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California's COVID-19 Vaccine Equity Policy: Cases, Hospitalizations, And Deaths Averted In Affected Communities

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ABSTRACT **In March 2021, California implemented a vaccine equity policy that prioritized COVID-19 vaccine allocation to communities identified as least advantaged by an area-based socioeconomic measure, the Healthy Places Index. We conducted quasi-experimental and counterfactual analyses to estimate the effect of this policy on COVID-19 vaccination, case, hospitalization, and death rates. Among prioritized communities, vaccination rates increased 28.4 percent after policy implementation. Furthermore, an estimated 160,892 COVID-19 cases, 10,248 hospitalizations, and 679 deaths in the least-advantaged communities were averted by the policy. Despite these improvements, the share of COVID-19 cases, hospitalizations, and deaths in prioritized communities remained elevated. These estimates were robust in sensitivity analyses that tested exchangeability between prioritized communities and those not prioritized by the policy; model specifications; and potential temporal confounders, including prior infections. Correcting for disparities by strategically allocating limited resources to the least-advantaged or most-affected communities can reduce the impacts of COVID-19 and other diseases but might not eliminate health disparities.**

After SARS-CoV-2 emerged in 2019, the COVID-19 pandemic exacerbated and further revealed long-standing health disparities in California, the United States, and the world.[1–4] Although these disparities are partially explained by differential rates of comorbidities and other medical risks, including age, social and structural determinants also played a key role.[5,6] These social and structural factors led to disparities in access to testing, health care, the opportunity to work remotely, the ability to isolate or quarantine, and other essential components of pandemic response strategies, including vaccine and treatment access.[5,7,8] Equity-focused policies that deliberately allocate more resources to communities most affected by these inequities offer a promising strategy to mitigate health disparities.

Vaccination strategies may be particularly amenable to equity-focused policies because of their long-lasting protective effects. The high efficacy of COVID-19 vaccines and their ability to induce durable protection against severe outcomes such as hospitalization and death make COVID-19 vaccines a valuable medical countermeasure to combat disparities.[9] However, equitable vaccination is unlikely to be achieved without explicit effort to account for disparate access to and uptake of vaccines.[10] Instead, vaccination policies that prioritize the least-advantaged or most-affected populations are required to equitably distribute the benefits of vaccination.[11,12]

To reduce inequities in COVID-19 burden and prevent inequities in vaccination among its diverse residents, the State of California implemented an equity-focused policy early during its vaccination rollout. This vaccine equity allocation policy (hereafter "the policy") implemented in March 2021 distributed 40 percent of available COVID-19 vaccines to the least-advantaged one-quarter of communities in California.[13] The policy used the Healthy Places Index, an area-based socioeconomic measure that provides an assessment of the ability of community residents to live a healthy life.[14] The Healthy Places Index facilitated the identification of COVID-19-related disparities in California and formed the basis of other equity-focused policies in the state during the pandemic, including the Blueprint for a Safer Economy, which was in effect from August 2020 through June 2021.[15] While making up approximately a quarter of the state's population, people residing in ZIP codes classified as least advantaged by falling in the lowest 25 percent of Healthy Places Index scores experienced almost 40 percent of all COVID-19 cases and deaths, motivating the allocation of 40 percent of vaccines to these communities.[13]

The primary objective of this analysis was to evaluate the impact of California's vaccine equity allocation policy on COVID-19 vaccination rates and outcomes. We used a quasi-experimental difference-in-differences approach to estimate the effect of the policy on vaccination rates in communities that received the equity allocation. We then used a counterfactual approach to estimate the numbers of COVID-19 cases, hospitalizations, and deaths averted as a result of the policy.

Study Data And Methods

DATA SOURCES The Healthy Places Index is an area-based socioeconomic measure developed by the Public Health Alliance of Southern California that integrates data from the Census Bureau's American Community Survey (ACS), California Environmental Protection Agency, Bureau of Labor Statistics, and other agencies to generate an index score calibrated to life expectancy at birth at the census tract level. Details of Healthy Places Index development are available in a technical report.[16] Some census tracts were not assigned scores because of their small population or other exclusion criteria, and vaccine allocation was conducted at the ZIP code level. Thus, the Vaccine Equity Metric (VEM) was developed by the California Department of Public Health in March 2021 to derive ZIP code–level scores for every ZIP code in the state.[14,17] The California Department of Public Health assigned a VEM score for every ZIP code in California by fitting regression models using known data points from the ACS, Surgo Ventures' COVID-19 Community Vulnerability Index,[18] and the California Hard-to-Count Index[19] to existing Healthy Places Index scores and then using the trained model to predict the VEM in ZIP codes that lacked a score. These scores were percentile ranked and partitioned into quartiles, using quartile thresholds from the Healthy Places Index to determine VEM quartile 1 ZIP codes prioritized by the policy. Thus, VEM quartile 1 was interpreted as the 25 percent of ZIP codes in the state where residents have the least opportunity to live a healthy life. The policy then allocated 40 percent of available vaccines to VEM quartile 1 communities, with the remaining 60 percent of vaccines divided evenly among VEM quartile 2–4 communities. The policy also included equity-oriented technical assistance, contracting support, staffing resources, and mobile vaccination sites for local health jurisdictions to aid their vaccination outreach. Finally, vaccination appointments were reserved for VEM quartile 1 residents to ensure that vaccines allocated to VEM quartile 1 communities were administered to the intended residents.[13]

COVID-19 vaccination records were collected from statewide immunization databases and the California Immunization Registry. The date of administration and ZIP code of residence of people receiving COVID-19 vaccination, regardless of dose number, were joined with ZIP code–level VEM scores to generate a data set of daily vaccinations received by VEM quartile.

Person-level records of confirmed SARS-CoV-2 infections in California reported to the California Department of Public Health as part of mandatory case reporting were used to derive weekly time series of COVID-19 cases, hospitalizations, and deaths. Individual addresses reported in the department's Electronic Lab Reporting system were used to assign ZIP code of residence. Cases were defined as laboratory-confirmed, positive SARS-CoV-2 nucleic acid amplification tests reported to the California Department of Public Health, regardless of symptom status. Hospitalizations were determined from the California COVID-19 Reporting System and supplementary reports submitted by hospitals statewide to the California Department of Public Health. COVID-19 deaths were defined as people with confirmed COVID-19-associated deaths reported to the California Department of Public Health by local health departments. COVID-19 confirmed cases and deaths follow California Department of Public Health guidance and definitions set by the Council of State and Territorial Epidemiologists.[20] Population data were drawn from 2016–20 ACS five-year estimates.

Analytic Approach

▶ **Vaccination Outcomes:** We conducted a difference-in-differences analysis to compare the rate of vaccination in prioritized VEM quartile 1 ZIP codes with rates in non–VEM quartile 1 ZIP codes before and after the policy was implemented. A Poisson generalized linear model was fit with the number of vaccinations administered by ZIP code as the outcome and ZIP code population as an offset term. Main effects for binary before/after policy implementation, binary VEM quartile 1/non–quartile 1 status, and their interaction were included, along with a main effect on county to account for variability between local health jurisdictions. Symmetric four-week periods before and after the policy was implemented on March 1, 2021, were used to estimate the immediate effect of the policy on vaccination rates before COVID-19 vaccines became less supply constrained around May 2021. The target parameter in the generalized linear model was the interaction term between VEM quartile 1 and the binary before/after policy variable, representing the change in vaccination rates in VEM quartile 1 ZIP codes compared with rates in non–VEM quartile 1 ZIP codes, ostensibly due to the policy. Robust standard errors using the sandwich estimator were used for all regression models to generate 95% confidence intervals around effect estimates.

We conducted additional analyses described in detail in the online appendix[21] to probe key assumptions of the difference-in-differences model, including the potential effect of secular declines in vaccination rates due to depletion of the eligible population, the suitability of non–VEM quartile 1 populations to serve as controls for VEM quartile 1 populations, the potential for unmeasured confounders, and the length of the symmetric pre-post policy period.

▶ **COVID-19 Outcomes:** Analyzing the effect of an upstream vaccine policy on COVID-19 outcomes (cases, hospitalizations, and deaths) is more challenging than evaluating the effect of the policy on vaccinations. Multidose vaccination schedules, along with variability in exposure, testing access, and underlying health conditions, may affect observed rates of COVID-19 outcomes. We used a counterfactual approach used previously to estimate the impact of vaccination campaigns in which a control group does not exist.[22,23] In this approach, the expected number of COVID-19 cases, hospitalizations, and deaths in the absence of the policy were estimated from fitted generalized linear models and compared with observed outcomes.[22] Procedures for fitting and assessing candidate generalized linear models to derive the most accurate counterfactual estimates of COVID-19 outcomes are described in the appendix.[21] All case, hospitalization, and death data were aggregated at the ZIP code–week level, with weeks defined by the preceding Monday of each record to align with the Monday, March 1, 2021, policy start date. The observation period was defined as December 14, 2020, when phase 1A of California's vaccination campaign began,[24] through November 1, 2021, just before the emergence of the Omicron variant and widespread booster rollout.

For each outcome, the generalized linear model with the lowest mean squared error was used to generate counterfactual estimates for VEM quartile 1 in the absence of the policy by setting the intervention variable (and any interaction terms with the intervention variable) to 0 and re-estimating the outcome from the fitted model. Averted COVID-19 cases, hospitalizations, and deaths in VEM quartile 1 were estimated as the difference between these counterfactual model predictions and observed values. Clustered nonparametric bootstrapping at the ZIP code level with 10,000 bootstrapped samples was conducted to generate estimates of uncertainty in outcomes avoided that were robust to model misspecification. To ensure that outcomes-averted results were not driven solely by the best-performing model, estimates were also generated from the next-best-performing models, as described in the appendix.[21]

Data And Code Availability Where possible, the data and code used in these analyses are available on the California Open Data Portal[25] and on GitHub.[26] However, ZIP code–level weekly time series of COVID-19 outcomes are considered protected public health data. Investigators interested in obtaining these data should contact the corresponding author to discuss the process for developing a data use agreement and obtaining the data. All analyses were conducted using R Statistical Software, version 4.04, using the tidyverse,[27] splines, lme4,[28] sandwich,[29] and fastglm packages.

Equity-based policies to guide public health programs and resource allocation are critical to addressing health disparities.

LIMITATIONS There are inherent limitations in a complex policy analysis assessing the impact of vaccine policies. Our main challenge was overcoming the lack of a consistently reliable comparison group for VEM quartile 1 communities that were prioritized by the policy. Our counterfactual approach was similar to a synthetic control analysis in which counterfactual estimates are generated for the target population in the absence of a control group and compared with what was actually observed.[23] Our approach to evaluating candidate models on their out-of-sample performance optimized our counterfactual estimates by rigorously identifying the model with the best out-of-sample predictions. Bootstrapped resampling at the ZIP code level to generate uncertainty estimates also ensured that our results were not reliant on a small number of overly influential observations (such as very high population ZIP codes) and that results accurately reflected uncertainty in the estimation procedure.

Study Results

POLICY IMPACT ON VACCINATIONS ADMINISTERED

Nearly 14.9 million COVID-19 vaccinations were administered in California in the combined four-week periods before and after the vaccine equity allocation policy began on March 1, 2021 (February 1, 2021–March 29, 2021). The vaccination rate per 100,000 in the eight-week period was highest in VEM quartile 4 and lowest in VEM quartile 1 (exhibit 1). However, the vaccination rate increased the most in VEM quartile 1 after the equity allocation, from 9,998 vaccinations per 100,000 in the four weeks before the equity allocation to 18,146 per 100,000 in the four weeks after (exhibit 1). Appendix exhibit S1 shows that trends in vaccination rates across each VEM quartile were consistent leading up to the policy period, validating the essential parallel trends assumption of the difference-in-differences analysis.[21]

The vaccination rate in VEM quartile 1 ZIP codes in the four weeks after policy implementation increased by an estimated 28.4 percent (95% confidence interval: 22.1, 35.1) compared with non–VEM quartile 1 ZIP codes. Adjusting for the proportion of the population unvaccinated led to an insignificant change in the effect estimate to 26.9 percent (95% CI: 20.9, 33.1) (data not shown). Pairwise comparisons among all VEM quartiles in the negative controls sensitivity analysis suggest that there were also significant relative increases in the vaccination rate among VEM quartile 2 ZIP codes compared with VEM quartiles 3 and 4 ZIP codes (increases of 8.0 percent [95% CI: 2.4, 13.8] and 10.3 percent [95% CI: 5.0, 15.7], respectively, in the after-policy period; appendix table S1).[21] Rerunning the difference in differences analysis with two- and eight-week periods before and after the policy was implemented did not meaningfully affect estimates (appendix table S1).[21] Finally, restricting the analysis to ZIP codes in the second and third VEM octiles (that is, the upper half of VEM quartile 1 and the lower half of VEM quartile 2) for better exchangeability between treated and untreated groups led to an estimated 8.9 percent increase (95% CI: 1.1, 17.2) in vaccination rates in VEM octile 2 communities (data not shown).

POLICY IMPACT ON COVID-19 OUTCOMES Out-of-sample error from the best-performing cases model was relatively low (appendix exhibit S2),[21] translating to approximately seventeen cases per ZIP code–week observation, and the model closely reproduced observed outcomes, providing confidence in the counterfactual estimates used to estimate cases averted.

From this model, it was estimated that in the eight months after the policy was implemented, 160,892 cases (95% CI: 108,878, 221,815) were

EXHIBIT 1

COVID-19 vaccinations administered in California by Vaccine Equity Metric (VEM) quartile in the four-week periods before and after the vaccine equity allocation policy was implemented on March 1, 2021

		Vaccinations administered			
		Before		After	
VEM quartiles	Population	Number	Per 100,000	Number	Per 100,000
1	10,617,434	1,061,509	9,998	1,926,615	18,146
2	9,902,750	1,386,711	14,003	2,085,838	21,063
3	9,397,006	1,641,233	17,465	2,285,986	24,327
4	9,298,697	1,898,517	20,417	2,589,952	27,853

SOURCE Authors' analysis of vaccination data from the California Immunization Registry, February 1, 2021–March 29, 2021. **NOTE** This exhibit demonstrates that COVID-19 vaccination rates increased more in prioritized VEM quartile 1 communities (the least-advantaged communities) after the policy was implemented.

averted in VEM quartile 1 ZIP codes (exhibit 2, sum of the light blue hashed areas; see also appendix exhibit S7).[21] This represents 30.3 percent of all expected cases that would have occurred in VEM quartile 1 between March 1 and November 1, 2021, in the absence of the policy. Most of the cases averted in this time frame came after July 1, 2021, during the beginning of California's Delta variant wave. However, 22,875 cases (95% CI: 16,067, 30,582) were averted in the first two months after the equity allocation.

Although approximately one-fourth of California's population resides in VEM quartile 1 areas, residents in VEM quartile 1 accounted for 37 percent of cases in the two months before the policy was implemented (exhibit 3). Excess COVID-19 cases among the least-advantaged VEM quartile 1 communities prioritized by the policy were reduced in the postpolicy period (exhibit 3, "observed" line), whereas counterfactual estimates suggest that disparities would have persisted unabated without the policy (exhibit 3, "counterfactual" line). In fact, in April 2021 and again in July 2021, the proportion of overall cases occurring in VEM quartile 1 matched the proportion of the state population residing in VEM quartile 1, suggesting that the burden of disease in these communities was briefly not disproportionate.

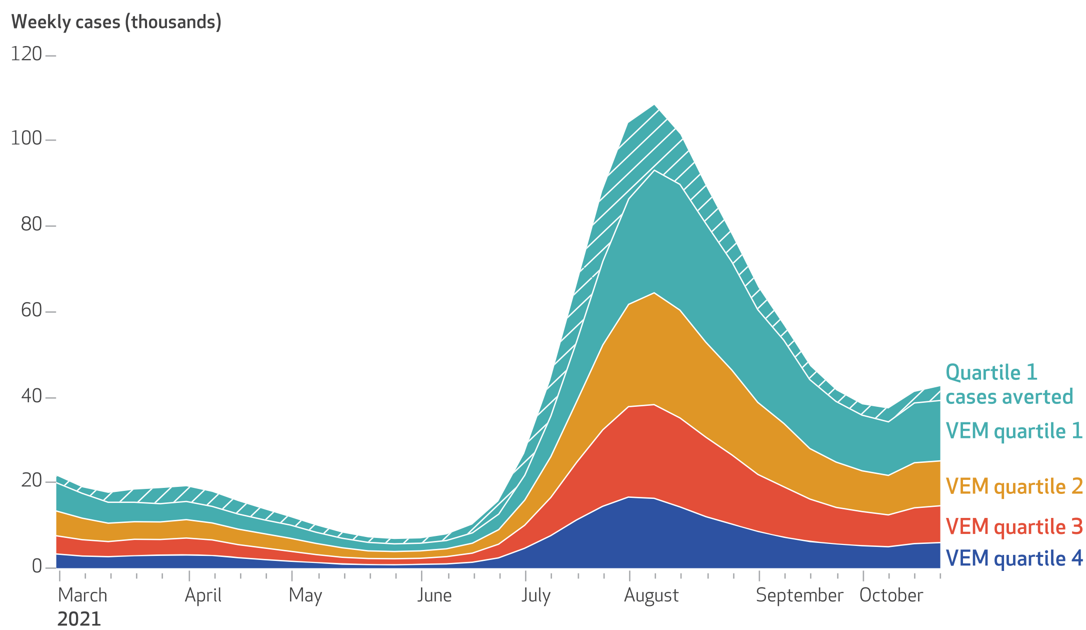
Results from the same analyses estimating the impact of the policy on COVID-19 hospitalizations and deaths are reported in detail in appendix exhibits S3–S11.[21] In brief, 10,248 hospitalizations (95% CI: 6,111, 14,853) and 679 deaths (95% CI: −32, 1,451) were estimated to have been averted as a result of the policy.

Discussion

Equity-based policies to guide public health programs and resource allocation are critical to addressing health disparities. The effectiveness of these policies, however, often lacks rigorous evaluation. Throughout the COVID-19 pandemic, the California Department of Public Health used area-based socioeconomic measures such as the Vaccine Equity Metric to aid equity-focused policies. In this analysis, we demonstrated that one such policy to distribute more vaccines to less advantaged communities led to increased vaccination rates and subsequent decreases in COVID-19 cases, hospitalizations, and deaths among the prioritized populations that

EXHIBIT 2

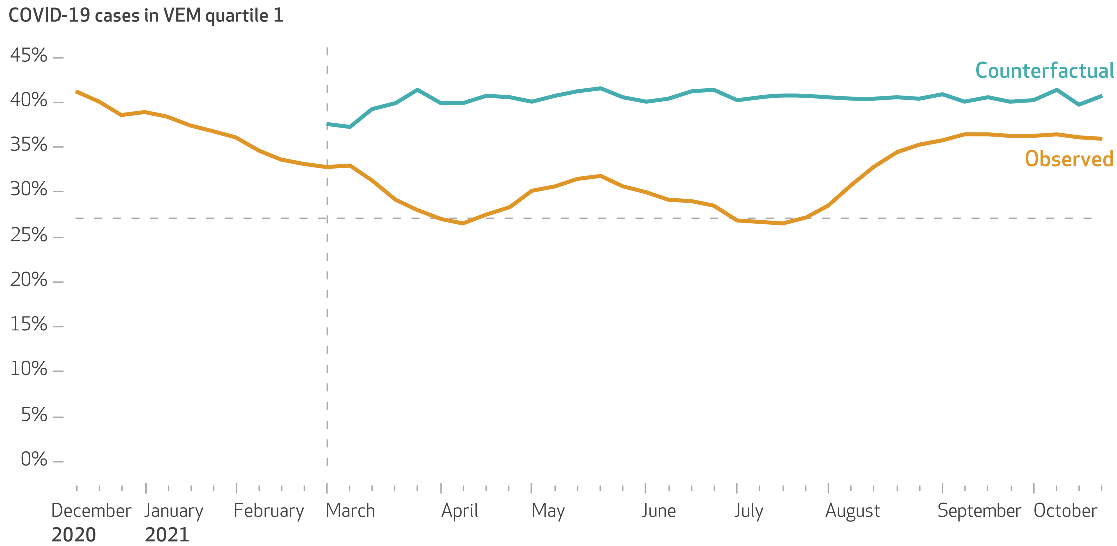
Time series of weekly COVID-19 cases in California, stratified by Vaccine Equity Metric (VEM) quartile, March 1–November 1, 2021



SOURCE Authors' analysis of COVID-19 case data collected from routine public health surveillance by the California Department of Public Health, December 2020–November 2021. **NOTES** This exhibit depicts COVID-19 cases by VEM quartile and cases in quartile 1 (the least-advantaged quartile) averted after policy implementation. Cases remained at relatively low levels around the time the policy was implemented on March 1, 2021, until the Delta variant caused increased activity beginning in July 2021. Light blue hashed areas indicate cases that were averted in VEM quartile 1, as estimated in the counterfactual analyses. Significant estimates of cases averted were reached soon after the policy was implemented, although the majority of cases averted came during the Delta wave, when COVID-19 activity was significantly higher.

EXHIBIT 3

Percent of all weekly COVID-19 cases in California occurring among residents of the least-advantaged quartile of the Vaccine Equity Metric (VEM quartile 1), December 14, 2020–November 1, 2021



SOURCE Authors' analysis of COVID-19 case data collected from routine public health surveillance by the California Department of Public Health, December 2020–November 2021. **NOTES** This exhibit shows the disproportionate burden of COVID-19 cases occurring in VEM quartile 1. The blue and orange lines show, respectively, the counterfactual estimates of and observed percent of cases occurring among VEM quartile 1 populations. The vertical dashed line (March 1, 2021) indicates the week the policy was implemented, and the horizontal dashed line indicates the percent of California's overall population residing in VEM quartile 1 ZIP codes (27 percent). This population percent serves as a reference for the percent of cases that would have occurred in VEM quartile 1 if cases were equally distributed across VEM quartiles. Observations above this line suggest that COVID-19 cases were occurring disproportionately among VEM quartile 1 populations. The orange line falling closer to the horizontal reference line after the policy was implemented suggests that the policy reduced disparities in COVID-19 cases among VEM quartile 1 residents.

were disproportionately affected by the pandemic. Specifically, we estimated that vaccination rates increased by 28.4 percent, and more than 160,000 cases, 10,000 hospitalizations, and 670 deaths were averted because of the policy.

Our estimate of a 28.4 percent increase in the vaccination rate in VEM quartile 1 areas in the four weeks after the policy was implemented compared with all other areas varied in sensitivity analyses that tested key assumptions of the base model. When we compared VEM quartile 1 areas with VEM quartile 2 areas only, we estimated a 20.7 percent increase, whereas comparing only the upper half of VEM quartile 1 with the lower half of VEM quartile 2 (octiles 2 and 3) resulted in a further attenuated 8.9 percent increase. Although our negative controls analysis suggested that there were significant increases in vaccination rates in both VEM quartile 2 and quartile 3 communities compared with those in quartile 4, adjustment for the proportion of the population that was vaccinated before and after the policy was implemented had very little effect on these estimates. Together, these results may suggest the presence of additional factors that influenced vaccination rates at the time the policy was implemented. Another potential explanation is that VEM quartile 1 and quartile 2 ZIP codes often border each other, leading to the potential for spillover effects of the policy into VEM quartile 2 ZIP codes. Regardless, the equity allocation appears to have led to at least an 8.9 percent increase in the vaccination rate among intended VEM quartile 1 residents.

The increased vaccination rate among VEM quartile 1 communities also resulted in significant decreases in COVID-19 outcomes. Over the course of the eight months after the policy, more than 160,000 cases, 10,000 hospitalizations, and 670 deaths were averted among VEM quartile 1 residents. These results corroborate prior theoretical work that found that vaccine distribution to disadvantaged communities can reduce inequities in COVID-19 outcomes.[11] Our results are also in agreement with previous analyses that quantified the impact of vaccinations on COVID-19 outcomes among all Californians during a similar period. Sophia Tan and colleagues found that approximately 1.5 million cases, 72,000 hospitalizations, and 20,000 deaths were averted as a result of all vaccinations in California through mid-October 2021.[30] Our results—evaluated from the beginning of the policy in March 2021 through the end of

October 2021—suggest that the policy accounted for 10.5 percent of these averted cases, 14.1 percent of averted hospitalizations, and 3.5 percent of averted deaths.

Our analysis has the added value of assessing how equitably these averted outcomes were distributed across the population. COVID-19 heavily affected VEM quartile 1 communities in the prevaccine era of the pandemic, with these communities accounting for 40 percent of all cases and deaths despite making up only about a quarter of California's population.[13] Our counterfactual estimates imply that this disparity would have persisted at similar levels without the policy. However, the observed proportion of cases occurring in VEM quartile 1 communities was briefly equivalent to the proportion of the population in these communities after the policy was implemented (exhibit 3). This implies that the policy reduced inequities in the distribution of COVID-19 cases but did not eliminate these inequities entirely.

The majority of estimated COVID-19 outcomes averted in this analysis were accumulated during the Delta wave in July and August 2021, more than four months after the policy was implemented in early March. Attributing COVID-19 outcomes averted in this period to the policy may be tenuous, as people vaccinated earlier because of the policy may feasibly have been vaccinated by August 2021 despite the policy. However, some people who were vaccinated because of the policy may otherwise never have been vaccinated as a result of the increased politicization of the vaccine[31] in summer 2021 or other factors, such as lack of access. Estimating the size of these and other relevant population subsets that were affected by the policy is infeasible. Despite the large effect estimated during the Delta wave, significant estimates of cases, hospitalizations, and deaths averted were attained quickly after the equity allocation policy was implemented, well before the Delta wave in California.

The estimate of cumulative deaths averted because of the policy failed to reach significance (that is, overlapped with zero deaths averted) at the end of the estimation period, although estimates were significant in some weeks before the Delta period (appendix exhibit S9).[21] Temporal trends of deaths averted in the eight months after the policy also did not align as well with cases and hospitalizations, suggesting that different factors may have influenced the progression of COVID-19 cases and hospitalizations to deaths. The Delta variant's increased severity, particularly among unvaccinated people,[32] is likely partially responsible for this. In addition, changing clinical treatment aided by the approval of remdesivir[33] and monoclonal antibodies[34] over the course of 2021 could have confounded the effect of the intervention variable and influenced the counterfactual mortality estimates. Similarly, survivorship bias could have affected the accurate estimation of deaths in the postpolicy era, as many people who were vulnerable to severe COVID-19 outcomes may have succumbed to the disease before the widespread availability of vaccines.[35]

These findings have important implications for developing equity-focused policies that rely on resource allocation to combat disparities.

These findings have important implications for developing equity-focused policies that rely on resource allocation to combat disparities. Area-based measures of social vulnerability such as the VEM or broader metrics such as the COVID-19 vaccine equity index,[36] social vulnerability index,[37] and Area Deprivation Index[38] are essential to facilitating these policies. Because vaccine delivery was conducted at the ZIP code level, the VEM was developed at the ZIP code level to implement the vaccine equity allocation policy. However, even at the ZIP code level, neighborhood-level disparities may be masked, potentially leaving behind communities with higher social vulnerability that are embedded in ZIP codes with generally more advantaged conditions. Equity-focused resource allocation strategies should therefore be implemented at the smallest scale feasible for implementation to maximize coverage.

Conclusion

We found consistent evidence that California's vaccine equity allocation policy that distributed more vaccines to the least-advantaged and most-affected communities resulted in substantial increases in vaccination rates and reductions in COVID-19 cases, hospitalizations, and deaths. However, the policy was not sufficient to eliminate disparities in vaccination rates and COVID-19 risk experienced by these communities. Additional public health interventions that address disparities across all social determinants of health, in addition to outcome-specific policies such as vaccine equity allocation, are needed to achieve health equity.[39] ■

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21 To access the appendix, click on the Details tab of the article online.

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