What prioritizing worse-off minority groups for COVID-19 vaccines means quantitatively: practical, legal and ethical implications

Simulating the impact of three different measures of disadvantage under the National Academies Framework for equitable covid-19 vaccine allocation

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Background

To help mitigate structural disadvantage, the National Academies of Science, Engineering and Medicine (NASEM) framework for equitably allocating COVID-19 vaccines proposed increasing allocations to worse-off minorities through the CDC's Social Vulnerability Index (SVI).[1,2,3] However, the extent of benefit is unknown. Moreover, since SVI includes a race variable and could face legal challenges,[4] it is desirable to quantify using an alternative such as the Area Deprivation Index (ADI) that does not include race and can offer more targeted prioritization as it is centered on the block-group, not census-tract level. We therefore sought to determine what shares of minorities would be offered vaccines under the NASEM's allocation framework comparing: 1) no disadvantage index, to 2) SVI to 3) ADI.[4,5]

Methods

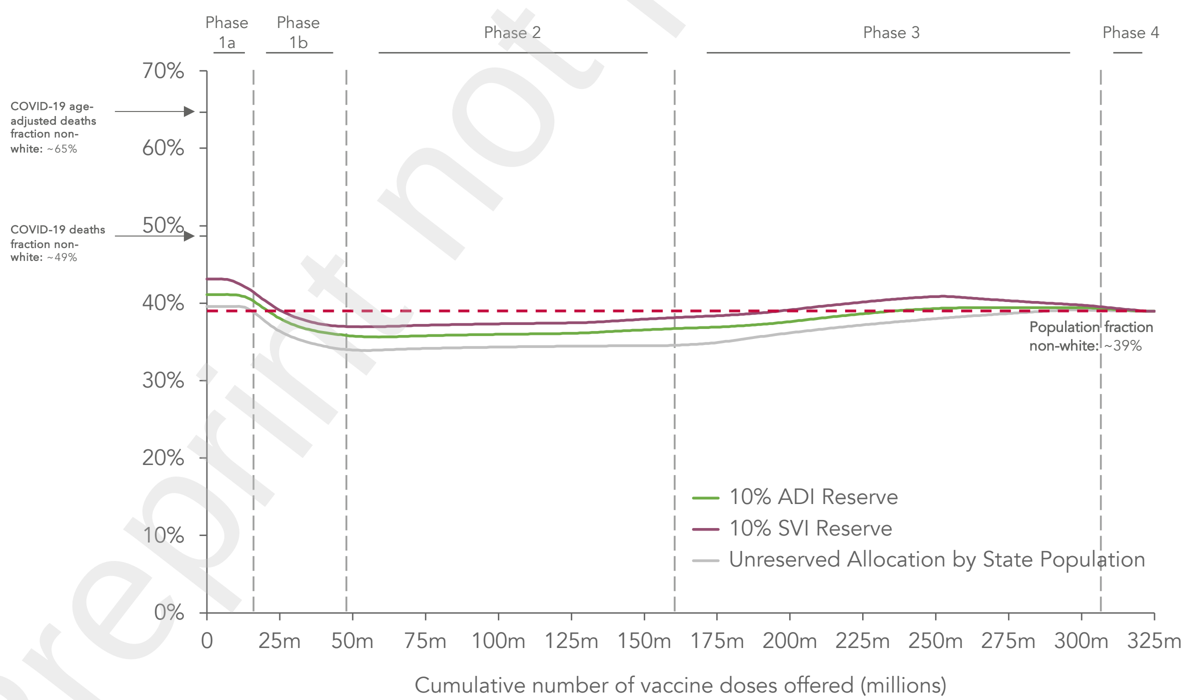
Expanding earlier work (see Appendix), we simulated NASEM's framework with 1) no disadvantage index, 2) SVI, 3) ADI.[6] We used the American Community Survey (ACS) 2014-2018 5-year Public Use Microdata Sample (PUMS) and the 2018 Behavioral Risk Factor Surveillance System (BRFSS) to capture key population groups, consistent with NASEM and key analyses (see Appendix).[1,6] We implemented SVI's dominant application, weighing its constituent elements equally,[7] and ADI as defined.[5]

Following NASEM, states received vaccines proportionate to their population and 10% of the total allocation was reserved for the worst-off quartiles (in addition to their regular allocation).[1,2,3] NASEM's instructs states to undertake additional "special efforts" to reach worse-off populations, which we show with an additional 10% allocation.[1] We consider an allocation procedure that uses reserve allocation in the most beneficial manner for the worse-off quartile while allocating available vaccines following the NASEM phases for worse-off and better-off population separately (see the Appendix for details). Below, "worse-off" refers to SVI's or ADI's most deprived quartile, "better-off" to the remainders of the population.

Results

Figure 1 shows vaccine offers to all minorities across all phases with no adjustments and 10% reserve for worse-off groups, using SVI or ADI.

Figure 1: Proportion of vaccine doses offered to non-white populations,
By cumulative number of vaccine doses offered



Notes: COVID-19 death fraction and age-adjusted death fraction is as of 09/15/2020. Death rates and age-adjusted death rates may be inaccurate in the presence of multi-racial groups and racial groups outside Indigenous, Asian, Black, Latino, white, and Pacific Islander. Non-white includes all racial groups excluding non-Hispanic, white. Phase labels at top of figure represent estimates of approximate NASEM phase populations
Sources: National Academies of Sciences, Engineering, and Medicine Framework for Equitable Allocation of Vaccine for the Novel Coronavirus, American Community Survey (ACS) 5-Year, and APM Research Lab, Color of Coronavirus.

Under each adjustment index, minorities benefit more, until almost the entire population is served. SVI benefits minorities consistently more than ADI. SVI with 10% reserve tracks the population share most consistently. (For each minority group the corresponding graphs are in the Appendix.)

Figure 2 shows (side-by-side, not in direct comparison) SVI's and ADI's incremental gains relative to no adjustments.

Figure 2: Distribution of offers of vaccines with respect to racial groups and disadvantage: incremental gains and losses with 10% and 20% reserve sizes for the worse-off quartile under SVI and ADI when compared with allocation without any reserve adjustment

Notes: All Hispanic populations are grouped under the heading Hispanic and excluded from other groups Black, Indigenous, Asian, other, white. Hispanics are included in all non-white group. In NASEM guidelines approximately 48 million individuals qualify for Phase 1, while 161 million individuals qualify for Phases 1 and 2.
The definition of worse-off groups are different in two indexes, thus, the differences from the allocation without any reserve adjustment pertain to their respective worse-off group definitions, but not difference within the same set of individuals.
Sources: National Academies of Sciences, Engineering, and Medicine Framework for Equitable Allocation of Vaccine for the Novel Coronavirus, American Community Survey (ACS) 5-Year, and APM Research Lab, Color of Coronavirus.

Worse-off minorities across all racial and ethnic groups receive higher shares on the two alternatives. Overall gains of minorities are offset by losses for the better-off non-Hispanic white majority. Increasing a 10% reserve to 20% more than doubles gains for worse-off minorities.

Discussion

Statistical measures of disadvantage can increase worse-off minorities' vaccine shares. Methodologically, gains and losses across indices are not directly comparable among the three indexes (as worse-off groups are defined differently), yet, policy makers face a practical dilemma: while ADI (with better targeting-potential) substantially reduces risks of legal challenges, it also yields lower benefits to minority groups than SVI. Even delays caused by protracted litigation can cause harm. Legal constraints need to be taken seriously in the near-term. But the finding also raises the question of, whether considering race should remain impermissible in rationing settings such as the one encountered here, given COVID-19's unacceptable disparate impact.

While a pragmatically determined 10% reserve (with or without additional state efforts) has potential to promote equity, the threshold's justification, and, related, its adequacy and meaningfulness remain important. Further analysis should contextualize the impact with other reference points such as determining allocations proportionate to the impact disadvantaged groups experienced in terms of COVID-related excess mortality, or reduced general life expectancy tied to the geographical unit that is captured by the respective index of disadvantage, which we explore in separate ongoing analyses.

Likewise, we assumed here, following the NASEM framework, that allocation to states would be made proportionate to population. However, this would have the consequence that the severity of rationing for minorities becomes more intense in states that have higher than average shares of minority populations. In a separate analysis we therefore also analyze the consequences of the above approach when states receive vaccines proportionate to their share of minorities (which would be a consistent application of the NASEM framework), as opposed to proportionate to population. Finally, while we followed the dominant application of the SVI in which each of its constituent elements—including race and ethnicity—are weighed equally,[5] the SVI permits users to modify its construction. While analysis of the effects of removing race from the SVI is ongoing, doing so could substantially reduce the risk of challenges, but preserve the incrementally larger benefits for minorities.

Our simulation should inform further planning of the implementation of vaccine allocation guidance at the federal and state level, and is also of likely relevance for disparate impact monitoring that may become necessary.

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Authorship note
HS wrote the first draft of the manuscript and led subsequent revisions, all authors critically reviewed and edited. MUU, TS, and PAP led all simulations. HS, MW and LG shaped the conceptualization of the study and visualization of data jointly with MUU, TS and PAP.

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Appendix: Simulation Procedure and Data Sources and Supplementary Graphs

to "**What prioritizing worse-off minority groups for COVID-19 vaccines means quantitatively: practical, legal and ethical implications**
Simulating the impact of two different measures of disadvantage under the National Academies Framework for equitable covid-19 vaccine allocation?"[1]
by

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[1] The methodology and appendix itself at several places follow the technical appendix of the NBER working paper Pathak et al. (2020) that measured the distributional effects of adopting reserves based on ADI measures in allocating vaccines in a severe pandemic scenario as outlined by CDC's 2018 guidelines flu pandemic (CDC 2018a).

A1. Overview

A1.1. Data Sources

We base our phases on the COVID-19 vaccine allocation framework outlined in the 2020 NASEM guidance (Gayle et al. 2020). The US population is partitioned into 5 subphases/phases (Phase 1(a), Phase 1(b), Phase 2, Phase 3, Phase 4) based on essential or high-risk occupations and demographic factors indicating risk for spreading/contracting severe disease.

The NASEM document contains approximate estimates of the number of people within each phase based on various sources. As these numbers are based on estimates from various sources and they are not available to us, we use the American Community Survey (ACS) 2014-2018 5-year Public Use Microdata Sample (PUMS) (U.S. Census Bureau 2014-2018). The 5-year PUMS contains two datasets, one containing housing unit characteristics for a sample of housing units and another containing individual characteristics for the individuals within those same housing units. We link the person data, which has over 15 million observations, with the household data for our labelling of phases.

The PUMS person data is a weighted sample. Every observation of an individual in the PUMS person data is associated with a weight called "person's weight for generating statistics on individuals" (PWGTP). This weight is "used to bring the characteristics of the sample more into agreement with those of the full population by compensating for differences in sampling rates across areas, differences between the full sample and the interviewed sample, and differences between the sample and independent estimates of basic demographic characteristic estimates of population characteristics", according to the ACS Design and Methodology report (U.S. Census Bureau 2014).

PWGTP was also scaled such that the size of any population group could be estimated by the sum of PWGTP across observations in the PUMS belonging to the group. Further details about calculation of weights in the ACS can be found in the PUMS technical documentation (U.S. Census Bureau 2020a).

The ACS PUMS does not include data on the presence of high-risk conditions, which impacts one's phase priority. We supplement with 2018 data from the Behavioral Risk Factor Surveillance System (BRFSS) (CDC 2018b). As the observations in the BRFSS are unrelated to

those in the PUMS, we rely on randomization to link the two datasets by computing the proportion with high-risk conditions for each characteristic demographic group in the BRFSS and assigning each observation in PUMS person data as high-risk using weighted coin flips. More details are in the "Phase Inclusion Criteria" section of this document.
In order to implement the NASEM guidelines, we need a methodology to identify critical workers who are at high risk of exposure to COVID-19 in the workplace. To do so, we utilize a list of occupations identified by the U.S. Department of Homeland Security (DHS) that are designated as Essential Critical Infrastructure Workers (DHS 2020). We then merge this list with occupation specific Bureau of Labor Statistics (BLS) O*NET survey results indicating how often an individual of a particular occupation is exposed to disease at work (O*NET Online). Further details are in the "Phase Inclusion Criteria" section of this document.

We chose to run the phase assignment process only once due to the large size of the dataset and the large sizes of groups and demographic categories relative to PWGTP. This is not a Monte Carlo simulation.

We use both the person and the housing unit PUMS data for assigning Area Deprivation Index (ADI) 2.0 (University of Wisconsin School of Medicine and Public Health 2015) to individuals, as the components of the ADI involve both individual-level attributes found only in the person data and household-level attributes found only in the housing unit data. We were able to link the two datasets, as well as identify residents of the same housing unit within the person data, using the variable SERIALNO, an ID number unique to the housing unit that is present in both the person and the household data.

We cannot assign the actual ADI of each person in the PUMS data because ADI is computed using census block level averages and the PUMS geographic specificity only goes down to the Public Use Microdata Area (PUMA) level. We instead approximate the ADI of each family using averages taken at the family level. We then use SERIALNO to assign to each individual in the person data the ADI of her family We do not perform any randomization in computing ADI.

Similar to the ADI computation, the assignment of Social Vulnerability Index (SVI) (CDC 2020a) to individuals involves both the person and housing unit PUMS data. As with ADI, we are able to link the two datasets as well as identify residents of the same housing unit with the person data, using the variable SERIALNO, and identifier unique to the housing unit that is available in both the person and housing unit data.

As with ADI, we are unable to assign the actual SVI of each person in the PUMS data because SVI is calculated at the census tract or county level and the granularity of the PUMS data is only available at the PUMA level. We instead approximate SVI at the individual level through a procedure described in further detail below. We do not perform any randomization in computing SVI.

Data on proportion of COVID deaths by race/ethnicity and age-adjusted proportion of COVID deaths by race/ethnicity are sourced from APM Research Lab (2020). The data was accessed October 2, 2020 and released September 16, 2020, reflecting data releases through September 15, 2020.

A1.2. Allocation Procedure

We implement a dynamic over-and-above reserve for the worse-off groups which makes maximum use of the worse-off reserve and allows jumps of the worse-off group to a further phase while the better off-group is served at an earlier phase if needed.
Suppose $r < 1$ is a reserve of the 25% (quartile) worse-off regions in each state (NASEM recommended $r = 10\%$, we also consider $r = 20\%$ in the simulation).

1. The regions that qualify for the worse-off quartile reserve of each state are determined by:
   a. Ranking the geographic regions of the state from the lowest-hit to hardest-hit based on the index used: for SVI the smallest geographic region is "census tract" and for ADI the smallest geographic region is "block" (See Sections A3 and A4 for construction of the indexes for the individuals in the simulation data as we do not have access to block- and tract-level data), and then
   b. Finding the geographic regions in the population-weighted *hardest-hit* quartile[2]
2. For each additional batch of vaccines allocated by the federal government, we assume that the whole batch is allocated to the states based on their population proportion.
3. Given a state, let $\alpha_{1a}, \alpha_{1b}, \alpha_2, \alpha_3, \alpha_4 < 1$ be the proportions of the population of individuals in the better-off group with respect to the whole population of the state falling in prioritization phases 1a, 1b, 2, 3, 4 according to the NASEM framework, respectively. (See Section A.2 for the explanation of who qualifies for which phase in the US population and how individuals qualifying for phases are determined in the simulation data).

   Suppose V is the share of the state from the national batch of vaccines offered in a point in time. Each group, the worse-off regions and better-off regions, is offered vaccines beginning from its members that qualify for Phase 1a. When the individuals in one phase end in one group, we continue to allocate the groups share to the next individual from the next phase.

   A *random lottery* determines the priority order among the individuals who belong to the same phase (if an individual qualifies for multiple phases, she is offered a vaccine in the earliest phase she qualifies for).

   - As long as there are unserved individuals in the worse-off group: if the current phase of the *better-off group* is phase $x \in \{1a, 1b, 2,3,4\}$ we offer $\alpha_x(1-r)V$ vaccines to the better-off group and serve it with respect to the priority order of that phase; the remainder of the vaccines go to the *worse-off group* and are offered with respect to the priority order of the phase the *worse-off group* currently is in, which can be equal to or past phase x.
   - When there are no longer unserved individuals in the worse-off group: All V vaccines are offered to the *better-off group* with respect to the priority order of the remainder of the individuals in better-off group following the group's phases.

[2] Some ADI values are missing given incomplete data availability for individuals in group quarters. These individuals are not included in the calculation of the hardest-hit quartile. Treatment of these individuals is discussed in greater detail in Section A3

The graphs of marginal shares of the vaccines offered to the better-off population and Black population are graphed nationally and for a single state California as an example to illustrate how the allocation procedure distributes vaccines for each batch in Figures A6-A9.

We use the following simulation methodology to simulate this procedure.

A1.3. Simulation Methodology

We consider three treatment groups for NASEM allocation: guidelines without reserve adjustment, NASEM allocation with the NASEM recommended over-and-above $r = 10\%$ worse-off-SVI reserve and $r = 10\%$ worse-off-ADI reserve. We also extend the analyses to $r = 20\%$ reserve for the latter three reserve allocation schemes. We follow the below procedure in our simulation analysis.

1. Approximate the ADI of each household, SVI of every individual as explained in "Calculation of Index Values: ADI" and "Calculation of Index Values: SVI" sections of this appendix. Assign household ADI values to individuals.
2. Label every person in the PUMS with the highest phase group they qualify for. PUMS variables do not perfectly match up to the phase groups but can be used as a crude approximation. Our inclusion criteria for each phase is outlined in the "Phase Inclusion Criteria" section of this appendix.
3. For each individual, determine whether they fall in the most disadvantaged quartile by ADI/SVI within their state of residence.
4. For each state's population in each phase, calculate the demographic averages (proportion breakdown of race, gender, age, etc.).
5. Incrementally adding 100,000 vaccine units from 0 to about 323 million total doses allocated, use the allocation procedure explained in the previous subsection.

We use statistical open-source R software (version 4.0.0) and Microsoft Excel in our simulation. The names of program files are given in a table at the end of this appendix. The programs and data files are available from the authors upon request.

A2. Phase Inclusion Criteria

A2.1. NASEM phases

We integrate Figure S-2 of the NASEM (2020) to arrive at the following phased approach:

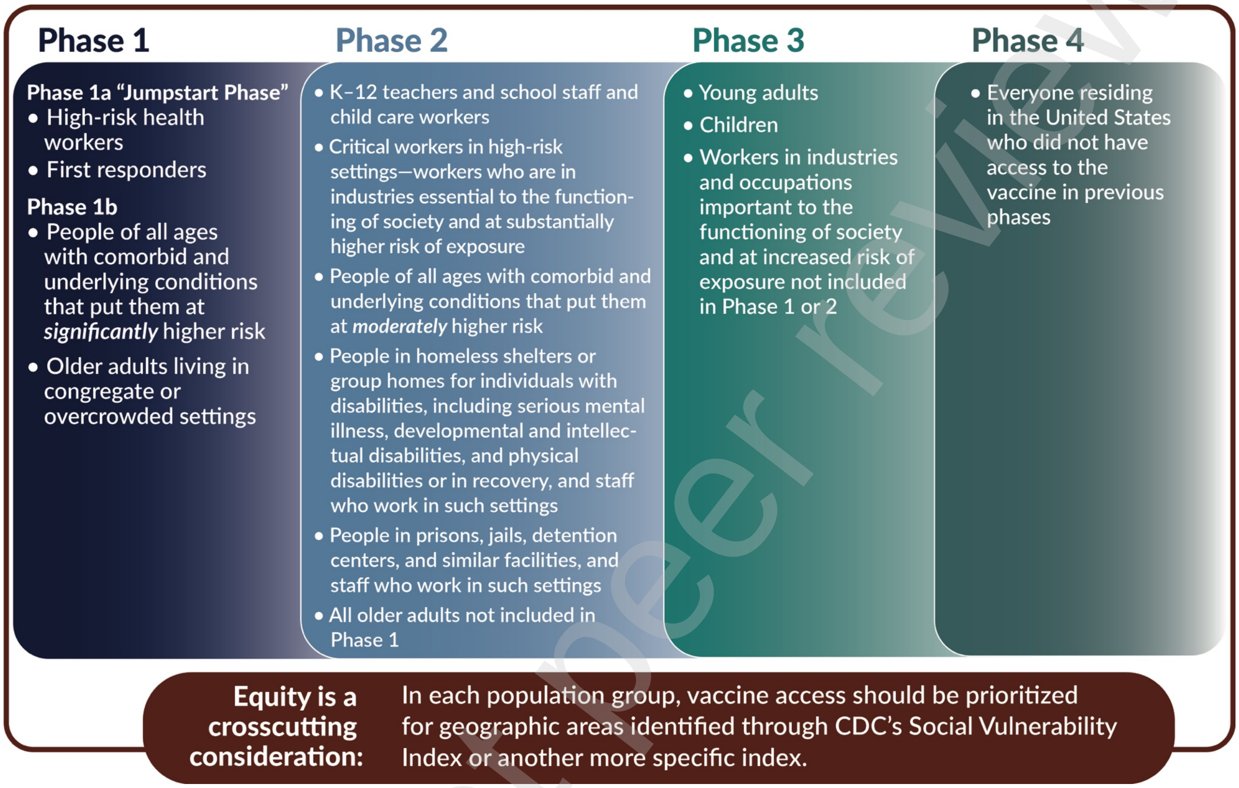


FIGURE S-2 A phased approach to vaccine allocation for COVID-19.

A2.2. Data issues and imperfect workarounds

A2.2.1. High-risk conditions and the BRFSS

The PUMS does not have data on the health conditions of the surveyed individuals. We therefore impute COVID-19 risk for each observation in the PUMS using the BRFSS data.

We label each observation in the BRFSS as <u>significantly higher risk</u> for COVID-19 if at least <u>two</u> of the following is true. We label an observation in the BRFSS as <u>moderately higher risk</u> for COVID-19 if at least <u>one</u> of the following is true:

- The individual has been "(Ever told) you had skin cancer"
- The individual has been "(Ever told) you had any other types of cancer"
- The individual has been "(Ever told) you have kidney disease" not including kidney stones, bladder infection or incontinence
- The individual has been "(Ever told) you have chronic obstructive pulmonary disease, C.O.P.D., emphysema or chronic bronchitis"
- The individual is obese, defined as having a BMI >= 30

- The individual has been "(Ever told) you had angina or coronary heart disease"
- The individual has been "(Ever told) you have diabetes," not including diabetes only while pregnant, pre-diabetes, or borderline diabetes

For each of the above statements, we consider each statement false if the variable takes any value other than the one listed, including values for "don't know/not sure," "not asked or missing," and "refused." The above variable definitions and question wordings are sourced from the 2018 BRFSS codebook (CDC 2018c).

The medical conditions chosen are cited by the NASEM guidelines when identifying individuals with comorbid and underlying conditions that put them at risk. The listed conditions are as follows:

- Cancer
- Chronic kidney disease
- COPD (chronic obstructive pulmonary disease)
- Immunocompromised state (weakened immune system) from solid organ transplant
- Obesity (body mass index [BMI] of 30 or higher)
- Serious heart conditions, such as heart failure, coronary artery disease, or cardiomyopathies
- Sickle cell disease
- Type 2 diabetes mellitus

Our approximation of these risk factors omits immunocompromised state from solid organ transplant and sickle cell disease due to lack of data in the BRFSS. Our risk factors also include all diabetes, not just type 2 diabetes, as the BRFSS does not distinguish between different types of diabetes.

Using the BRFSS data, labelled with whether or not there is significant or moderate COVID-19 risk, we group the data by age bin, sex, whether or not the person is Hispanic, and race/ethnicity other than Hispanic. For each interaction of those variables, we find the proportion of the population that is significant/moderate-risk. We omit any observations where one or more of these demographic variables are unknown or missing.

The age bins are the following:

- 18-24
- 25-29
- 30-34
- 35-39
- 40-44
- 45-49
- 50-54
- 55-59
- 60-64
- 65-69

- 70-74
- 75-79
- 80-84
- 85+

For non-Hispanic race, those of known race are categorized into the following:

- White only
- Black or African American only
- American Indian or Alaskan Native only
- Asian Only
- Native Hawaiian or other Pacific Islander only
- Other race only
- Multiracial

Hispanic status is coded in a separate variable from non-Hispanic race.

We considered adding income bins to the interaction of demographic variables, but the introduction of income resulted in lack of data for some variable interactions. We leave income out to avoid this and for simplicity.

We output the significantly/moderately higher risk proportion of each demographic interaction in the BRFSS data. Then, we find the demographic probability of each PUMS person data observation being at significantly/moderately higher risk based on the proportions calculated from the BRFSS. We then throw a weighted coin for each individual in the PUMS to label each individual as significant/moderate risk or not. As the BRFSS does not have risk factor data for people under 18, we extrapolate the calculated risk probabilities of 18 to 24-year-olds of the same sex, race, and ethnicity for those under 18.

A2.3. Comment on phase sizes

The NASEM guidelines provide estimates of the sizes of each phase as below:

- Phase 1a (~5% of U.S. population)
- Phase 1b (~10% of U.S. population)
- Phase 2 (~30-35% of U.S. population)
- Phase 3 (~40-45% of U.S. population)
- Phase 4 (~5-15% of U.S. population)

These estimates do not take into account individual overlap between phases. Our phase by phase labeling of PUMS data as below maps each individual to the highest phase that they qualify for and thus identifies an individual's phase when taking into account phase overlap. Upon labeling individuals as in Section A2.4, the U.S. population is segmented among phases as follows:

- Phase 1a (~5% of U.S. population)
- Phase 1b (~11% of U.S. population)
- Phase 2 (~37% of U.S. population)
- Phase 3 (~39% of U.S. population)

- Phase 4 (~8% of U.S. population)

A2.4. Phase by phase details for labelling of PUMS data

A2.4.1. Phase 1a

A2.4.1.1. High-risk health workers

The NASEM guidelines define this group as frontline health care workers who are in hospitals, nursing homes, or providing home care with unavoidable risk of exposure and transmission of the virus. They also specify that morticians, funeral workers, and other death care professionals involved in handling bodies as part of this group. Additionally, NASEM includes pharmacists, public health workers, and dentists. In order to label these frontline health care workers and other individuals working in such high-potential exposure settings, we use the below NAICS (industry) codes:

- 622M: General Medical and Surgical Hospitals, and Specialty (Except Psychiatric and Substance Abuse) Hospitals
- 6231: Nursing Care Facilities (Skilled Nursing Facilities)
- 623M: Residential Care Facilities, Except Skilled Nursing Facilities
- 6216: Home Health Care Services

In order to label morticians and death care professionals, pharmacists, public health workers, and dentists, we rely on SOC (occupation) codes and include all workers with the below occupation code:

- 394031: Morticians, Undertakers, and Funeral Arrangers
- 3940XX: Embalmers, Crematory Operators, and Funeral Attendants
- 292052: Pharmacy Technicians
- 291051: Pharmacists
- 211022: Healthcare Social Workers
- 21109X: Other Community and Social Service Specialists
- 291020: Dentist
- 391091: Dental Assistants

Our labeling of public health workers is approximated by two occupation codes identifying Healthcare Social Workers and Other Community and Social Service Specialists (includes Community Health Workers). This is due to the lack of a clear occupation code in the PUMS data to indicate whether an individual is a public health worker.

The NASEM guidelines reference those frontline health care workers with unavoidable risk of exposure and transmission. In order to approximate this, we use the fraction of workers exposed to disease more than one time per month as calculated by Baker et al. (2020). Specifically, Baker et al. note that ~96.1% of Healthcare Support (2-digit SOC code of 31) and ~91.5% of Healthcare Practitioners and Technical (2-digit SOC code of 29) workers are exposed to disease at work more than once per month. As a crude approximation, we randomly sample our set of frontline health workers defined by NAICS and SOC code above to randomly assign 93.8% as health care workers at high-risk of exposure or transmission.

A2.4.1.2. First responders

NASEM guidelines identify this group as emergency medical services (EMS) personnel, police, and firefighters. We use occupation codes to assign individuals with an occupation code as one of the below as a first responder:

- 292042: Emergency Medical Technicians
- 292043: Paramedics
- 533011: Ambulance Drivers and Attendants, Except Emergency Medical Technicians
- 331011: First-Line Supervisors of Police and Detectives
- 333050: Police Officers
- 331021: First-Line Supervisors of Fire Fighting and Prevention Workers
- 332011: Firefighters

A2.4.2. Phase 1b

A2.4.2.1. People of all ages with comorbid and underlying conditions that put them at significantly higher risk

NASEM guidelines define individuals at significantly higher risk as individuals with two or more of the following conditions: cancer, chronic kidney disease, chronic obstructive pulmonary disease, immunocompromised state from solid organ transplant, obesity (body mass index [BMI] greater than or equal to 30), serious heart conditions, sickle cell disease, and type 2 diabetes mellitus. We assign this group using the procedure outlined in the Section A2.2.1.

A2.4.2.2. Older adults living in congregate or overcrowded settings

The NASEM guidelines identify these individuals as the older population living in congregate and overcrowded situations. NASEM does not propose an age cutoff and so we refer to 2018 CDC Vaccine Allocation during an Influenza Guidelines (CDC 2018a) and their definition of older as at least 65 years old. We label individuals as living in congregate and overcrowded situations as those who live in multigenerational housing or institutional group quarters (e.g., correctional facilities, nursing homes, or mental hospitals) (CDC 2018d).

A2.4.3. Phase 2

A2.4.3.1. K-12 teachers and school staff and child care workers

We rely on SOC codes to label K-12 teachers, school staff, and child care workers by including the below occupation codes:

- 252010: Preschool and Kindergarten Teachers
- 252020: Elementary and Middle School Teachers
- 252030: Secondary School Teachers
- 252050: Special Education Teachers
- 2530XX: Other Teachers and Instructors
- 259040: Teaching Assistants
- 2590XX: Other Educational Instruction and Library Workers
- 193034: School Psychologists
- 339094: School Bus Monitors
- 533051: Bus Drivers, School
- 119030: Education and Childcare Administrators
- 211021: Child, Family, and School Social Workers
- 211012: Educational, Guidance, and Career Counselors and Advisors
- 399011: Child care Workers

We note that the Teaching Assistant occupation code may include post-secondary Teaching Assistants, but we lack the granularity of occupation in the PUMS data to adjust for this.

A2.4.3.2. Critical workers in high-risk settings – workers who are in industries essential to the functioning of society and at substantially higher risk of exposure

The NASEM guidelines note that there is no single list of all workers who should be included in this phase. They reference the U.S. Department of Homeland Security categories of Essential Critical Infrastructure Workers as a list of critical workers that may have differing levels of exposure risk at work.

As an approximation, we crosswalk a list of DHS-defined critical infrastructure worker occupation codes to the occupation codes in the PUMS data. To the best of our knowledge, the version of the DHS list released on March 29, 2020 is the most recent list of critical infrastructure worker that explicitly labels SOC codes as critical infrastructure or not (DHS 2020). The PUMS data granularity of SOC codes is less detailed than the level of granularity of the DHS-defined critical infrastructure worker SOC codes. We define a PUMS SOC code as a critical infrastructure occupation if at least one of the more granular DHS-labeled SOC codes that map to the PUMS SOC code is a critical infrastructure occupation.

In order to identify critical infrastructure workers who are at a high level of disease exposure, we rely on BLS O*NET survey results that label SOC codes with an index corresponding to how often the workers surveyed are exposed to disease in the workplace (O*NET Online). The index is from 0 (Never) to 100 (Every Day) and a 50 corresponds to “Once a month or more but not every week". As with critical infrastructure worker labeling, the PUMS SOC codes are less granular than the O*NET SOC codes. We define a PUMS SOC code's disease exposure as the average disease exposure of the granular O*NET SOC codes that map to the PUMS SOC code.

Finally, to label individuals as critical workers with high-risk of exposure we take all individuals in a critical infrastructure occupation that have a disease exposure index of at least 50 where, as mentioned above, 50 corresponds to an exposure of "Once a month or more, but not every week".

A2.4.3.3. People of all ages with comorbid and underlying conditions that put them at moderately higher risk

As in Phase 1b, NASEM defines comorbid conditions as the following: cancer, chronic kidney disease, chronic obstructive pulmonary disease, immunocompromised state from solid organ transplant, obesity (body mass index [BMI] greater than or equal to 30), serious heart conditions, sickle cell disease, and type 2 diabetes mellitus. NASEM guidelines define individuals with one or more of these conditions as at moderately higher risk. We assign this group using the procedure outlined in Section A2.2.1.

A2.4.3.4. People in homeless shelters or group homes for individuals with disabilities, including serious mental illness, developmental and intellectuals, and physical disabilities or in recovery, and staff who work in such settings

To label individuals in homeless shelters or group homes, we first consider individuals who live in non-institutional group quarters defined to include college dormitories, military barracks, group homes, missions, and shelters (U.S. Census Bureau 2018). Unfortunately, the PUMS data granularity does not allow for labeling individuals as a particular type of non-institutional group quarters. However as a partial workaround, we are able to exclude undergraduate college students and active members of the military. We use the SOC code 119151, Social and Community Service Managers, to approximate the staff that work in such settings.

A2.4.3.5. People in prisons, jails, detention centers, and similar facilities, and staff who work in such setting

In order to label individuals as prisoners, we include all people living in institutionalized group quarters. This includes those in correctional facilities, nursing homes, and mental hospitals (U.S. Census Bureau 2018) and unfortunately the PUMS data is not granular enough to distinguish between the three. We note that it is likely that the majority of nursing home residents are above the age of 65 and would be included in Phase 1b meaning that our imprecision in this phase is mostly due to the presence of mental hospitals among institutional group quarters. We label the staff of correctional facilities by including individuals with SOC codes as below:

- 331011: First-Line Supervisors of Correctional Officers
- 331012: Correctional Officers and Jailers

A2.4.3.6. All older adults not included in Phase 1

As discussed, the NASEM guidelines do not specify an age cutoff for defining older adults. As before, we rely on the 2018 CDC Vaccine Allocation Guidelines (CDC 2018a) and define an older adult as anyone at least 65 years old.

A2.4.4. Phase 3

A2.4.4.1. Young adults

Per NASEM guidelines, young adults are identified as any individual at least 18 years old and at most 30 years old.

A2.4.4.2. Children

Children are defined as any individual under the age of 18 years old.

A2.4.4.3. Workers in industries and occupations important to the functioning of society and at increased risk of exposure not included in Phase 1 or 2

We use the same process as above in Section 2.4.3.2 to identify critical infrastructure workers as defined by the DHS. The NASEM guidelines note that ideally, Phase 3 would vaccinate the remaining critical infrastructure workers that have not been vaccinated in a previous phase. We therefore include any individual in a critical risk occupation in this group.

A2.4.5. Phase 4

A2.4.5.1. Everyone residing in the United States who did not have access to the vaccine in previous phases

We include any remaining individuals who have not been assigned a phase in Phase 4.

A3. Calculation of Index Values: ADI

A3.1. Overview

We calculate raw numerical ADI values using the 1990 components and weighing formula from Singh (2003). Table 1 of Singh (2003), copied below, defines each component in the "Census Variable" column and provides each component's weights in the "Factor Score Coefficient" column.

TABLE 1—Factor Loadings and Factor Score Coefficients for the Census Variables Comprising the Area Deprivation Index: United States, 1970 and 1990[21]

Census Variable	Factor Loading: Tract Index, 1990	Factor Loading: Zip Code Index, 1990	Factor Loading: County Index, 1990	Factor Score Coefficient: Tract Index, 1990	Factor Loading: County Index, 1970
Population aged ≥ 25 y with < 9 y of education, %[a]	0.7498	0.7383	0.7885	0.0849	0.8340
Population aged ≥ 25 y with at least a high school diploma, %	−0.8562	−0.8089	−0.8231	−0.0970	−0.8788
Employed persons aged ≥ 16 y in white-collar occupations, %	−0.7721	−0.7118	−0.6890	−0.0874	−0.6075
Median family income, $	−0.8629	−0.8690	−0.9218	−0.0977	−0.8694
Income disparity[b]	0.8262	0.7054	0.8827	0.0936	0.7559
Median home value, $	−0.6074	−0.6764	−0.6740	−0.0688	−0.6703
Median gross rent, $	−0.6896	−0.7081	−0.7876	−0.0781	−0.7872
Median monthly mortgage, $	−0.6795	−0.7362	−0.7812	−0.0770	...
Owner-occupied housing units, % (home ownership rate)	−0.5431	−0.4688	−0.4408	−0.0615	...
Civilian labor force population aged ≥16 y unemployed, % (unemployment rate)	0.7117	0.5231	0.5679	0.0806	0.2195
Families below poverty level, %	0.8623	0.7996	0.8796	0.0977	0.9480
Population below 150% of the poverty threshold, %	0.9157	0.8781	0.9266	0.1037	0.9503
Single-parent households with children aged < 18 y, %	0.6346	0.3487	0.3329	0.0719	0.5520
Households without a motor vehicle, %	0.6126	0.4335	0.4549	0.0694	0.7540
Households without a telephone, %	0.7748	0.6837	0.7830	0.0877	0.8745
Occupied housing units without complete plumbing, % (log)	0.4505	0.4863	0.6392	0.0510	0.8921
Households with more than 1 person per room, % (crowding)	0.4910	0.3963	0.4018	0.0556	0.6854
Proportion of total variance explained by factor	0.5195	0.4432	0.5140	...	0.5990
Cronbach α (reliability coefficient)	0.9484	0.9311	0.9473	...	0.9573

Note. Values were derived from a principal-components analysis of census ecological data for 59 525 census tracts, 29 320 zip codes, and 3097 counties.
[a]For the 1970 index, percentage of population with less than 5 years of education was used.
[b]Income disparity in 1990 was defined as the log of 100 × ratio of number of households with < $10 000 income to number of households with ≥$50 000 income. Income disparity in 1970 was defined as the log of 100 × ratio of number of households with < $3000 income to number of households with ≥$15 000 income.

The raw numerical ADI score of each family is calculated as the weighted sum of its value for each component using the weights above. For a family F, the raw numerical ADI is as follows:

$$ADI_F^{raw} = \sum_{component} value_{component,F} \times weight_{component}$$

We then assign the raw numerical ADI of each family to each member of the family. Now, each individual is assigned some ADI raw numerical value. We next convert an individual's ADI value into a within-state percentile rank. This percentile-rank computation takes into account the weighted nature of PUMS observations and follows the percentile-rank midpoint procedure described in A4.2 below.

A3.2. Missing values and omitted observations

Many of the PUMS variables involved in computing ADI are not counted for the ~8 million living in group quarters, which include prisons, nursing facilities, and college/university housing (US Census Bureau 2017). We do not compute a raw numerical ADI for those people and they are excluded from the percentile-rank computation. Thus, people in group quarters are automatically excluded from the implementation of a worse-off ADI reserve.

We note that the actual ADI computed at the census block level also omits computing an ADI for census blocks with more than 33% of the population living in group quarters (University of Wisconsin School of Medicine and Public Health 2015).

For those living in households, any missing components will be considered 0. Every household has at least 1 missing component, as property value and mortgage are missing for all renters and gross rent is missing for all who own the houses they live in.

For averages computed at the family level, we consider the household of those living in a household with a non-missing family income variable to be a family. This includes households headed by same-sex couples. For those not living with family due to living by themselves or with non-family roommates, we consider each person to be their own family.

A3.3. Component by component details

1. Population aged ≥25 y with < 9 y of education, %
    a. Calculate the family proportions of those 25 and over in the family whose highest educational attainment is under grade 9. Families with no member over 25 have this value missing.
2. Population aged ≥25 y with at least a high school diploma, %
    a. Calculate the family proportions of those 25 and over in the family whose have graduated high school, have a GED, or completed at least some college. Families with no member over 25 have this value missing.
3. Employed persons aged ≥16 y in white-collar occupations, %
    a. Calculate the family proportion of those over 16 and employed whose NAICS industry code is in the MGR, BUS, FIN, CMM, ENG, SCI, CMS, LGL, EDU, ENT, MED, SAL, or OFF categories. Families with no employed member over 16 have this value missing.
4. Median family income, $
    a. Use the family income adjusted to constant dollars. For those not living with family, use individual income adjusted to constant dollars.
5. Income disparity
    a. Skipped and set to 0 for all, due to data constraints
6. Median home value, $
    a. Use household property value adjusted to constant dollars. Non-homeowners have this value missing.
7. Median gross rent, $
    a. Use monthly gross rent adjusted with to constant dollars. Non-renters have this value missing.
8. Median monthly mortgage, $
    a. Use the first mortgage payment adjusted with to constant dollars. Non-homeowners and those who did not mortgage have this value missing.
9. Owner-occupied housing units, %

   a. Home ownership is 100% if the house is owned by its resident and 0% if otherwise
10. Civilian labor force population aged ≥16 y unemployed, %
    a. Calculate the family proportion of those over 16 in the civilian labor force who are unemployed. This component is missing for families whose members over 16 are all in the armed forces or not in the labor force.
11. Families below poverty level, %
    a. For households containing families, 100% if family-income-to-poverty percentage < 100%. For individuals not living with family, compare unadjusted individual income to poverty thresholds of the sample's year (U.S. Census Bureau 2020b).
12. Population below 150% of the poverty threshold, %
    a. For households containing families, 100% if family-income-to-poverty percentage < 150. For individuals not living with family, compare unadjusted individual income to 150% of poverty thresholds of the sample's year (U.S. Census Bureau 2020b).
13. Single-parent households with children aged < 18 y, %
    a. 100% if the household is a family not headed by a same sex married couple and with a man and no wife or a woman and no husband with related children under 18. 0 otherwise.
14. Households without a motor vehicle, %
    a. 100% if at least 1 vehicle available
15. Households without a telephone, %
    a. 100% if no telephone service AND no cell data plan for smartphone or other mobile device
16. Occupied housing units without complete plumbing, %
    a. 100% if there are complete plumbing facilities
17. Households with more than 1 person per room, %
    a. 100% if the number of people in the household is greater than the number of rooms.

A4. Calculation of Indexes: SVI

A4.1. Overview

We compute the CDC Social Vulnerability Index (SVI) within-state and at the individual level by weighting each of its 15 components equally. SVI is generally computed at the census tract or county level (CDC 2020a) but given the limitations of the geographic granularity of the PUMS data, we compute each of the 15 SVI components at the individual level.

A4.2. Computation details

Most of the SVI components become binary variables at the individual level. These binary components present a challenge when following the SVI procedure of computing, summing, and then again computing percentile ranks. In order to approximate the percentile rank of a now-binary SVI component for an individual within the individual's state using the PUMS data, we follow the below procedure:

- Suppose that we have a set of individuals indexed by *i* for which we wish to compute SVI component *j* within some state *s*
- Suppose that this SVI component *j* takes on *n* discrete values (in the binary case, *n=2*)
- We first compute the histogram representing the proportion of individuals in *s* that take on each of the *n* discrete values of *j*; such proportions are denoted $x_1, \ldots, x_n$ where the set of x_i are ordered from the most advantaged to least advantaged discrete value of *j*
- For any individual *i*, suppose that individual *i* is assigned the k^{th} value of SVI component *j*
- Then, the value of component *j* for individual *i* is the k^{th} midpoint of the histogram as below:

$$SVI_{i,j} = (x_{k-1} - x_k) \,/\, 2$$

Throughout this document, the above will be referred to as the "percentile-rank midpoint procedure".

Some of the SVI components are household-level variables – for example whether or not a housing unit is a mobile home. In this case, we use the percentile-rank midpoint procedure using the household histogram rather than the individual histogram. The decision as to whether we compute a histogram at the household or individual level is noted for each component in Section A4.3 as *level of summarization*.

There are instances in which the histogram step in the percentile-rank midpoint procedure is not conducted for every individual or every household. For example, one of the SVI components is whether an individual is unemployed or not. For this component, we do not include individuals who are not in the labor force during the histogram computation. For these individuals, the SVI component is set to whatever the percentile-rank midpoint procedure computes for an advantaged individual. This is done because we have no reason to believe these omitted individuals are disadvantaged with respect to the SVI component and they will need to be assigned some value for the summed SVI component percentile rank to be possible. The population included as disadvantaged in the histogram step is noted for each component in Section A4.3 as *numerator of proportion computation.* The population excluding the omitted individuals discussed above is noted as *denominator of proportion computation*.

Once we have computed each SVI component's within-state percentile rank, we sum the computed percentile ranks across all 15 components. We then perform the percentile-rank midpoint procedure on the summed components to obtain a final within-state individual-level SVI measure.

A4.3. Component by component details

We compute individual-level within-state percentile ranks for each of the SVI components (CDC 2020a) as below:

1. Below poverty
    a. Numerator of proportion computation: Population with family income-to-poverty ratio below 100%. Augment with a comparison of unadjusted individual income to poverty thresholds of the sample's year (U.S. Census Bureau 2020b) if income-to-poverty income is missing but individual income is not.
    b. Denominator of proportion computation: All individuals with non-missing augmented income-to-poverty ratio
    c. Level of summarization: Individual
2. Unemployed
    a. Numerator of proportion computation: Population unemployed
    b. Denominator of proportion computation: Population in the labor force
    c. Level of summarization: Individual
3. Income
    a. Individual income adjusted to constant dollars. Even though income is not binary, we use the percentile-rank midpoint procedure to set the percentile rank to account for multiple individuals with the same income. If individual income is missing, set to the individual's average household income component percentile rank. If both are missing, set the component to 0.
4. No high school diploma
    a. Numerator of proportion computation: Population aged 25+ with less than a high school diploma
    b. Denominator of proportion computation: Population aged 25+
    c. Level of summarization: Individual
5. Aged 65 or older
    a. Numerator of proportion computation: Population aged 65+
    b. Denominator of proportion computation: Full population
    c. Level of summarization: Individual
6. Aged 17 or younger
    a. Numerator of proportion computation: Population aged 17 or younger
    b. Denominator of proportion computation: Full population
    c. Level of summarization: Individual
7. Older than age 5 with a disability

   a. Numerator of proportion computation: Civilian non-institutionalized population with a disability over the age of 5
   b. Denominator of proportion computation: Civilian non-institutionalized population over the age of 5
   c. Level of summarization: Individual
8. Single-parent household
   a. Numerator of proportion computation: Single parent household with related children under the age of 18
   b. Denominator of proportion computation: All households (excludes group quarters)
   c. Level of summarization: Household
9. Minority
   a. Numerator of proportion computation: All persons except white, non-Hispanic
   b. Denominator of proportion computation: All persons
   c. Level of summarization: Individual
10. Speaks English "Less than Well"
   a. Numerator of proportion computation: Persons age 5+ who speak English "Not well" or "Not at all"
   b. Denominator of proportion computation: Population aged 5+
   c. Level of summarization: Individual
11. Multi-unit structures
   a. Numerator of proportion computation: Households with 10 or more units
   b. Denominator of proportion computation: All households (excludes group quarters)
   c. Level of summarization: Household
12. Mobile homes
   a. Numerator of proportion computation: Households that are a mobile home or trailer unit
   b. Denominator of proportion computation: All households (excludes group quarters)
   c. Level of summarization: Household
13. Crowding
   a. Numerator of proportion computation: Households for which number of people in household / number of rooms in the household is greater than 1
   b. Denominator of proportion computation: All occupied households (excludes group quarters)

c. Level of summarization: Household

14. No vehicle
    a. Numerator of proportion computation: Households with no vehicle
    b. Denominator of proportion computation: All occupied households
    c. Level of summarization: Household (excludes group quarters)
15. Group quarters
    a. Numerator of proportion computation: Individuals living in group quarters
    b. Denominator of proportion computation: Full population
    c. Level of summarization: Individual

A5. Worse-off and better-off computation

Once we have assigned an individual an ADI and SVI value, we are able to define within-state *worse-off* and *better-off* populations. For both ADI and SVI, a higher value indicates greater relative disadvantage. As discussed above, individual ADI and SVI are in their final form computed to be within-state percentile ranks. We define the individuals with the highest 25% ADI and SVI in the state to be *worse-off*. All other individuals in the state are defined to be *better-off*. We note that because some ADI percentile ranks are missing (see Section A3.2 for more details), the share of individuals that are *worse-off* in an ADI-sense is slightly below 25%.

A6. Death rates (actual and age-adjusted) by race/ethnicity

The 9/16/2020 release of APM Research Lab's Color of Coronavirus data only provides actual death rates and age-adjusted death rates for the racial categories of Indigenous, Asian, Black, Latino, White, and Pacific Islander, omitting actual death rates and age-adjusted death rates for those who are multiracial, some other race, or unknown race.
Therefore, to approximate the actual proportion of deceased COVID-19 victims who are of a particular race *r*, we use the following formula:

$$\widehat{deathshare}_r = \frac{population_r \times deathrate_r}{\sum_{race\,=\,I,A,B,L,W,PI} population_{race} \times deathrate_{race}}$$

This equals the true value of the race *r* share of COVID-19 actual deaths with the following sufficient assumptions:

1. APM Research Lab's values for each race's share of population and actual death rate are accurate given their assumptions, and data deficiencies (APM Research Lab 2020).
2. Of the deceased victims counted by APM Research Labs as multiracial, some other race, or unknown race, the proportion who identified as race *r* is equal to $\widehat{deathshare}_r$

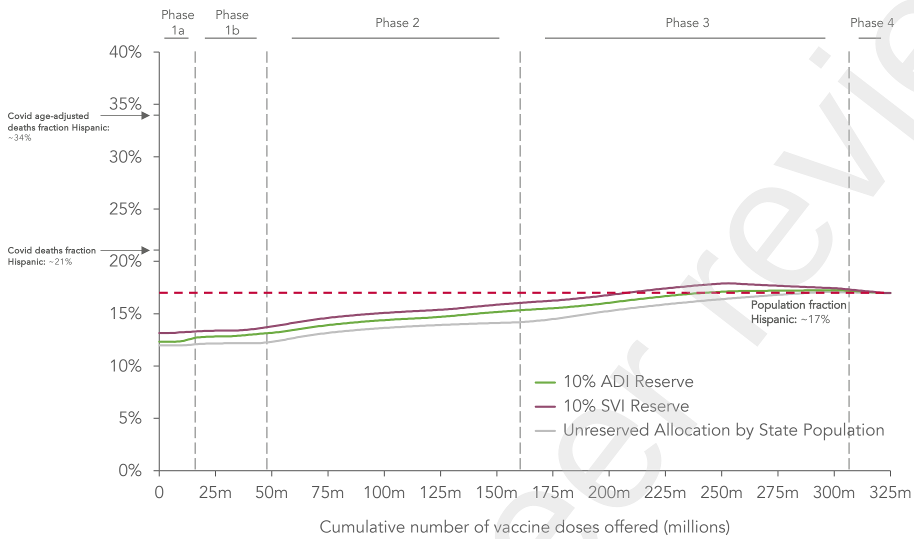
A7. Table of Program Files

File name	Description
personal_adi_calculation.R	Assigns ADI to PUMS data.
brfss.R	Calculates proportion of each demographic group that has a significant/moderate-risk condition, using the BRFSS.
pums_nasem_phase_labelling.R	Assigns highest qualifying NASEM phase to PUMS data.
calculate_svi.R	Assigns SVI to PUMS data.
aggregate_cleaned_dataset.R	Consolidate SVI, ADI, and NASEM phase data into one dataset.
build_master_soc_xwalk.R	Creates a crosswalk between critical infrastructure occupations, occupation disease exposure, and PUMS SOC codes.
allocate_vaccines.R	Iteratively perform vaccine allocation procedure.
compute_demographic_matrix.R	Create matrix of demographic proportions by state by phase by worse-off/better-off status.
compute_sim_descriptives.R	Outputs demographic proportions by number of doses allocated.
compute_marginal_share_descriptives.R	Calculates demographic proportions of the marginal vaccine recipients during an iterative allocation.

A8. Appendix Graphs

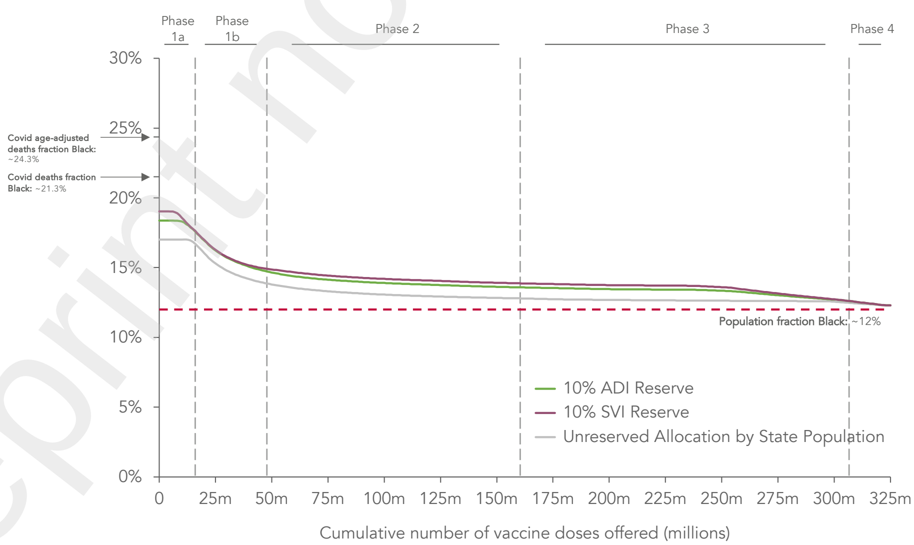
A8.1. Graphs referred to in the main text

Figure A1: Proportion of vaccine doses offered to Hispanic population,
By cumulative number of vaccine doses offered



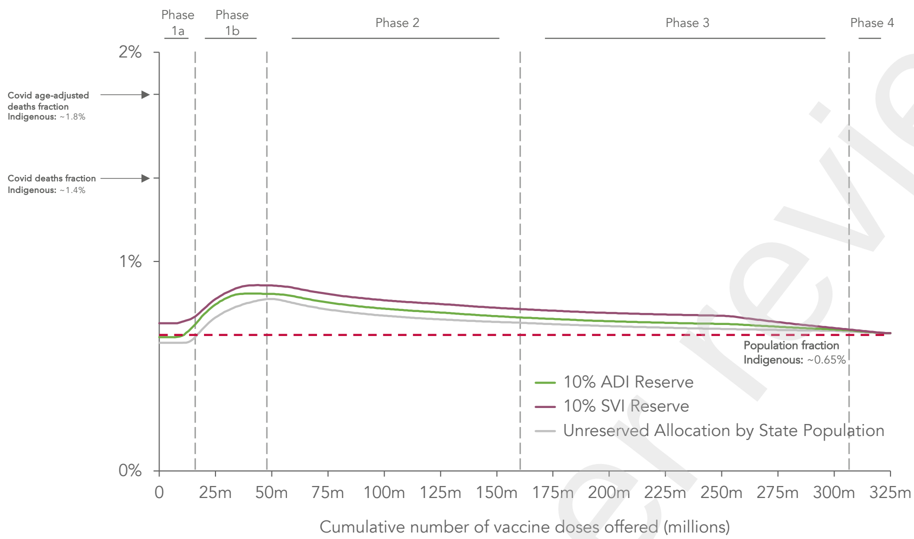
Notes: COVID-19 death fraction and age-adjusted death fraction is as of 09/15/2020. Death rates and age-adjusted death rates may be inaccurate in the presence of multi-racial groups and racial groups outside Indigenous, Asian, Black, Latino, White, and Pacific Islander. Hispanic racial group excludes individuals identifying as two or more races. Phase labels at top of figure represent NASEM estimates of approximate phase size.
Sources: National Academies of Sciences, Engineering, and Medicine Framework for Equitable Allocation of Vaccine for the Novel Coronavirus, American Community Survey (ACS) 5-Year, and APM Research Lab, Color of Coronavirus.

Figure A2: Proportion of vaccine doses offered to Black population,
By cumulative number of vaccine doses offered



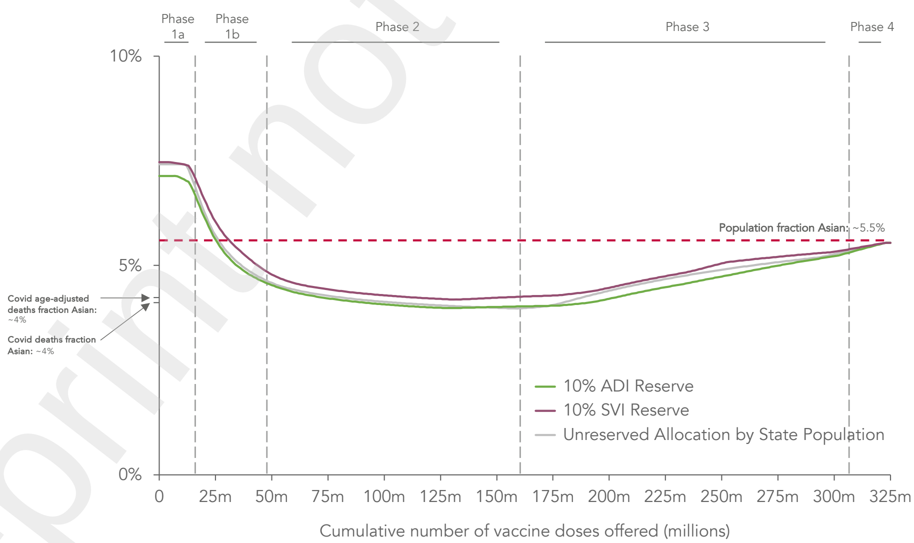
Notes: COVID-19 death fraction and age-adjusted death fraction is as of 09/15/2020. Death rates and age-adjusted death rates may be inaccurate in the presence of multi-racial groups and racial groups outside Indigenous, Asian, Black, Latino, White, and Pacific Islander. Black is defined as Non-Hispanic, Black racial group and excludes individuals identifying as two or more races. Phase labels at top of figure represent NASEM estimates of approximate phase size.
Sources: National Academies of Sciences, Engineering, and Medicine Framework for Equitable Allocation of Vaccine for the Novel Coronavirus, American Community Survey (ACS) 5-Year, and APM Research Lab, Color of Coronavirus.

Figure A3: Proportion of vaccine doses offered to Indigenous population,
By cumulative number of vaccine doses offered



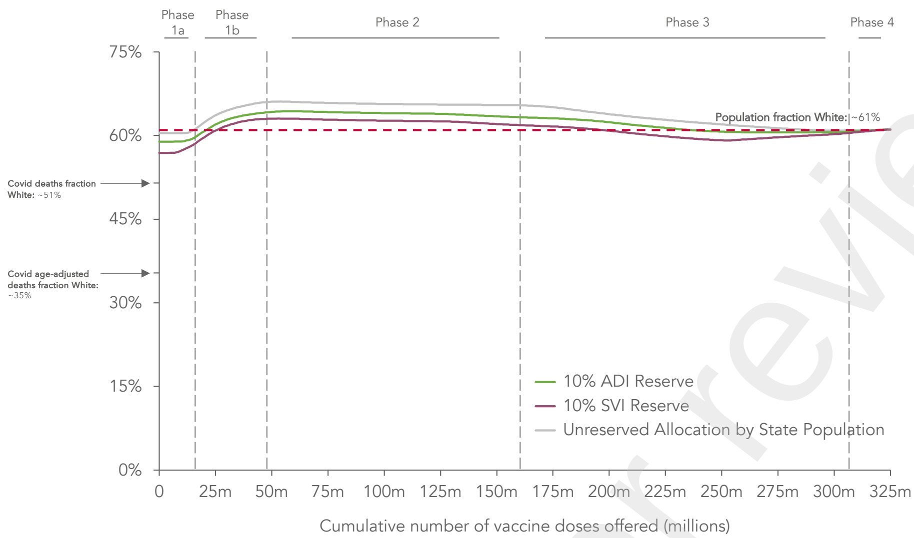
Notes: COVID-19 death fraction and age-adjusted death fraction is as of 09/15/2020. Death rates and age-adjusted death rates may be inaccurate in the presence of multi-racial groups and racial groups outside Indigenous, Asian, Black, Latino, White, and Pacific Islander. Indigenous is defined as Non-Hispanic, Alaska Native racial group and Non-Hispanic, American Indian racial group. Indigenous definition excludes individuals identifying as two or more races. Phase labels at top of figure represent NASEM estimates of approximate phase size.
Sources: National Academies of Sciences, Engineering, and Medicine Framework for Equitable Allocation of Vaccine for the Novel Coronavirus, American Community Survey (ACS) 5-Year, and APM Research Lab, Color of Coronavirus.

Figure A4: Proportion of vaccine doses offered to Asian population,
By cumulative number of vaccine doses offered



Notes: COVID-19 death fraction and age-adjusted death fraction is as of 09/15/2020. Death rates and age-adjusted death rates may be inaccurate in the presence of multi-racial groups and racial groups outside Indigenous, Asian, Black, Latino, White, and Pacific Islander. Asian is defined as Non-Hispanic, Asian racial group and Non-Hispanic, Native Hawaiian and Other Pacific Islander. Asian definition excludes individuals identifying as two or more races. Phase labels at top of figure represent NASEM estimates of approximate phase size.
Sources: National Academies of Sciences, Engineering, and Medicine Framework for Equitable Allocation of Vaccine for the Novel Coronavirus, American Community Survey (ACS) 5-Year, and APM Research Lab, Color of Coronavirus.

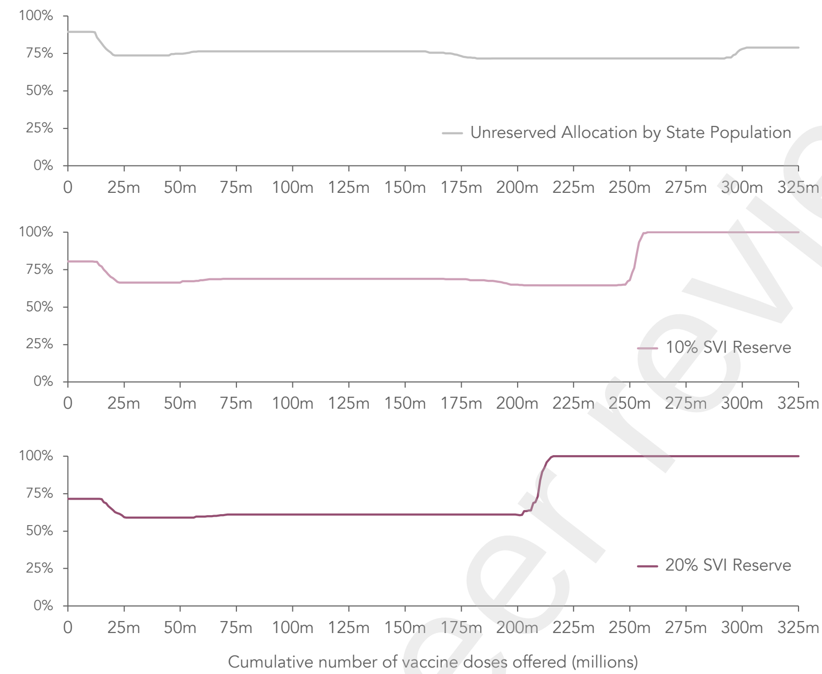
Figure A5: Proportion of vaccine doses offered to white population,
By cumulative number of vaccine doses offered



Notes: COVID-19 death fraction and age-adjusted death fraction is as of 09/15/2020. Death rates and age-adjusted death rates may be inaccurate in the presence of multi-racial groups and racial groups outside Indigenous, Asian, Black, Latino, White, and Pacific Islander. White is defined as Non-Hispanic, White racial group and excludes individuals identifying as two or more races. Phase labels at top of figure represent NASEM estimates of approximate phase size.
Sources: National Academies of Sciences, Engineering, and Medicine Framework for Equitable Allocation of Vaccine for the Novel Coronavirus, American Community Survey (ACS) 5-Year, and APM Research Lab, Color of Coronavirus.

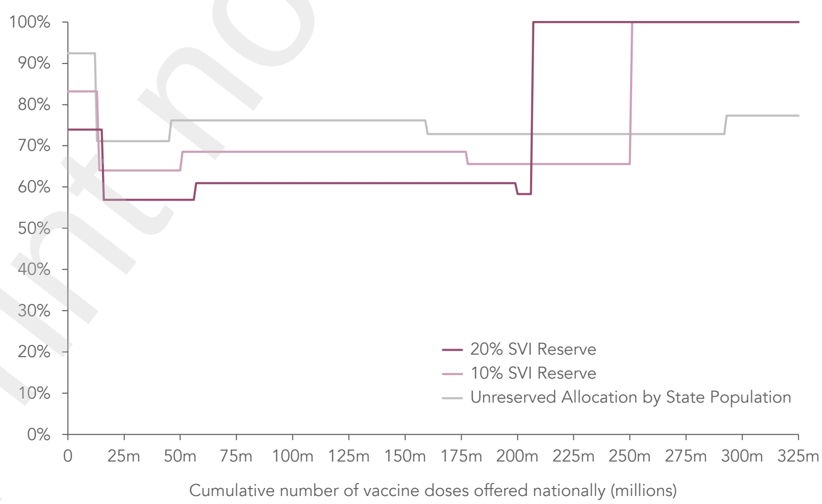
A8.2. Marginal share graphs

Figure A6: Marginal share of better-off population obtaining a vaccine on SVI



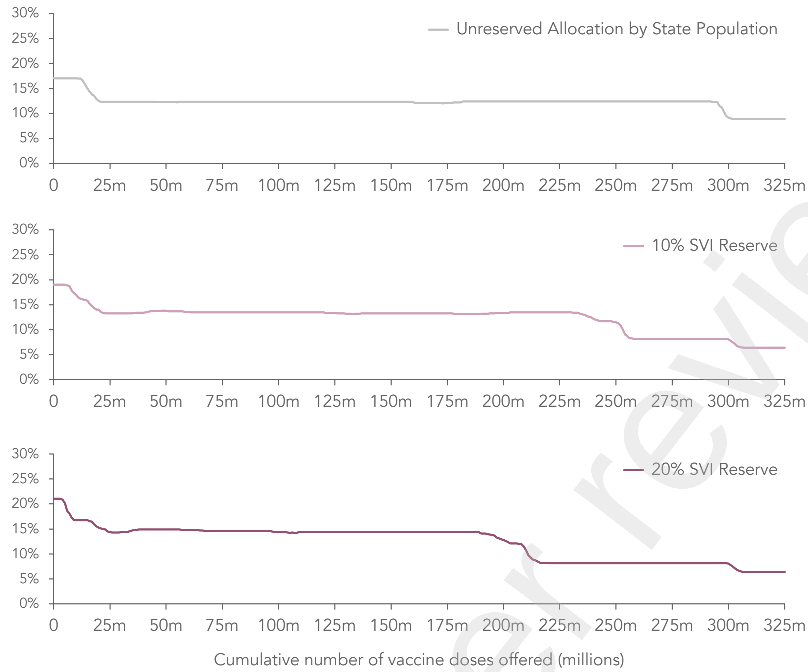
Sources: National Academies of Sciences, Engineering, and Medicine Framework for Equitable Allocation of Vaccine for the Novel Coronavirus, American Community Survey (ACS) 5-Year, and APM Research Lab, Color of Coronavirus.

Figure A7: Marginal share of the better-off population with respect to SVI obtaining a vaccine in California



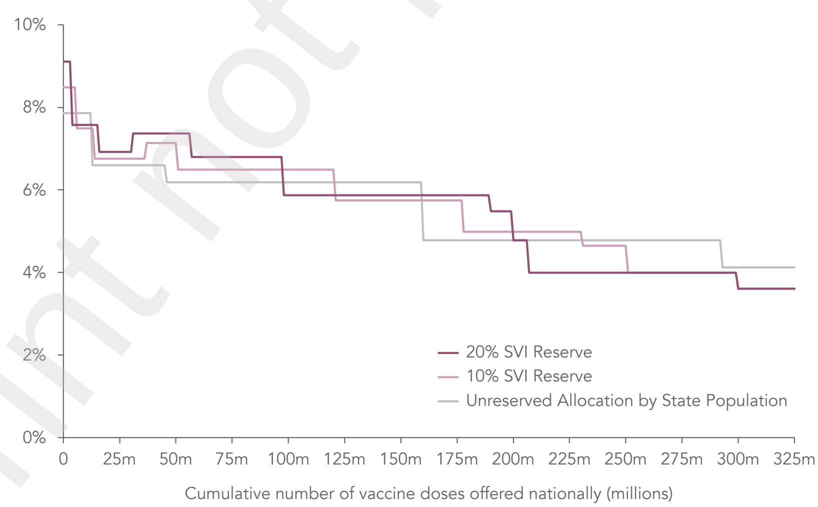
Sources: National Academies of Sciences, Engineering, and Medicine Framework for Equitable Allocation of Vaccine for the Novel Coronavirus, American Community Survey (ACS) 5-Year, and APM Research Lab, Color of Coronavirus.

Figure A8: Marginal share of Black population obtaining a vaccine on SVI



Sources: National Academies of Sciences, Engineering, and Medicine Framework for Equitable Allocation of Vaccine for the Novel Coronavirus, American Community Survey (ACS) 5-Year, and APM Research Lab, Color of Coronavirus.

Figure A9: Marginal share of Black population obtaining a vaccine in California on SVI



Sources: National Academies of Sciences, Engineering, and Medicine Framework for Equitable Allocation of Vaccine for the Novel Coronavirus, American Community Survey (ACS) 5-Year, and APM Research Lab, Color of Coronavirus.

References for the Appendix

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