to life expectancy is used to adjust QALE estimates. QALE estimates for each subgroup used age-adjusted, sex-based QALY weights for the general US population (all races) from Sullivan and Ghushchyan[27] (see Appendix Table 2 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010).[22] The conversion to QALE makes the analysis consistent with the standard QALY metric used in CEA.

Estimating Health Effects for Each Subgroup

The outcome of COVID-19 treatments for a typical patient in each subgroup was estimated by incorporating distributional functionality within the CEA model. Appendix Figure 2 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010 shows the inequality staircase used for inpatients receiving COVID-19 treatments.

Figure 1. US subgroups for COVID-19 DCEA. SVI ranks each tract based on 15 social measures including (1) socioeconomic status (below poverty, unemployed, income, or no high school diploma), (2) household composition and disability (aged 65 years or older, aged 17 years or younger, older than age 5 years with a disability, and single-parent households), (3) minority status and language (minority, speak English "less than well"), and (4) housing type and transportation (multiunit structures, mobile homes, crowding, no vehicle, and group quarters). SVI scores fall between 0 (least vulnerable) and 1 (most vulnerable). The SVI was created by the CDC and Agency for Toxic Substances and Disease Registry. From: https://www.atsdr.cdc.gov/placeandhealth/svi/at-a-glance_svi.html.



CDC indicates Centers for Disease Control and Prevention; DCEA, distributional cost-effectiveness analysis; SVI, social vulnerability index.

Trial data on differences in treatment effects across our subgroups of interest were not available, so we applied the same mortality RR reductions to each subgroup but different estimates of baseline risk based on real-world evidence on the link between social vulnerability and baseline risk of COVID-19 hospitalization and inpatient mortality. Areas with greater levels of social vulnerability were more likely to become COVID-19 hotspots and individuals in socially vulnerable communities were more likely to have poorer outcomes including COVID-19 mortality. A cross-sectional national study examining the relationship between SVI and COVID-19 outcomes showed that for every 0.1 increase in the SVI, a 14.3% relative increase in COVID-19 incidence and a 13.7% relative increase in COVID-19 mortality were observed.[3]

Estimates of COVID-19 hospitalizations for each subgroup were derived based on the underlying age distribution of the subgroup (Appendix Table 1 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010) and the age-based hospitalization rates.[28] These initial estimates were adjusted to reflect the impact of county-level social vulnerability, based on each county's deviation from the national average SVI score per the risk effect of increased SVI.[3] It was assumed that the impact of SVI on the risk of COVID-19 incidence (14.3% increase per 0.1 increase in SVI) could be used to adjust SVI-based impact on COVID-19 hospitalizations. This county-level deviation from average SVI in our national sample was also used to adjust the baseline risk of death for the standard-of-care arm in our model, to reflect how different root causes drove inequality in inpatient COVID-19 mortality outcomes (13.7% increase per 0.1 increase in SVI) (Table 1[3,28]) (Appendix Table 3 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010).[3]

Patient-level average health effects for each subgroup were generated from the CEA and then converted to population-level subgroup effects based on the estimated number of hospitalized patients, considering the average SVI and underlying age distribution of the subgroup.

Assumptions About the Distribution of Health Opportunity Costs

Given that the assumed perspective was that of a single public payer (Medicare), we did not need to look at potential differences between subgroups in drug costs, inpatient reimbursement, or postdischarge costs. Instead we focused on differences in health opportunity cost based on subgroup, as described below. Outside of changes to baseline mortality related to average SVI score for each subgroup, all remaining model cost-effectiveness inputs remained unchanged from the published analysis for the base-case healthcare payer perspective.[13] The Medicare healthcare payer perspective assumed that the cost of inpatient COVID-19 medicines would represent an incremental cost on top of bundled payments to hospitals for episode-based care.

When assessing population-level health equity impacts, standard DCEA methodology was used in which the average health of an individual based on subgroup was estimated after accounting for health losses due to inpatient COVID-19 mortality.[15,22] Total opportunity costs were estimated by converting the total spend on COVID-19 inpatient treatments into health losses, expressed as QALYs, with an assumed opportunity cost threshold of $150 000 per QALY gained, with sensitivity analyses testing the impact of alternative ranges ($50 000-$150 000). Conceptually, the appropriate threshold for analyzing the distribution of health opportunity costs is an "opportunity cost" threshold, which estimates the marginal cost of producing 1 QALY from alternative uses of Medicare funding. Our estimate of $150 000 is at the high end of the best available estimate of the US opportunity cost of healthcare spending.[29] In the absence of data on the distribution of this

Table 1. Summary of inputs for COVID-19 DCEA.

Subgroup	Average SVI score	Total population	COVID-19 inpatient mortality adjustor*	COVID-19 hospitalization (per 100 000)		Total number of hospitalizations	Percent hospitalized with COVID-19 (%)
				Unadjusted COVID-19 hospitalization rate†	SVI-adjusted COVID-19 hospitalization rate‡		
HQ1	4 143 362	0.145	0.61	537.2	325.6	13 493	0.33
HQ2	7 473 781	0.352	0.80	529.1	421.0	31 462	0.42
HQ3	9 992 513	0.531	1.01	567.1	570.2	56 979	0.57
HQ4	18 289 880	0.709	1.27	557.7	708.3	129 541	0.71
HQ5	14 018 354	0.897	1.62	599.0	972.6	136 348	0.97
BQ1	3 251 954	0.145	0.61	664.3	402.7	13 096	0.40
BQ2	5 621 186	0.352	0.80	648.4	516.0	29 003	0.52
BQ3	8 037 859	0.531	1.01	669.2	672.8	54 082	0.67
BQ4	12 066 135	0.709	1.27	681.7	865.7	104 459	0.87
BQ5	7 875 448	0.897	1.62	687.9	1117.0	87 972	1.12
WQ1	34 435 697	0.145	0.61	827.8	501.8	172 794	0.50
WQ2	34 445 350	0.352	0.80	830.1	660.5	227 527	0.66
WQ3	35 177 231	0.531	1.01	865.0	869.8	305 959	0.87
WQ4	31 837 920	0.709	1.27	855.2	1086.0	345 755	1.09
WQ5	14 803 158	0.897	1.62	860.7	1397.5	206 877	1.40
US Sample	241 469 828	0.527				1 915 345	0.79

Note. Average SVI score indicates fractional rank among all 810 US counties.
B indicates non-Hispanic black; DCEA, distributional cost-effectiveness analysis; H, Hispanic; Q, quintile (1= least socially vulnerable; 5 = most socially vulnerable); SVI, social vulnerability index; W, non-Hispanic white.
*Inpatient mortality adjustor: the difference between the subgroup SVI and the national sample SVI was used to create an adjustment factor for the baseline risk of COVID-19 inpatient mortality, based on the 13.7% increase per 0.1-point increase in SVI, per Karmakar et al[3] (based on data from March 25 to June 29, 2020).
†Unadjusted COVID-19 hospitalization rate: estimated rate of hospitalization based on the number of patients in the subgroup and the age distribution of patients within the subgroup, per Reese et al[28] based on data from February 27 to September 30, 2020 (see Appendix in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010 for detail on demographics based on subgroup).
‡SVI-adjusted COVID-19 hospitalization rate: estimated rate of hospitalization based on adjustments to baseline rate to reflect 14.3% increase in COVID-19 hospitalizations for every 0.1-point increase in SVI (relative to the national average SVI), per Karmakar et al.[3]

opportunity cost across our subgroups, the model base case assumed an equal distribution of opportunity costs across the population (ie, health losses were taken proportionally from each subgroup based on sample size alone), with scenario analyses testing the impact of alternative assumptions involving opportunity cost burdens. In particular, 1 scenario assumed 100% of opportunity costs were borne by the least socially deprived group, and another assumed 100% were borne by the most deprived subgroup. An equal distribution is not an unreasonable base-case assumption in the context of Medicare, which comes close to universal coverage but is not as pro-poor in terms of the benefit incidence of healthcare expenditure as the UK National Health Service.[30]

Health equity impact was expressed as the percentage reduction in health inequality, based on change in the Atkinson index of inequality in QALE at birth.[15] The Atkinson index is welfare-based measure of inequality that depends on the decision maker's degree of aversion to health inequality and willingness to accept trade-offs in exchange for a more equal distribution. The index is scaled from 0 to 1, where 0 represents no inequality and 1 represents full inequality. Following methods outlined by Cookson and colleagues,[31] we estimated the Atkinson index before and after accounting for the impact of inpatient COVID-19 treatments. Given that published information on US health inequality inversion are unavailable, our base-case analysis assumed an inequality aversion level of 11 based on the median inequality aversion parameters for the Atkinson index in a study of UK general public views, with scenario analyses to test the sensitivity of alternate inequality aversion parameters (0.5-20; higher scores indicate more aversion). To help contextualize the magnitude of health equity impact, we also expressed it as a change in the population-level burden of health inequality. Using the Atkinson approach, this can be defined as the Atkinson index times mean QALE at birth times population size.

Results

CEA Results

The deterministic CEA results per average patient across each model subgroup are presented in Table 2. Differences in direct medical costs and incremental QALYs gained across subgroups are driven by changes to baseline mortality for the standard-of-care arm, per SVI adjustment. Increasing social vulnerability and the associated higher baseline mortality in the hospital result in greater absolute effects of treatment and hence greater incremental QALYs gained, which translated into a greater change in life-years after hospital discharge and higher incremental costs accumulated over a patient's lifetime from increased survival (Table 2).

Table 2. Deterministic patient-level CEA based on subgroup.

Sample	Patient-level outcomes (based on subgroup)					Subgroup outcomes	
	Incremental direct medical costs		Incremental QALYs		QALY gain per 100 000 population	Total incremental costs ($)	Total QALYs gained
	Short-term acute model ($)	Postdischarge ($)	Short-term acute model	Postdischarge			
HQ1	1586	7374	0.005	0.296	98	120 909 211	4061
HQ2	1586	9190	0.005	0.365	156	339 032 405	11 641
HQ3	1586	10 986	0.005	0.434	250	716 341 025	25 014
HQ4	1586	12 977	0.005	0.510	365	1 886 505 857	66 714
HQ5	1586	15 247	0.004	0.597	586	2 295 149 707	82 082
BQ1	1586	7374	0.005	0.296	121	117 349 372	3942
BQ2	1586	9190	0.005	0.365	191	312 535 672	10 731
BQ3	1586	10 986	0.005	0.434	295	679 915 404	23 742
BQ4	1586	12 977	0.005	0.510	446	1 521 237 961	53 796
BQ5	1586	15 247	0.004	0.597	672	1 480 832 835	52 959
WQ1	1586	7374	0.005	0.296	151	1 548 403 663	52 011
WQ2	1586	9190	0.005	0.365	244	2 451 826 694	84 185
WQ3	1586	10 986	0.005	0.434	382	3 846 518 715	134 316
WQ4	1586	12 977	0.005	0.510	559	5 035 222 809	178 064
WQ5	1586	15 247	0.004	0.597	841	3 482 364 613	124 540
Average/total*	1586	11 155	0.005	0.440	376	25 834 145 944	907 797

Note. Subgroup costs are estimated by multiplying total incremental costs from the CEA by the number of hospitalized patients per subgroup. Within the model, no rounding was used, and therefore, calculated estimates based on table inputs may slightly vary from reported results.
B indicates non-Hispanic black; CEA, cost-effectiveness analysis; H, Hispanic; Q, quintile (1 = least socially vulnerable; 5 = most socially vulnerable); QALYs, quality-adjusted life-years; SVI, social vulnerability index; W, non-Hispanic white.
*Average values are reported for patient-level outcomes and total values are reported for subgroup outcomes.

DCEA Results

Through combining patient-level CEA outputs, information on incidence of COVID-19 hospitalization, and average starting patient QALE, the population-level results were determined (Tables 2 and 3). The total cost of inpatient COVID-19 interventions was estimated at $25.83 billion with an estimated 907 797 QALYs gained and health losses of 172 228 QALYs per the assumed $150 000 opportunity cost threshold. Net health benefits were generally higher in more socially vulnerable groups, because these patients had the highest mortality and therefore the greatest capacity to benefit (Fig. 2).

Comparing net health benefits across racial and ethnic subgroups, we see 2 competing factors driving the results. First, the non-Hispanic black and Hispanic subgroups had more patients in more deprived quintiles with higher baseline COVID-19 hospitalization and mortality risks and therefore increased health benefits (Table 3). Nevertheless, these gains were offset by the differences in age distributions of those groups relative to the non-Hispanic white subgroup. An average of 19.7% of the population was 65 years or older across non-Hispanic white subgroups compared with 10.8% and 6.8% in the non-Hispanic black and Hispanic subgroups, respectively (Appendix Table 1 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010). Given that COVID-19 incidence and hospitalization rate increase notably with age, these differences in population age mix result in a higher number of COVID-19 hospitalizations in the non-Hispanic white population (Table 1)[3,28]. Overall, nevertheless, SVI remained the dominant driver of results, with larger health benefits in socially disadvantaged groups.

Using the Atkinson index approach, we found that funding of COVID-19 treatments reduced the population-level burden of health inequality by 0.234%. Expressed in absolute population-level terms and using our base-case Atkinson parameter of 11,

Table 3. Population-level DCEA outcomes.

Subgroups	Total population within each subgroup*	Average starting patient QALE†	Health benefits from COVID-19 inpatient treatment (QALYs)‡	Health losses (per opportunity costs) (QALYs)§	Net health benefits (QALYs)
HQ1	4 143 362	71.22	4061	(2955)	1106
HQ2	7 473 781	69.91	11 641	(5331)	6310
HQ3	9 992 513	68.76	25 014	(7127)	17 887
HQ4	18 289 880	67.75	66 714	(13 045)	53 668
HQ5	14 018 354	65.90	82 082	(9999)	72 083
BQ1	3 251 954	70.26	3942	(2319)	1622
BQ2	5 621 186	68.94	10 731	(4009)	6722
BQ3	8 037 859	67.87	23 742	(5733)	18 009
BQ4	12 066 135	66.84	53 796	(8606)	45 190
BQ5	7 875 448	64.98	52 959	(5617)	47 342
WQ1	34 435 697	70.45	52 011	(24 561)	27 450
WQ2	34 445 350	69.75	84 185	(24 568)	59 617
WQ3	35 177 231	68.00	134 316	(25 090)	109 226
WQ4	31 837 920	67.06	178 064	(22 708)	155 355
WQ5	14 803 158	65.19	124 540	(10 558)	113 982
Total/average	241 469 828	68.20	907 797	(172 228)	735 569

B indicates non-Hispanic black; DCEA, distributional cost-effectiveness analysis; H, Hispanic; QALE, quality-adjusted life expectancy; QALY, quality-adjusted life-year; W, non-Hispanic white.
*Total population based on subgroups: the total US population modeled is based on the remaining 810 US counties in our sample (see Methods).
†Average patient QALE: this estimate represents the average population before considering inpatient COVID-19 interventions. Given the lag in reporting of mortality data and the large observed impact of COVID-19 on mortality, estimates of QALE (in years) derived from US data were further adjusted to reflect QALY losses owing to COVID-19 by estimating average years lost due to COVID-19 for hospitalized patients (based on age and setting of care) multiplied by the number of hospitalized patients in the subgroup. This was done by calculating the expected total QALYs of an individual under standard-of-care treatment in the hospital by taking a weighted average between the subgroup-specific disability-free expected life expectancy and the average age of patients in the CEA model.
‡Health benefits from COVID-19 inpatient treatment: estimate reflects the incremental QALY gains per COVID-19 patient treated inpatient that are scaled based on the estimated number of hospitalized patients in the subgroup.
§Health losses (opportunity costs): the model base-case scenario assumes that opportunity costs are borne equally across the full population. Estimates above were based on the total opportunity costs per a $150 000 opportunity cost threshold, distributed across subgroups based on relative population sizes.

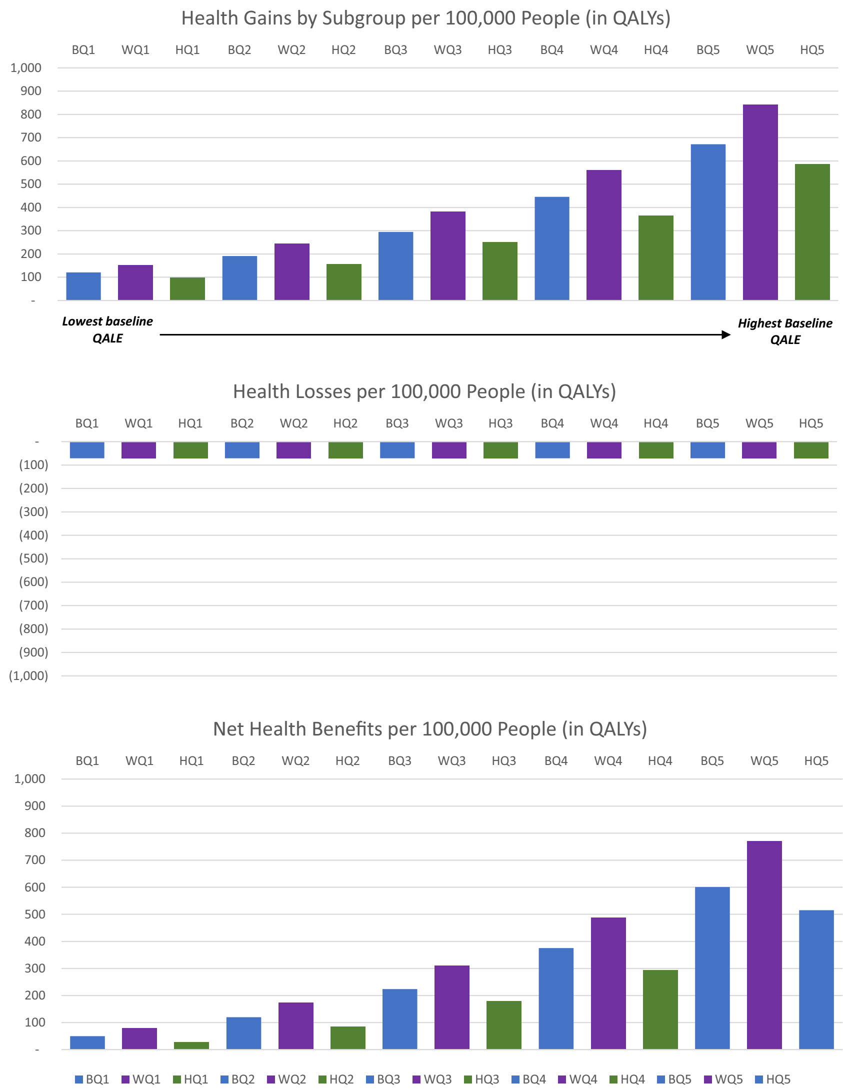
this represents a reduction of more than 130 000 QALYs in the population-level burden of health inequality across the whole US general population (see Appendix Fig. 3 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010).

Plotting the individual-level net monetary benefit per recipient of COVID-19 treatment on the y-axis and the change in population-level health inequality burden (estimated via the Atkinson index) on the x-axis, the relationship between cost-effectiveness and equity impact can be visualized in an equity-efficiency impact plane (Fig. 3).[31] Inpatient COVID-19 treatments fall into the upper right-hand quadrant, indicating that funding COVID-19 treatments not only increases population health overall but also decreases health inequality.

Sensitivity Analyses

Overall conclusions remained robust across scenario and sensitivity analyses. These include the use of alternate opportunity cost thresholds ($50 000, $100 000) for estimation of health losses, alternative Atkinson inequality aversion parameter values, and changes to the assumed cost of the inpatient COVID-19 treatment. Lower thresholds reduced the total population net health benefits from COVID-19 treatments from 735 569 QALYs (base-case 150 000 QALYs threshold) to 391 114 and 649 456 for the 50 000 and 100 000 QALYs thresholds, respectively, because lower thresholds assume that more QALYs are forgone owing to the use of resources for funding the new COVID-19 intervention (see Appendix Table 4 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010). At thresholds of $100 000 and lower, we observed a small negative change in net health in the least deprived subgroups for Hispanics and non-Hispanic whites who had the highest baseline QALE in the sample, but overall population health gains and inequality reduction remained. Results for the relative reduction in health inequality were also consistent across levels of inequality aversion, consistently remaining close to 0.23% when testing inequality aversion levels between 0.5 and 20 at the 150 000 QALYs opportunity cost threshold (see Appendix Table 3 and Appendix Fig. 3 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010). When the assumption was made that opportunity costs were faced by the most or least socially disadvantaged, this had very minor effects on overall health benefits but affected the estimated level of relative inequality reduction in the population (decrease to 0.032% if the most deprived face all opportunity costs and increases to 0.350% if the least deprived face all opportunity costs; see Appendix Table 5 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010). Scenarios exploring the impact of changing

Figure 2. Population-level distribution of gains and losses based on equity-relevant subgroup per 100 000 population.



B indicates non-Hispanic black; H, Hispanic; Q, quintile (1 = least socially vulnerable; 5 = most socially vulnerable); QALE, quality-adjusted life expectancy; QALY, quality-adjusted life-year; SVI, social vulnerability index; W, non-Hispanic white.

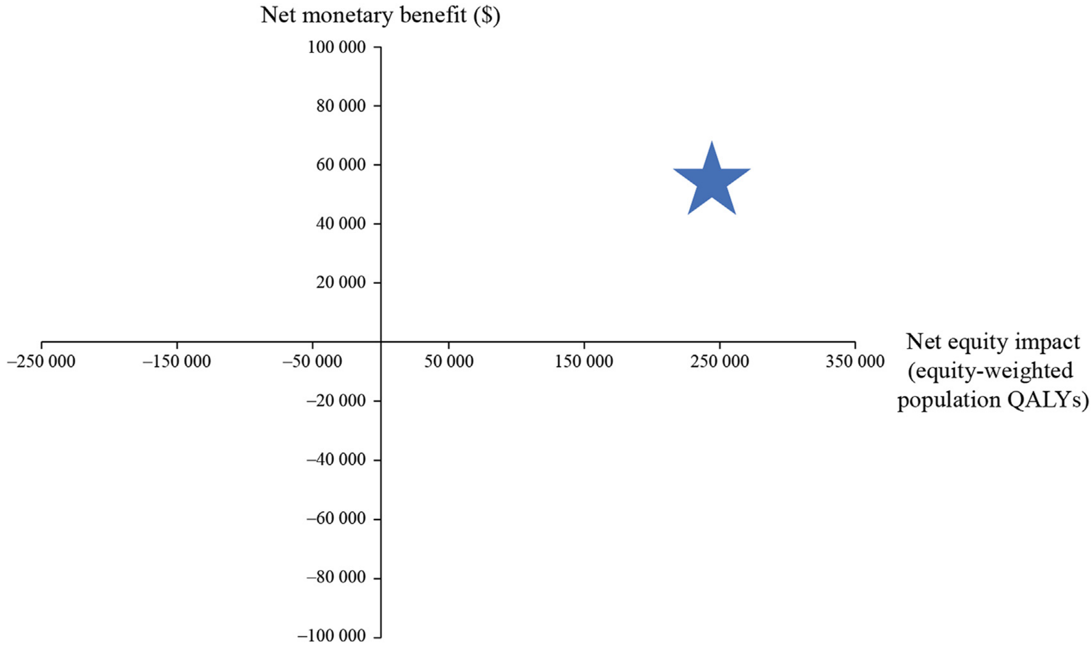
inpatient COVID-19 treatment costs (from $1500 to $3500) did not notably change conclusions from the base case, and threshold analyses revealed that net population health benefits would remain positive as long as the COVID-19 treatment cost was less than $60 100 (see Appendix Table 6 in Supplemental Materials found at https://doi.org/10.1016/j.jval.2022.08.010).

Discussion

A novel DCEA evaluated the equity effects of funding COVID-19 inpatient treatments. First, current levels of health equity were estimated across the United States at all levels of social vulnerability and race and ethnicity to create a nationally representative sample. Next, a previously published CEA for COVID-19 treatments was updated reflecting the impact of underlying social vulnerability and population age demographics on the risk of COVID-19 hospitalization and inpatient mortality. Considering the net health gains and losses across each subgroup at an opportunity cost threshold of $150 000/QALY gained, we found that funding of COVID-19 treatments increased overall population health and reduced inequality. At population level, this translates into 735 569 QALYs gained and a 0.234% reduction in the population-level burden of health inequality. As of 2019, the United States spent approximately $3.8 trillion annually on healthcare. With a total intervention cost of $25.83 billion, funding of inpatient COVID-19 treatments would use approximately 0.68% of the healthcare budget.[32]

To the best of our knowledge, this is the first DCEA conducted in the United States following methods outlined by Cookson and colleagues[15] and the only DCEA to examine COVID-19 treatments.[8] Although the reporting of results aligns with DCEAs conducted in other settings, direct interpretation and comparison are difficult given the many unique features of the US population and healthcare system. For example, we found that more socially vulnerable groups experienced more health benefits from inpatient COVID-19 treatments across all subgroups. Nevertheless, the ethnicity and race differentials are more complex due to

Figure 3. Equity impact plane. Equity impact in equity-weighted QALYs is calculated as the equity-weighted QALY gain of the intervention divided by the standard, unweighted QALY gain. This shows how much the equity impact is worth, in terms of equity-weighted QALYs. This equity impact is plotted on the x-axis and the total net monetary benefit per patient is plotted on the y-axis to clearly demonstrate the impact on both cost-effectiveness on health equality.



QALY indicates quality-adjusted life-year.

confounding by age—leading to nonmonotonic patterns of “intersectionality” among the 15 equity-relevant subgroups. Further application of DCEA is needed in the United States to better explore this intersectionality and to better establish suitable metrics for reporting and benchmarking health inequality impacts in a US context.

Limitations

There is high uncertainty in COVID-19 data. In particular, there is underreporting of COVID-19 cases, hospitalizations, and deaths, and the level of accurate reporting might vary across subgroups. No trial data were identified that reported subgroup effects based on social vulnerability and race and ethnicity, and we were unable to identify any information on distributional effects or costs for postdischarge care that could affect health outcomes. Broader application of DCEA will require further information on how treatments affect heterogenous subgroups and information on the association between other measures of deprivation and health outcomes.[2,3,23]

To date, DCEA has been most commonly applied to single or universal payer settings, with limited application in the United States.[33] The choice of payer is most relevant for selecting unit costs for the model but does not affect the baseline assessment of underlying differences in QALE or the projected impact of COVID-19 treatments on health outcomes. We were able to frame our analysis from a single payer Medicare perspective, but future methodological research is needed to analyze more complex cases when multiple payer perspectives are relevant. The remaining limitations relate to current challenges with US application that can be mitigated through future research. A key data limitation is the quality of US data. Data become sparser as we stratify based on more races and ethnicities and more granular levels of geography, leading to data suppression that limits the ability to understand mortality trends for the full US population across both age groups and racial and ethnic minority populations. Although our sample covered more than 80% of the population and presents a first summary of current health inequality in the United States, we probably underestimate the current level of inequality given that (1) we used county-level data that do not always reflect within-county heterogeneity in mortality and disability and (2) we omitted counties with missing mortality data for non-Hispanic black and Hispanic populations for this current analysis.[34,35] Nevertheless, the trends observed were in line with published estimates of mortality inequalities.[36] We need greater investment in data and methodology enrichment and data imputation or innovations in small area estimation, especially for smaller, rural, and single-race or ethnicity counties.

At present, there is a lack of quality of life data at the county level and for racial and ethnic groups based on age. Although we used a previously published mapping process to address this gap,[22] more data are needed to capture health-related quality of life across racial and ethnic subgroups. For example, reintroducing the 5-level EQ-5D questionnaire instrument to the Medical Expenditure Panel Survey could help to address this gap.[37] In addition, information on US preferences for inequality aversion is missing. Although we used data from the UK as a proxy and we tested alternate aversion levels, a study in the United States is needed to understand the general population preferences for trading overall health for improved health equity. Finally, the COVID-19 research question aligns with the national decision making of Medicare, but the implications of funding affect patients across a range of payers. At present, the US population is covered by both private and public payers in a fragmented system that makes analysis of lifetime health effects more challenging. Nevertheless, irrespective of the current payer for a patient's healthcare, estimation of equity effects should play an increased role in healthcare decision making to ensure that we do not further perpetuate underlying system inequalities.

Conclusion

DCEA of inpatient COVID-19 treatments in the United States suggests that Medicare funding of COVID-19 treatments may improve overall health while reducing existing health inequalities, given the disproportionate impact of COVID-19 hospitalizations on vulnerable communities. To the best of our knowledge, this study represents the first analysis to quantify the equity implications of funding COVID-19 treatments in the United States. To further support application of DCEA in the US context, future research needs to

1 address data suppression to include all geographies and racial and ethnic groups to establish the social distribution of health for the entire United States.[38] Additionally, nationally representative QALY data across age, sex, and race and ethnicity should be generated to replace the need to create proxy mapped estimates, and this will require new national surveys or improved use of historic estimates;
2 survey the US general population to establish benchmark health inequality aversion parameters that can be used in social welfare functions that underpin DCEAs, such as the Atkinson index; and
3 analyze healthcare expenditure patterns across equity-relevant subgroups to better inform the true distribution of opportunity costs from increased health spending.

In addition to filling the research gaps mentioned earlier, US decision makers need to align to endorse their preferred equity-relevant priorities, which will guide the development of consistent generic equity measures (like the SVI) and the creation of core subgroup definitions to be used across settings and research questions.

Supplemental Material

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.jval.2022.08.010.

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Other: Sheinson (development of the economic model), Cookson (advised on methods of DCEA design and contributed to revising the manuscript)

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REFERENCES

1. COVID data tracker. Centers for Disease Control and Prevention. https://covid.cdc.gov/covid-data-tracker. Accessed June 6, 2022.
2. Dasgupta S, Bowen VB, Leidner A, et al. Association between social vulnerability and a county's risk for becoming a COVID-19 hotspot - United States, June 1-July 25, 2020. *MMWR Morb Mortal Wkly Rep.* 2020;69(42):1535–1541.
3. Karmakar M, Lantz PM, Tipirneni R. Association of social and demographic factors with COVID-19 incidence and death rates in the US. *JAMA Netw Open.* 2021;4(1):e2036462.
4. Price-Haywood EG, Burton J, Fort D, Seoane L. Hospitalization and mortality among black patients and white patients with Covid-19. *N Engl J Med.* 2020;382(26):2534–2543.
5. Yehia BR, Winegar A, Fogel R, et al. Association of race with mortality among patients hospitalized with coronavirus disease 2019 (COVID-19) at 92 US hospitals. *JAMA Netw Open.* 2020;3(8):e2018039.
6. Polyakova M, Udalova V, Kocks G, Genadek K, Finlay K, Finkelstein AN. Racial disparities in excess all-cause mortality during the early COVID-19 pandemic varied substantially across states. *Health Aff (Millwood).* 2021;40(2):307–316.
7. Biden Jr . Executive order on ensuring an equitable pandemic response and recovery. The White House. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/21/executive-order-ensuring-an-equitable-pandemic-response-and-recovery/. Accessed June 6, 2022.
8. Podolsky MI, Present I, Neumann PJ, Kim DD. A systematic review of economic evaluations of COVID-19 interventions: considerations of non-health impacts and distributional issues. *Value Health.* 2022;25(8):1298–1306.
9. Kelton K, Klein T, Murphy D, et al. Cost-effectiveness of combination of baricitinib and remdesivir in hospitalized patients with COVID-19 in the United States: a modelling study. *Adv Ther.* 2022;39(1):562–582.
10. Whittington MD, Pearson SD, Rind DM, Campbell JD. The cost-effectiveness of remdesivir for hospitalized patients with COVID-19. *Value Health.* 2022;25(5):744–750.
11. Shah NH, Suthar AH, Jayswal EN. Control strategies to curtail transmission of COVID-19. *Int J Math Sci.* 2020;2020:2649514.
12. O'Day K, Mezzio D, Meyer K. The potential impact of pharmaceutical and non-pharmaceutical interventions to mitigate the COVID-19 crisis in the United States: a model-based analysis. Xcenda. https://www.xcenda.com/-/media/assets/xcenda/english/content-assets/white-papers-issue-briefs-studies-pdf/xcenda_interventions_mitigate_covid-19_model-based_analysis.pdf?la=en&hash=9E915914F9B4BD0CFEA40EE02B9E7C1029B25279. Accessed June 6, 2022.
13. Sheinson D, Dang J, Shah A, Meng Y, Elsea D, Kowal S. A cost-effectiveness framework for COVID-19 treatments for hospitalized patients in the United States. *Adv Ther.* 2021;38(4):1811–1831.
14. Sheinson DM, Wong WB, Solon CE, et al. Estimated impact of public and private sector COVID-19 diagnostics and treatments on US healthcare resource utilization. *Adv Ther.* 2021;38(2):1212–1226.
15. Cookson R, Griffin S, Norheim O, Culyer A. *Distributional Cost-Effectiveness Analysis: Quantifying Health Equity Impacts and Trade-Offs.* Oxford, England: Oxford University Press; 2021.
16. Beigel JH, Tomashek KM, Dodd LE, et al. Remdesivir for the treatment of Covid-19 - final report. *N Engl J Med.* 2020;383(19):1813–1826.
17. RECOVERY Collaborative Group, Horby P, Lim WS, et al. Dexamethasone in hospitalized patients with Covid-19. *N Engl J Med.* 2021;384(8):693–704.
18. weekly summary of U.S A. COVID-19 hospitalization data. COVID-NET. https://gis.cdc.gov/grasp/COVIDNet/COVID19_5.html. Accessed June 6, 2022.
19. Golestaneh L, Neugarten J, Fisher M, et al. The association of race and COVID-19 mortality. *EClinicalMedicine.* 2020;25:100455.

20. Renelus BD, Khoury NC, Chandrasekaran K, et al. Racial disparities in COVID-19 hospitalization and in-hospital mortality at the height of the New York City pandemic. *J Racial Ethn Health Disparities*. 2021;8(5):1161–1167.
21. Ogedegbe G, Ravenell J, Adhikari S, et al. Assessment of racial/ethnic disparities in hospitalization and mortality in patients with COVID-19 in New York City. *JAMA Netw Open*. 2020;3(12):e2026881.
22. Asaria M, Griffin S, Cookson R. Distributional cost-effectiveness analysis: a tutorial. *Med Decis Mak*. 2016;36(1):8–19.
23. Nayak A, Islam SJ, Mehta A, et al. Impact of social vulnerability on COVID-19 incidence and outcomes in the United States. *medRxiv*. 2020. https://doi.org/10.1101/2020.04.10.20060962.
24. CDC SVI documentation 2018. Agency for Toxic Substances and Disease Registry. https://www.atsdr.cdc.gov/placeandhealth/svi/documentation/pdf/SVI2018Documentation-H.pdf. Accessed June 6, 2022.
25. Gross CP, Essien UR, Pasha S, Gross JR, Wang SY, Nunez-Smith M. Racial and ethnic disparities in population-level Covid-19 mortality. *J Gen Intern Med*. 2020;35(10):3097–3099.
26. Remington PL, Catlin BB, Gennuso KP. The county health rankings: rationale and methods. *Popul Health Metr*. 2015;13:11.
27. Sullivan PW, Ghushchyan V. Preference-Based EQ-5D index scores for chronic conditions in the United States. *Med Decis Making*. 2006;26(4):410–420.
28. Reese H, Iuliano AD, Patel NN, et al. Estimated incidence of coronavirus disease 2019 (COVID-19) illness and hospitalization-united states, February-September 2020. *Clin Infect Dis*. 2021;72(12):e1010–e1017.
29. Vanness DJ, Lomas J, Ahn H. A health opportunity cost threshold for cost-effectiveness analysis in the United States. *Ann Intern Med*. 2021;174(1):25–32.
30. French E, Kelly E. Medical spending around the developed world. *Fisc Stud*. 2016;37(3-4):327–344.
31. Robson M, Asaria M, Cookson R, Tsuchiya A, Ali S. Eliciting the level of health inequality aversion in England. *Health Econ*. 2017;26(10):1328–1334.
32. National health expenditure data - historical. Centers for Medicare & Medicaid Services. https://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/NationalHealthExpendData/NationalHealthAccountsHistorical. Accessed June 6, 2022.
33. Avanceña ALV, Prosser LA. Examining equity effects of health interventions in cost-effectiveness analysis: a systematic review. *Value Health*. 2021;24(1):136–143.
34. Chetty R, Stepner M, Abraham S, et al. The association between income and life expectancy in the United States, 2001-2014. *JAMA*. 2016;315(16):1750–1766.
35. Dwyer-Lindgren L, Stubbs RW, Bertozzi-Villa A, et al. Variation in life expectancy and mortality by cause among neighbourhoods in King County, WA, USA, 1990-2014: a census tract-level analysis for the Global Burden of Disease Study 2015. *Lancet Public Health*. 2017;2(9):e400–e410.
36. Mariotto AB, Zou Z, Johnson CJ, Scoppa S, Weir HK, Huang B. Geographical, racial and socio-economic variation in life expectancy in the US and their impact on cancer relative survival. *PLoS One*. 2018;13(7):e0201034.
37. Cohen SB, Unangst J. Data integration innovations to enhance analytic utility of clinical trial content to inform health disparities research. *Front Oncol*. 2018;8:365.
38. Love-Koh J, Asaria M, Cookson R, Griffin S. The social distribution of health: estimating quality-adjusted life expectancy in England. *Value Health*. 2015;18(5):655–662.