Supplemental Digital Content

Using Microsimulation Modeling to Inform EHE Implementation Strategies in Los Angeles County

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1 Introduction

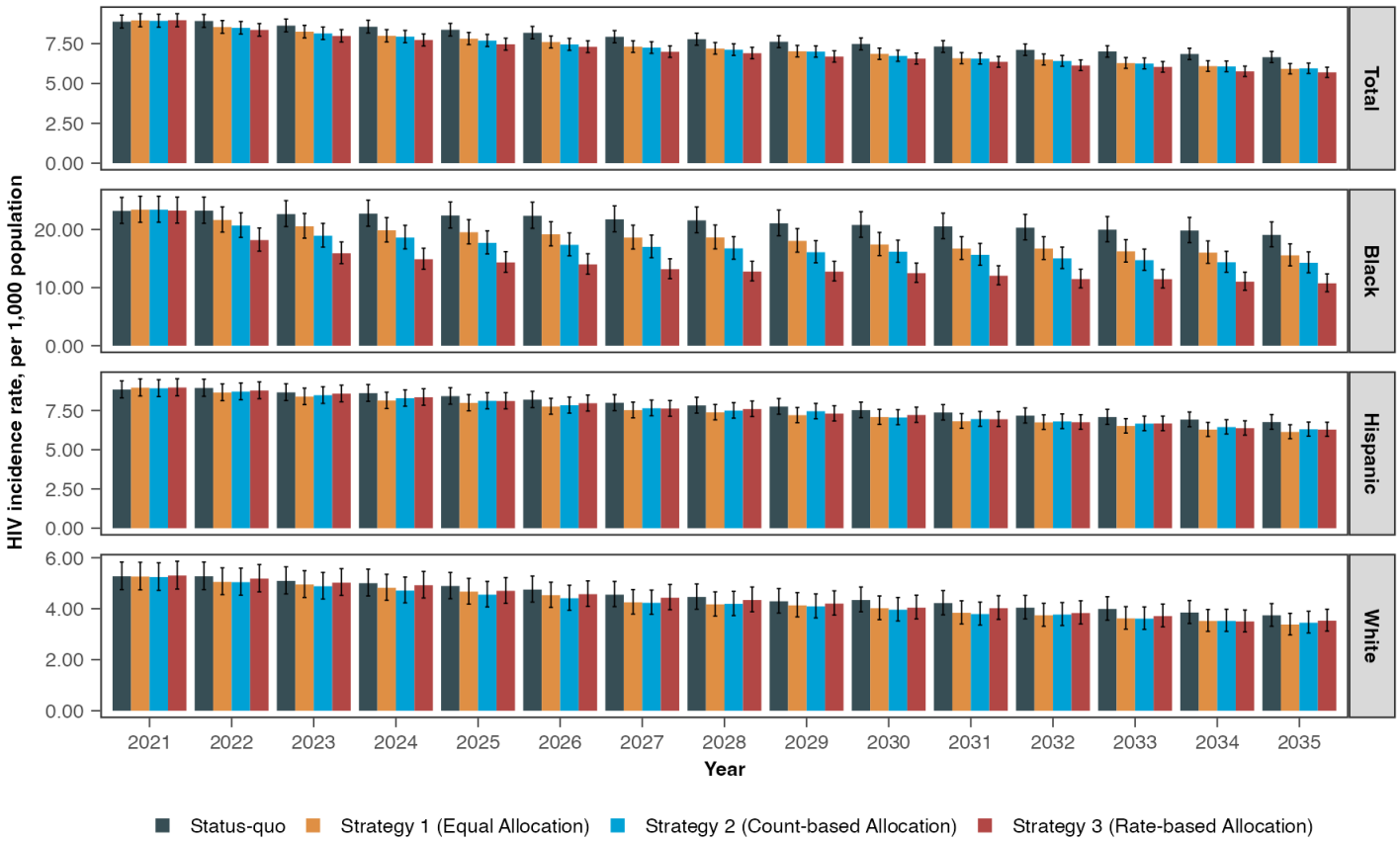
Mathematical models that permit the analysis of public health intervention across population subgroups and geographic areas can be useful laboratories for understanding the impacts of policies and generating new hypotheses that can later be tested. In this supplemental appendix, we describe an example of such models, which we have developed, in partnership with community and public health stakeholders, for the purpose of guiding HIV prevention and PrEP policies in Los Angeles County (LAC). We have previously applied this model to study HIV outcomes in LAC; this work is described in a preprint article entitled "Impact and Equality of Expanding PrEP for Men who have Sex with Men in Los Angeles". [31] Herein, we provide a more comprehensive description of the model, its development, parameterization, calibration and validation.

The purpose of this Supplemental Digital Content is two-folds: First, we seek to present additional results obtained from the application of the model to understand the impacts on HIV outcomes of equity-based PrEP allocation strategies among men who have sex with men (MSM) of different race and ethnic groups, in LAC. Second, we aim to offer a detailed overview of the microsimulation mode, which underlies those findings.

2 Additional Model Results

2.1 Annual trends in HIV incidence rates

Figure S1: Annual trends in HIV incidence rates, after increasing PrEP by 9,000 units annually for MSM racial and ethnic subgroups in LAC, by allocation strategy.



Abbreviations: PrEP, pre-exposure prophylaxis; MSM, men who have sex with men; LAC, Los Angeles County; HIV, human immunodeficiency virus.

Notes: Authors' analysis of the microsimulation model's outputs. Under each strategy, PrEP coverage is increased by 9,000 units annually above the Status-quo PrEP coverage levels, from 2021 to 2035. The annual HIV incidence rates are calculated as the ratios of the annual incident HIV cases in each year to the total population at risk of infection during that year. Status-quo refers to the allocation strategy which uniformly allocates currently available PrEP units (hence, no additional units of PrEP) to all at-risk MSM without consideration of equity. Strategy 1 equally allocates the 9,000 additional PrEP units to each racial and ethnic group. Strategy 2 allocates the 9,000 additional PrEP units to each racial/ethnic group proportionally to the count of PLWH in each group. Strategy 3 allocates the 9,000 additional PrEP units to each racial/ethnic group proportionally to new HIV diagnosis rates in each group in 2016.

Table S1: Annual HIV incidence rates per 1,000 person-years.

Year	Total Est. (95% CI)	Black Est. (95% CI)	Hispanic Est. (95% CI)	White Est. (95% CI)
		Status-quo*		
2021	8.88 (8.48-9.29)	23.20 (21.05-25.52)	8.83 (8.30-9.38)	5.27 (4.75-5.83)
2022	8.92 (8.52-9.33)	23.24 (21.07-25.57)	8.93 (8.40-9.49)	5.27 (4.75-5.83)
2023	8.63 (8.24-9.04)	22.65 (20.50-24.97)	8.65 (8.13-9.20)	5.09 (4.58-5.64)
2024	8.56 (8.17-8.97)	22.73 (20.56-25.06)	8.60 (8.08-9.15)	5.00 (4.50-5.55)
2025	8.37 (7.98-8.77)	22.41 (20.25-24.73)	8.41 (7.90-8.95)	4.89 (4.39-5.42)
2026	8.18 (7.80-8.58)	22.36 (20.20-24.70)	8.19 (7.68-8.72)	4.75 (4.26-5.28)
2027	7.93 (7.55-8.32)	21.75 (19.61-24.06)	7.99 (7.49-8.51)	4.55 (4.08-5.07)
2028	7.78 (7.40-8.16)	21.57 (19.43-23.88)	7.82 (7.33-8.34)	4.46 (3.98-4.97)
2029	7.62 (7.25-8.00)	21.06 (18.93-23.35)	7.75 (7.26-8.26)	4.29 (3.83-4.79)
2030	7.48 (7.11-7.86)	20.78 (18.66-23.07)	7.52 (7.04-8.03)	4.34 (3.88-4.85)
2031	7.32 (6.95-7.69)	20.53 (18.42-22.81)	7.37 (6.89-7.87)	4.22 (3.76-4.71)
2032	7.11 (6.76-7.48)	20.32 (18.22-22.60)	7.17 (6.70-7.66)	4.04 (3.60-4.52)
2033	7.01 (6.65-7.37)	19.97 (17.88-22.23)	7.08 (6.61-7.57)	3.99 (3.55-4.47)
2034	6.85 (6.50-7.21)	19.82 (17.74-22.08)	6.92 (6.46-7.40)	3.85 (3.42-4.32)
2035	6.65 (6.31-7.01)	19.07 (17.03-21.30)	6.76 (6.30-7.24)	3.74 (3.31-4.20)
		***Strategy 1 (Equal Allocation)**†		
2021	8.96 (8.56-9.38)	23.41 (21.24-25.73)	8.95 (8.42-9.51)	5.26 (4.74-5.82)
2022	8.54 (8.15-8.95)	21.64 (19.55-23.89)	8.64 (8.12-9.19)	5.05 (4.55-5.60)
2023	8.25 (7.86-8.65)	20.55 (18.51-22.76)	8.38 (7.87-8.92)	4.95 (4.44-5.49)
2024	7.99 (7.61-8.38)	19.86 (17.85-22.05)	8.13 (7.62-8.66)	4.82 (4.33-5.35)
2025	7.81 (7.44-8.20)	19.53 (17.52-21.70)	7.98 (7.48-8.51)	4.67 (4.18-5.19)
2026	7.60 (7.23-7.98)	19.17 (17.18-21.33)	7.75 (7.26-8.27)	4.53 (4.05-5.04)
2027	7.31 (6.95-7.68)	18.61 (16.64-20.74)	7.52 (7.03-8.03)	4.25 (3.79-4.75)
2028	7.19 (6.84-7.57)	18.63 (16.66-20.77)	7.38 (6.90-7.88)	4.17 (3.71-4.66)
2029	7.02 (6.67-7.39)	18.04 (16.10-20.16)	7.20 (6.72-7.69)	4.13 (3.68-4.63)
2030	6.86 (6.51-7.22)	17.42 (15.51-19.50)	7.08 (6.61-7.57)	4.02 (3.57-4.50)
2031	6.58 (6.24-6.94)	16.72 (14.85-18.77)	6.81 (6.36-7.30)	3.84 (3.40-4.31)
2032	6.50 (6.16-6.85)	16.72 (14.84-18.76)	6.74 (6.29-7.22)	3.74 (3.31-4.21)
2033	6.28 (5.95-6.63)	16.24 (14.39-18.26)	6.51 (6.06-6.98)	3.62 (3.20-4.08)
2034	6.09 (5.76-6.43)	16.02 (14.18-18.03)	6.28 (5.84-6.74)	3.52 (3.11-3.97)
2035	5.92 (5.60-6.25)	15.55 (13.74-17.53)	6.13 (5.70-6.59)	3.38 (2.97-3.82)
		***Strategy 2 (Count-based Allocation)**‡		
2021	8.93 (8.53-9.35)	23.41 (21.25-25.73)	8.91 (8.38-9.46)	5.24 (4.72-5.80)
2022	8.49 (8.10-8.89)	20.68 (18.64-22.88)	8.70 (8.18-9.25)	5.04 (4.53-5.59)
2023	8.14 (7.76-8.54)	18.93 (16.97-21.05)	8.47 (7.95-9.01)	4.88 (4.38-5.42)
2024	7.94 (7.56-8.33)	18.61 (16.66-20.72)	8.28 (7.77-8.81)	4.71 (4.23-5.24)
2025	7.69 (7.32-8.08)	17.70 (15.80-19.77)	8.11 (7.60-8.63)	4.55 (4.07-5.07)
2026	7.45 (7.08-7.83)	17.36 (15.47-19.41)	7.83 (7.33-8.35)	4.41 (3.94-4.92)
2027	7.25 (6.89-7.62)	17.01 (15.14-19.04)	7.64 (7.16-8.16)	4.23 (3.78-4.73)

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Table S1: Annual HIV incidence rates per 1,000 person-years (continued from previous page)

Year	Total Est. (95% CI)	Black Est. (95% CI)	Hispanic Est. (95% CI)	White Est. (95% CI)
2028	7.12 (6.76-7.49)	16.75 (14.89-18.77)	7.49 (7.01-8.00)	4.19 (3.73-4.68)
2029	7.00 (6.65-7.36)	16.09 (14.27-18.08)	7.45 (6.97-7.95)	4.09 (3.64-4.58)
2030	6.73 (6.39-7.09)	16.18 (14.35-18.17)	7.05 (6.59-7.55)	3.96 (3.52-4.44)
2031	6.56 (6.22-6.92)	15.64 (13.84-17.61)	6.95 (6.49-7.44)	3.79 (3.36-4.26)
2032	6.41 (6.08-6.76)	15.03 (13.27-16.97)	6.80 (6.34-7.28)	3.77 (3.34-4.24)
2033	6.25 (5.92-6.60)	14.72 (12.97-16.63)	6.66 (6.21-7.14)	3.61 (3.19-4.07)
2034	6.07 (5.74-6.41)	14.36 (12.64-16.25)	6.44 (6.00-6.91)	3.52 (3.11-3.98)
2035	5.95 (5.63-6.28)	14.27 (12.55-16.15)	6.30 (5.86-6.76)	3.45 (3.05-3.90)
Strategy 3 (Rate-based Allocation)[§]				
2021	8.97 (8.56-9.38)	23.25 (21.10-25.57)	8.96 (8.43-9.52)	5.30 (4.77-5.86)
2022	8.36 (7.97-8.76)	18.18 (16.27-20.26)	8.77 (8.25-9.32)	5.18 (4.66-5.73)
2023	7.98 (7.60-8.38)	15.91 (14.12-17.86)	8.57 (8.05-9.11)	5.02 (4.52-5.57)
2024	7.73 (7.35-8.11)	14.88 (13.15-16.78)	8.34 (7.83-8.88)	4.92 (4.42-5.46)
2025	7.46 (7.09-7.84)	14.33 (12.63-16.19)	8.10 (7.60-8.63)	4.70 (4.21-5.22)
2026	7.30 (6.94-7.68)	13.99 (12.31-15.83)	7.96 (7.46-8.48)	4.57 (4.09-5.09)
2027	6.99 (6.64-7.36)	13.17 (11.54-14.96)	7.62 (7.13-8.13)	4.43 (3.96-4.95)
2028	6.90 (6.55-7.27)	12.76 (11.16-14.53)	7.59 (7.11-8.10)	4.34 (3.88-4.85)
2029	6.69 (6.34-7.05)	12.75 (11.15-14.52)	7.30 (6.83-7.80)	4.20 (3.75-4.70)
2030	6.56 (6.22-6.91)	12.48 (10.90-14.22)	7.21 (6.74-7.71)	4.04 (3.60-4.53)
2031	6.36 (6.02-6.70)	12.04 (10.49-13.76)	6.94 (6.48-7.43)	4.02 (3.58-4.51)
2032	6.13 (5.81-6.48)	11.47 (9.96-13.15)	6.75 (6.30-7.23)	3.83 (3.40-4.31)
2033	6.04 (5.71-6.38)	11.45 (9.94-13.12)	6.67 (6.21-7.14)	3.71 (3.29-4.18)
2034	5.76 (5.44-6.09)	11.02 (9.54-12.66)	6.37 (5.93-6.84)	3.50 (3.09-3.95)
2035	5.70 (5.38-6.02)	10.74 (9.29-12.36)	6.28 (5.85-6.75)	3.53 (3.12-3.98)

Abbreviations: PrEP, pre-exposure prophylaxis; Est., estimate; CI, confidence interval.

Notes: Authors' analysis of the microsimulation model's outputs. Under each strategy, PrEP coverage is increased by 9,000 units annually above the Status-quo PrEP coverage levels, from 2021 to 2035.

[*] Status-quo refers to the allocation strategy which uniformly allocates currently available PrEP units (hence, no additional units of PrEP) to all at-risk MSM without consideration of equity.

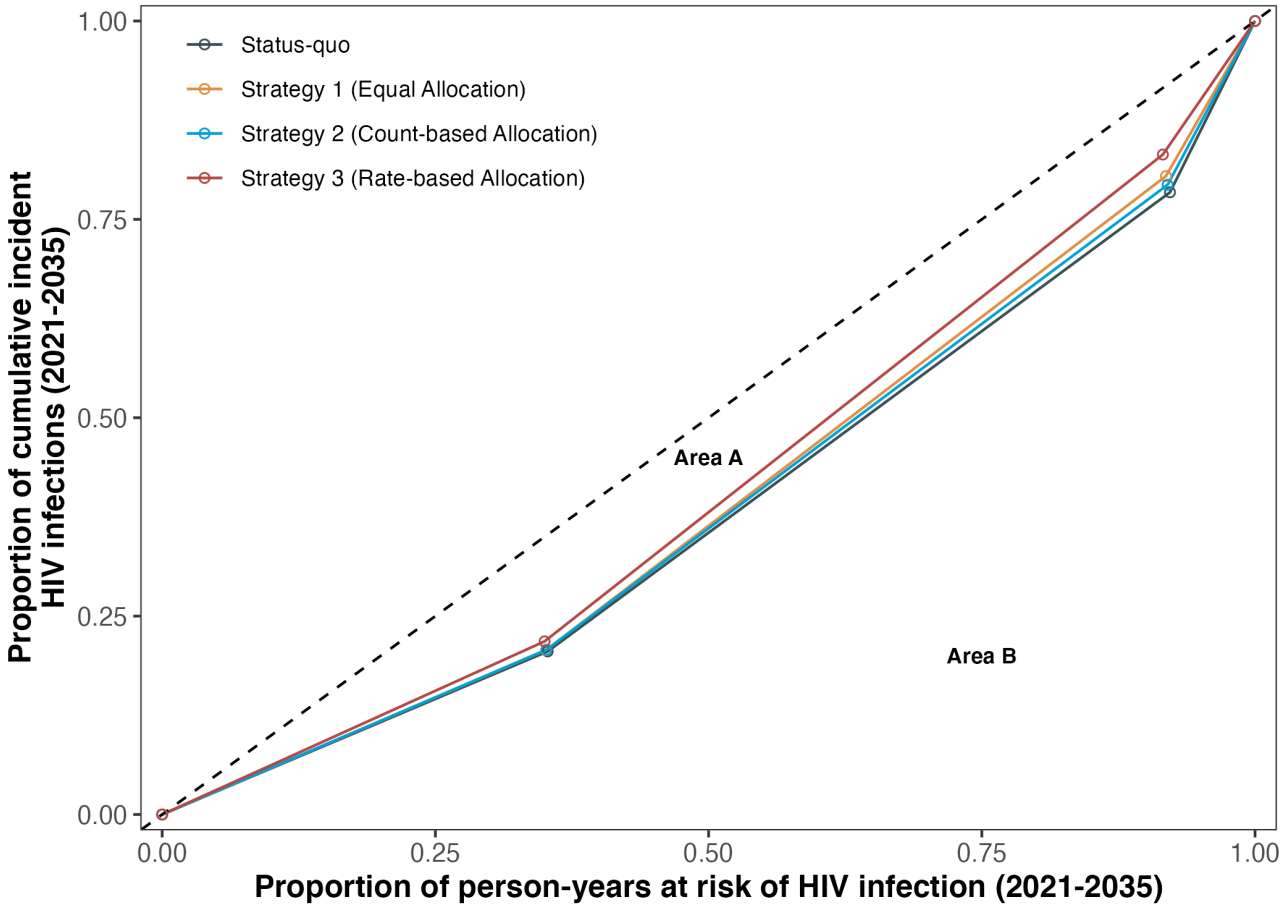
[†] Strategy 1 equally allocates the 9,000 additional PrEP units to each racial and ethnic group.

[‡] Strategy 2 allocates the 9,000 additional PrEP units to each racial/ethnic group proportionally to the count of PLWH in each group.

[§] Strategy 3 allocates the 9,000 additional PrEP units to each racial/ethnic group proportionally to new HIV diagnosis rates in each group in 2016.

2.2 Distribution of the burden of new HIV cases

Figure S2: Lorenz curves for the distribution of the burden of new HIV burden cases across racial and ethnic groups, and under alternative PrEP allocation strategies among MSM in LAC: 2021-2035.

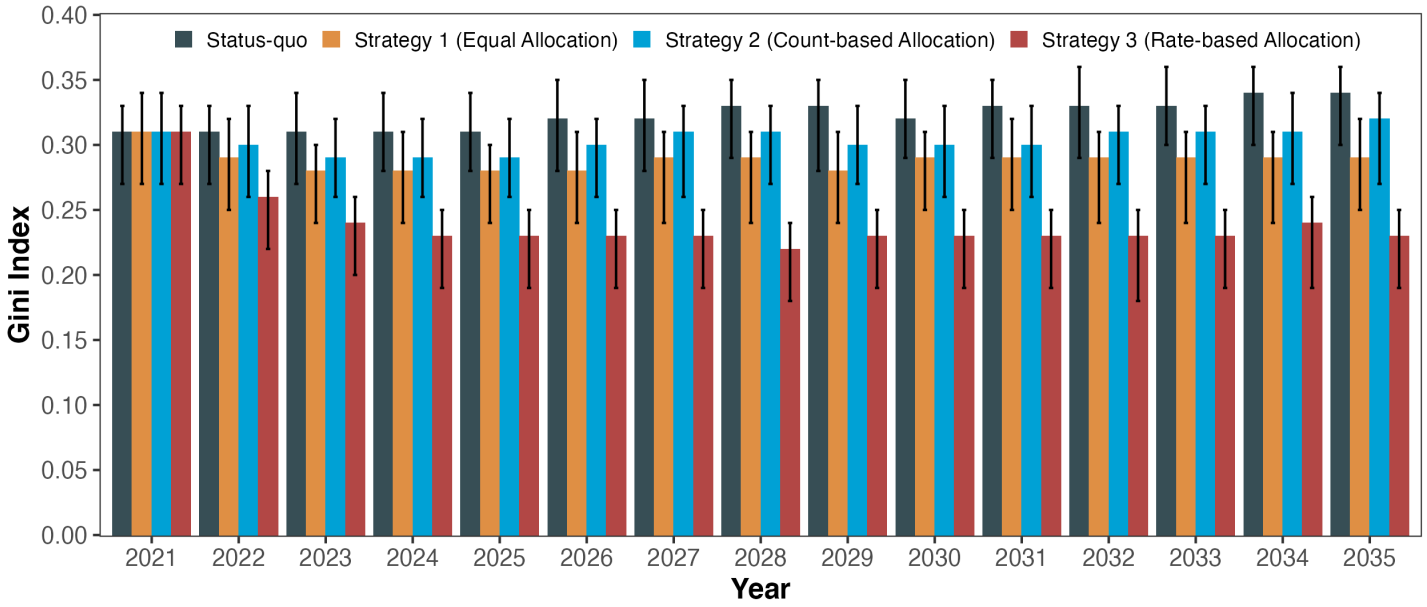


Abbreviations: PrEP, pre-exposure prophylaxis; MSM, men who have sex with men; LAC, Los Angeles County; HIV, human immunodeficiency virus.

Notes: Authors' analysis of the microsimulation model's outputs. Under each strategy, PrEP coverage is increased by 9,000 units annually above the Status-quo PrEP coverage levels, from 2021 to 2035. The dashed line represents the line of equality; the solid lines represent the Lorenz curves for each strategy, that is, the actual distributions of HIV burden in the population under each strategy. The cumulative numbers of incident HIV infections for different race and ethnic groups as well as the weighted Gini index associated with each strategy are summarized in Table 2. The Gini index for each strategy is the ratio of area between the line of perfect equality and the Lorenz curve for the strategy (area A), and the area below the line of perfect equality (area A + B). The Lorenz Curve for Status-quo is shown for comparison. Status-quo refers to the allocation strategy which uniformly allocates currently available PrEP units (hence, no additional units of PrEP) to all at-risk MSM without consideration of equity. Strategy 1 equally allocates the 9,000 additional PrEP units to each racial and ethnic group. Strategy 2 allocates the 9,000 additional PrEP units to each racial/ethnic group proportionally to the count of PLWH in each group. Strategy 3 allocates the 9,000 additional PrEP units to each racial/ethnic group proportionally to new HIV diagnosis rates in each group in 2016.

2.3 Annual Trends in Gini indices

Figure S3: Annual trends in Gini indices, after increasing PrEP by 9,000 units annually for MSM racial/ethnic subgroups in LAC, by implementation strategy.



Abbreviations: PrEP, pre-exposure prophylaxis; MSM, men who have sex with men; LAC, Los Angeles County; HIV, human immunodeficiency virus.

Notes: Authors' analysis of the microsimulation model's outputs. Under each strategy, PrEP coverage is increased by 9,000 units annually above the Status-quo PrEP coverage levels, from 2021 to 2035. The Gini index in each year represents the weighted Gini index, where the weights are the person-years at risk in each race and ethnic subpopulation, and the outcome measure is the annual HIV incidence rate in each year. The annual HIV incidence rates are calculated as the ratios of the annual incident HIV cases in each year to the total population at risk of infection during that year. Status-quo refers to the allocation strategy which uniformly allocates currently available PrEP units (hence, no additional units of PrEP) to all at-risk MSM without consideration of equity. Strategy 1 equally allocates the 9,000 additional PrEP units to each racial and ethnic group. Strategy 2 allocates the 9,000 additional PrEP units to each racial/ethnic group proportionally to the count of PLWH in each group. Strategy 3 allocates the 9,000 additional PrEP units to each racial/ethnic group proportionally to new HIV diagnosis rates in each group in 2016.

Table S2: Gini indices for the distribution of the health benefits of PrEP, by implementation strategy.

Year	Status-quo* Est. (95% CI)	Strategy 1† (Equal) Est. (95% CI)	Strategy 2‡ (Count-based) Est. (95% CI)	Strategy 3§ (Rate-based) Est. (95% CI)
2021-2035	0.32 (0.28-0.35)	0.29 (0.25-0.31)	0.30 (0.27-0.33)	0.24 (0.20-0.26)
2021	0.31 (0.27-0.33)	0.31 (0.27-0.34)	0.31 (0.27-0.34)	0.31 (0.27-0.33)
2022	0.31 (0.27-0.33)	0.29 (0.25-0.32)	0.30 (0.26-0.33)	0.26 (0.22-0.28)
2023	0.31 (0.27-0.34)	0.28 (0.24-0.30)	0.29 (0.26-0.32)	0.24 (0.20-0.26)
2024	0.31 (0.28-0.34)	0.28 (0.24-0.31)	0.29 (0.26-0.32)	0.23 (0.19-0.25)
2025	0.31 (0.28-0.34)	0.28 (0.24-0.30)	0.29 (0.26-0.32)	0.23 (0.19-0.25)
2026	0.32 (0.28-0.35)	0.28 (0.24-0.31)	0.30 (0.26-0.32)	0.23 (0.19-0.25)
2027	0.32 (0.28-0.35)	0.29 (0.24-0.31)	0.31 (0.26-0.33)	0.23 (0.19-0.25)
2028	0.33 (0.29-0.35)	0.29 (0.24-0.31)	0.31 (0.27-0.33)	0.22 (0.18-0.24)
2029	0.33 (0.28-0.35)	0.28 (0.24-0.31)	0.30 (0.27-0.33)	0.23 (0.19-0.25)
2030	0.32 (0.29-0.35)	0.29 (0.25-0.31)	0.30 (0.26-0.33)	0.23 (0.19-0.25)
2031	0.33 (0.29-0.35)	0.29 (0.25-0.32)	0.30 (0.26-0.33)	0.23 (0.19-0.25)
2032	0.33 (0.29-0.36)	0.29 (0.24-0.31)	0.31 (0.27-0.33)	0.23 (0.18-0.25)
2033	0.33 (0.30-0.36)	0.29 (0.24-0.31)	0.31 (0.27-0.33)	0.23 (0.19-0.25)
2034	0.34 (0.30-0.36)	0.29 (0.24-0.31)	0.31 (0.27-0.34)	0.24 (0.19-0.26)
2035	0.34 (0.30-0.36)	0.29 (0.25-0.32)	0.32 (0.27-0.34)	0.23 (0.19-0.25)

Abbreviations: PrEP, pre-exposure prophylaxis; Est., estimate; CI, confidence interval.

Notes: Authors' analysis of the microsimulation model's outputs. Under each strategy, PrEP coverage is increased by 9,000 units annually above the Status-quo PrEP coverage levels, from 2021 to 2035.

* Status-quo refers to the allocation strategy which uniformly allocates currently available PrEP units (hence, no additional units of PrEP) to all at-risk MSM without consideration of equity.

† Strategy 1 equally allocates the 9,000 additional PrEP units to each racial and ethnic group.

‡ Strategy 2 allocates the 9,000 additional PrEP units to each racial and ethnic group proportionally to the count of PLWH in each group.

§ Strategy 3 allocates the 9,000 additional PrEP units to each racial and ethnic group proportionally to new HIV diagnosis rates in each group in 2016.

3 Overview of the Microsimulation Model

This microsimulation model is designed to track HIV transmission and disease progression across various stages of HIV/AIDS infection among men who have sex with men (MSM) in Los Angeles County (LAC). The model tracks these changes among different population subgroups (i.e., age and race and ethnicity groups) and treatment status (e.g., treatment with pre-exposure prophylaxis, PrEP; treatment with antiretroviral therapy, ART). These transitions are governed by a Markovian process with a one-year cycle length.

3.1 Demographic Groups: Race and Ethnicity and Age Groups

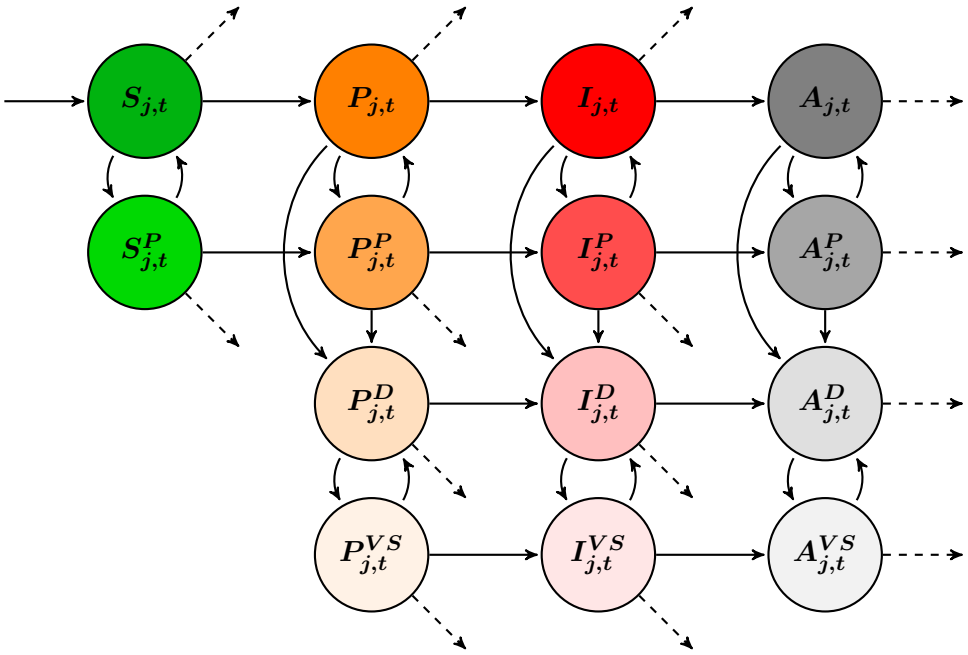
The population distribution in the model reflects the demographic makeup of the MSM population in LAC, along the characteristics of race and ethnicity (i.e., non-Hispanic Black [BMSM], Hispanic [HMSM or LMSM], non-Hispanic White [WMSM]) and age groups (i.e., 15-29, 30-49, 50-64, $\geq$ 65 years). Unfortunately, we are unable to model outcomes for other race and ethnic groups such as Asian American or other minority groups, due to data limitations. Instead, we proportionally redistributed the estimated number of men in these groups across the other race and ethnic groups described above.

3.2 Health States

The model includes a total of 15 distinct health states, each characterized by HIV infection status (HIV-positive or negative), level of CD4 cell counts (i.e., CD4 $\geq$ 500, 200 $\leq$ CD4 $<$ 500, CD4 $<$ 200), use of and retention in PrEP, HIV/AIDS diagnosis status, attainment of viral suppression (defined as HIV-1 RNA $<$ 200 copies/mL), and death, as illustrated in Figure S4. Figure S4 depicts the progression of men through different health states in the microsimulation model. By tracking the transitions of men across different health states over time, we can estimate changes in outcomes such as the annual prevalence and incidence of diagnosed and undiagnosed HIV, AIDS, and HIV/AIDS; treatment outcomes, and mortality, over time, and under alternative intervention strategies. In the current application of the model, we estimate these outcomes over a 15-year time horizon (2021-2035).

In the model, individuals previously diagnosed with HIV/AIDS become aware of their HIV/AIDS serostatus and, consistent with clinical guidelines and practice, do not initiate PrEP or discontinue treatment with PrEP. However, it is possible that an infected (undiagnosed) individual may initiate PrEP. If this occurs, it will only be for a small fraction of men, and for a short amount of time, for subsequent lab tests and will likely detect that infection. Therefore, while theoretically possible, it is unlikely that an undiagnosed infected individual treated with PrEP will progresses all the way to the AIDS stage (Stage 3) while on PrEP ($\boldsymbol{A^P_{j,t}}$) and without being diagnosed. Indeed, empirically, the health states $\boldsymbol{I^P}$ and $\boldsymbol{A^P}$ have fewer than 5 individuals for any demographic subgroup at any point in time. All individuals diagnosed with HIV/AIDS are assumed to initiate treatment with antiretroviral therapy (ART). Likewise, all individuals that are virally suppressed are assumed to be treated with ART.

Figure S4: Schematic of the Microsimulation Model.



Notes: This simplified flow diagrams is a representation of the various health states of the model, as well as transitions between them. The figure captures disease and treatment progression for individuals in one age and racial and ethnic group demographic pair, $j \in \mathcal{D} = \mathcal{D}_a \times \mathcal{D}_r$. All other pairs of age group and race and ethnicity are modeled, but not represented in the flow diagram for simplicity. Each circle represents a health state in the model: $\boldsymbol{S}$ represents susceptible individuals not treated with PrEP, while $\boldsymbol{P}$, $\boldsymbol{I}$ and $\boldsymbol{A}$ denote, respectively the state of undiagnosed infected individuals (thus unaware of their HIV serostatus) in Stage 1 (CD4 $\geq$ 500), Stage 2 (200 $\leq$ CD4 $<$ 500), and Stage 3 (AIDS; CD4 $<$ 200) of HIV infection. The superscripts P, D, and VS denote, respectively, treatment with PrEP, diagnosed, and virally suppressed. The subscripts j and t index the demographic subgroup and period of observation, respectively. The solid arrows connecting the circles represent possible transitions between health states within any particular pair of age group and race and ethnic group. The dashed lines represent transitions out of a given health state due to mortality from HIV or AIDS-related complications and/or other causes of death.

Table S3: Attributes of the simulated individuals.

Attributes	**Definitions and Assumptions**
Age	• Predetermined at model initialization or at entry in the model • Increases by 1 every year until death
Race and Ethnicity	• Predetermined at model initialization or at entry in the model • Invariant throughout the simulation
HIV Infection Status and Disease Stage	• Susceptible (uninfected), Stage 1 (CD4 $\geq$ 500), Stage 2 (200 $\leq$ CD4 $<$ 500), Stage 3 (AIDS; CD4 $<$ 200) • Progression independent of race and ethnicity and age
PrEP Use	• Ineligible for PrEP if previously diagnosed with HIV/AIDS • Variable levels of PrEP adherence among users
Diagnosed Status	• Aware of HIV serostatus • Are treated with ART
Viral Suppression	• Only achieved by diagnosed individuals • Are treated with ART • Can revert to viral rebound
Mortality	• AIDS-related mortality and mortality from all other causes • All individuals die after age 100 years (maximum allowed age) • Absorbing state: individual exits from the model

Table S4: Heath states of the microsimulation model.

Health State	Notation
Susceptible	
Untreated with PrEP	S_{jt}
Treated with PrEP	S_{jt}^{P}
Infected	
Stage 1 (CD4 ≥ 500)	
Undiagnosed and untreated with PrEP	P_{jt}
Undiagnosed and treated with PrEP	P_{jt}^{P}
Diagnosed and not Virally Suppressed	P_{jt}^{D}
Diagnosed and virally suppressed	P_{jt}^{VS}
Stage 2 ($200 \leq$ *CD4* ≤ 499*)*	
Undiagnosed and untreated with PrEP	I_{jt}
Undiagnosed and treated with PrEP	I_{jt}^{P}
Diagnosed and not Virally Suppressed	I_{jt}^{D}
Diagnosed and virally suppressed	I_{jt}^{VS}
Stage 3(AIDS; CD4 < 200)	
Undiagnosed and untreated with PrEP	A_{jt}
Undiagnosed and treated with PrEP	A_{jt}^{P}
Diagnosed and not Virally Suppressed	A_{jt}^{D}
Diagnosed and virally suppressed	A_{jt}^{VS}
Deceased	D_{jt}

3.3 Transitions Between Health States: State Transition Probabilities

Each year, new men enter the model at age 15, with discovery of sexual orientation, and at specified rates which vary by race and ethnicity and follow the same race and ethnicity distribution as the initial population. Once in the model, individuals can transition each year between health states based according to specific transition probabilities, which also vary by demographic and health characteristics. Individuals can exist the model through death from HIV/AIDS complications, or other causes. Our model does not capture population changes due to migrations (i.e., immigration or emigration).

In the model, the only permitted transitions between demographic strata are those due to aging. Thus, for all $j \neq k \in \mathcal{D}$, an individual in a state say, $\boldsymbol{X_{j,t}}$, during period t can only transition to state $\boldsymbol{X_{k,t+1}}$ due to aging.

3.3.1 Population Growth

3.3.2 Probabilities of Infection

The annual probabilities of infection for individuals in each demographic subgroup are determined dynamically based on a set of time-invariant parameters, as well as the population size and number of HIV positive individuals in the specified demographic subgroup in each period t. Specifically, the risk of infection is influenced by: (1) the prevalence of infectious individuals in the population, (2) the tansmissibility of HIV per unprotected sexual contact (biological parameter), (3) the individual's protection behavior (i.e., use of condom and use of PrEP) (4) the treatment status (with ART) and viral suppression status of the individual's infected sexual partners, (5) the individual's average number of sexual partners, and (6) the sexual partnership patterns between population subgroups (e.g., age, race and ethnicity).

The annual infection risk also varies by the following characteristics: (1) individual's race and ethnicity and age, (2) partner's race and ethnicity and age, (3) average annual number of sexual partners, (4) size of the infectious population at each period, (5) general ART adherence levels, and (6) individual's use PrEP status and PrEP adherence level. We do not explicitly differentiate MSM by risk behavior (e.g., high- vs medium- vs low-risk), as data on race and ethnicity on risk behaviors are limited. We use different transmissibility risk parameters to capture potential race and ethnic differences in infection probabilities due to risk behaviors.

The annual probability of infection for any individual in demographic group $i = (a_i, r_i) \in \mathcal{D} = \mathcal{D}_a \times \mathcal{D}_r$ is given by equation (1) below:

$$\pi_{i,t} = \phi_i \left(1 - \prod_{j \in \mathcal{D}} \left\{ 1 - \gamma_j^a \beta_j \left(\frac{I_{j,t}}{N_{j,t}} \right) \right\}^{P_j M_{i,j}} \right), \tag{1}$$

where $j = (a_j, r_j) \in \mathcal{D} = \mathcal{D}_a \times \mathcal{D}_r$ indexes the demographic group of individual i's sexual partner, a_d and r_d denote respectively the age group and race and ethnicity group of the individual, $\forall d \in \mathcal{D}$, $\mathcal{D} = \mathcal{D}_a \times \mathcal{D}_r$ represents the set of all pairs of demographic characteristics, $\pi_{i,t}$ denotes the annual probability of infection among susceptible individuals in demographic group i; T and $\bar{T}$ denote, respectively, ART treatment and non-treatment status, ϕ_i ($0 \leq \phi_i \leq 1$) is a PrEP efficacy multiplier for individuals in the low and medium PrEP adherence categories, relative to those in the high adherence group, and γ_j is a group multiplier for the transmission coefficient, and defined as follows:

$$\gamma_j^a = \begin{cases} \gamma & \text{if } 0 \leq a_j \leq 24 \\ 1 & \text{otherwise} \end{cases}, \tag{2}$$

where a_j denotes the age category in group j. The parameter β_j represents the transmission coefficient among individuals in group j, and is assumed to be time invariant, and vary only by race and ethnicity (not by age group). This parameter is the product of the average rate of contact between a susceptible individual and infected individuals in group j, $\bar{c}_j$ and the average transmissibility parameter, $\bar{\tau}$, which is average probability of infection given contact between a susceptible and infected individual:

$$\beta_j = \bar{c}_j \tau. \tag{3}$$

Notice that this formulation assumes that the transmissibility parameter is constant across all infected health states. But this needs not be the case; indeed, the probability of infection varies greatly across HIV stages and with the viral load of the infected partner. So, more generally, τ can be defined to depend on the infected state, $X \in I$, as follows:

$$\tau = \sum_{X \in I} \delta_X \tau_X, \tag{4}$$

where $0 \leq \tau_X \leq 1$, $0 \leq \delta_X \leq 1$ and $\sum_{X \in I} \delta_X = 1$. When $\delta_X = \delta = \frac{1}{|I|}$, $\forall X \in I$, then $\tau = \bar{\tau}$, so that the term in equation (3) is obtained.

We define $I_{j,t}$ to denote the number of infectious sexual partners in demographic group j. It's mathematical expression is as follows:

$$I_{j,t} = \sum_{X \in I} \delta_X X_{j,t}, \tag{5}$$

where δ_X $(0 \leq \delta_X \leq 1)$ denotes the fraction of individuals in the infected state X that are infectious. When $\delta_X = \delta = 1$, then $I_{j,t} = \sum_{X \in I} X_{j,t}$. For the current model, we assume that all non-virally suppressed infected individuals not treated with ART, $I_{j,t}^{\bar{T}}$, and a fraction $(1 - \alpha_j)$ of all non-virally suppressed infected individuals treated with ART, $I_{j,t}^{T}$, are infectious, so that the following holds:

$$I_{j,t} \quad = \quad I_{j,t}^{\bar{T}} + (1 - \alpha_j) I_{j,t}^{T}. \tag{6}$$

In this formulation, $I_{j,t}$ represents the number of infectious individuals in group j at time t, and is the sum of the number of untreated infected individuals $(I_{j,t}^{\bar{T}})$ and ART-treated individuals considered to have low adherence to their ART regimen (i.e., $(1 - \alpha_j) I_{j,t}^{T}$).

The parameter α_j represents the fraction of treated (infected) individuals in group j that are adherent to to their ART treatment. It is a weighted average of the ART adherence rates in the treatment health states of the model, and is defined as follows:

$$\alpha_j \quad = \quad \sum_{X \in X^T} \alpha_{X,j} = \sum_{X \in X^T} \rho_{X,j} \alpha, \tag{7}$$

where $0 \leq \alpha \leq 1$, $0 \leq \rho_{X,j} \leq 1$, and $\sum_{X \in X^T} \rho_{X,j} = 1$, and is defined as follows:

$$\rho_{X,j} = \frac{\hat{X}_{j,t}^{T}}{\sum_{Y \in X^T} \hat{Y}_{j,t}^{T}} = \frac{\kappa_X X_{j,t}^{T}}{\sum_{Y \in X^T} \kappa_Y Y_{j,t}^{T}}, \tag{8}$$

to denote the share of all ART-adherent individuals in state $X \in X^T$, that are adherent to their ART treatment, where $\hat{X}_{j,t}^{T} = \kappa_X X_{j,t}^{T}$, with κ_X denoting ART adherence rate in health state X^T and demographic group j. Notice that when $\kappa_X = \kappa$ such that κ is invariant with health states, $\rho_{X,j} = X_{j,t}^{T} \Big/ \sum_{Y \in X^T} Y_{j,t}^{T}$. Furthermore, when $\rho_{X,j}$ is assumed to be invariant with health states and demographic characteristics, it follows that:

$$\rho_{X,j} = \rho = 1 \Big/ \sum_{X \in X^T} X_j, \tag{9}$$

thus implying that $\alpha_j = \alpha$. As a result, equation (6) can be restated as follows:

$$I_{j,t} \quad = \quad I_{j,t}^{\bar{T}} + (1 - \alpha) I_{j,t}^{T}. \tag{10}$$

The term $N_{j,t}$ denotes the total number of men in the demographic group j in period t, and is defined such that $\sum_{j \in \mathcal{D}} N_{j,t} = N_t$, where $N_t = \sum_{X} X_t$. The ratio $\dfrac{I_{j,t}}{N_{j,t}}$ represents the fraction of individual i's sexual partners in group j, that are infectious. The term P_j denotes the average annual number of sexual partners for individuals in group j, $M_{i,j}$ $(0 \leq M_{i,j} \leq 1)$ denotes the probability that an individual in group i has an unprotected sexual contact with a partner in group j, and represents an entry of the sexual mixing matrix, M.

3.3.3 Disease Progression

Once infected, individuals can progress through different stages of HIV/AIDS infection and achievement of viral suppression at specified probabilities, which depend on the natural history of HIV/AIDS disease progression, and treatment status. Treatment with antiretroviral therapy (ART) reduces the risk of progression to a later stage, and increases the probability of achieving viral suppression, depending on adherence level.

3.3.4 Mortality

Mortality occurred in the model through AIDS-related complications or all other causes. We estimated risk from both types of causes by age category for men in the U.S. population, using life tables and estimates from the literature.

4 Model Input Parameters: Data and Estimation

4.1 Initial Population

Burn-in is an approach used to help prevent the tendency for fluctuations in disease prevalence at the initialization of the model from biasing the simulation results. Given that HIV trends among MSM in LAC are not in steady state, a burn-in procedure for the simulation would not be an appropriate method for determining the characteristics of the initial population. Thus, we use the available population data from disparate sources to initialize the model.

There is a paucity of detailed data on demographic and health characteristics of the MSM population in the U.S. more generally, and in LAC in particular. These data challenges are further compounded by the fact that estimates available from the literature or reports are not often stratified by demographic and health characteristics relevant to subgroup analyses (e.g., race and ethnicity and age, in our specific case). To overcome these challenges, we applied estimates from the general (male) population trends to our MSM population, whenever MSM-specific estimates were lacking. We used LAC-specific data wherever available; in the absence of such data, we used state or national estimates, with appropriate adjustments. Similarly, male-specific or general population estimates were used when MSM-specific estimates were lacking. To derive subgroup-specific estimates, we either assumed independence between some relevant characteristics (e.g., assume that age and race and ethnicity are not correlated) or conducted calibration exercises involving solving optimization sub-problems to identify a feasible joint distribution that could be used in our simulation.

4.1.1 LAC MSM Population

The initial population estimates for the simulations are summarized in Table S6. The estimated MSM population in LAC, aged 15 years and older at the beginning of the simulation (end of year 2011) was $n = 251,521$ individuals, as estimated from the 2009-2013 American Community Survey (ACS) [15]. The demographic characteristics (i.e., age and race and ethnicity) of this initial population were also reported by the U.S. Census Bureau [41]: the age distributions are summarized in Table S5; the distributions along race and ethnicity were 10% for Blacks, 57% for Hispanics and 33% for Whites.

4.1.2 Infected Population

An estimated 13.5% of PLWHs in the U.S. in 2008-2012 were undiagnosed, and thus unaware of their HIV infected status [16]. Using this estimate and the LAC surveillance data for diagnosed HIV cases in 2011, we estimated that approximately 18.3% of the overall LA County MSM population lived with an HIV/AIDS infection (PLWH).

The initial distributions of undiagnosed individuals in each stage of the HIV infection were derived from Khurana et al. (2018) [21], whereas the proportion of diagnosed individuals were estimated from the LA County HIV Surveillance data.

To determine the distributions of the infected (and uninfected) population across each age and race and ethnicity subgroup, we conducted again calibration exercises, by solving a quadratic programming optimization subproblem utilizing LA County Department of Public Health HIV Surveillance data on diagnosed HIV cases.

Data on age breakdowns by race and ethnicity for MSM in Los Angeles County were not available. Therefore, for the susceptible and undiagnosed populations, we assumed independence between the proportions identified for each demographic and health stratification (i.e., age, race and ethnicity, and HIV stage). We applied the joint proportion relevant for each subgroup to the overall MSM population to derive an estimate of the number of MSM in all HIV negative and undiagnosed compartments.

For the diagnosed population, MSM-specific estimates for the number of individuals diagnosed with HIV by age and race for 2011, and the number of virally suppressed individuals by age and race, from the LA County Department of Public Health Surveillance data. We therefore make use of these data to estimate the distributions of the diagnosed MSM population by race, age, and viral suppression status. We do so by minimizing the weighted sum of squared errors between the imputed and empirical values, using the MATLAB CVX package, while ensure that no compartments are empty.

Table S5: Age distribution of the male population in Los Angeles County in 2011.

Age groups (years)	**Estimate (%)**
15-19	10
20-24	10
25-29	10
30-34	9
35-39	9
40-44	9
45-49	9
50-54	8
55-59	7
60-64	6
65-69	4
70-74	3
75-79	2
80-84	2
≥ 85	1

Source: U.S. Census Bureau data [41].

Table S6: Initial state values in 2011, and model input parameter values.

Parameter	Total	Black	Hispanic	White	Source
LAC MSM population, N	251,521	—	—	—	[27; 15; 41]
Age distribution of LAC male population, % of total	Varies	—	—	—	Table S5
PLWH, % total MSM	18.3	—	—	—	Calculation, [9]
Infected (PLWH) MSM, % total PLWH	—	19.0	43.0	38.0	‡
Uninfected MSM, % total uninfected	—	10.0	57.0	33.0	[41; 36]
Age group, % total PLWH					
15-29 y	11.0	—	—	—	‡
30-49 y	58.0	—	—	—	‡
50-64 y	28.0	—	—	—	‡
$\geq$ 65 y	3.0	—	—	—	‡
Diagnosed HIV, % of MSM PLWH	15.8	—	—	—	†
Infection stage, % diagnosed PLWH					
CD4 $\geq$ 500					
$\geq$ 15 y	29.0	—	—	—	‡
15-29 y	—	33.9	47.1	22.9	†
30-49 y	—	30.0	43.7	18.5	†
50-64 y	—	12.5	6.3	6.5	†
$\geq$ 65 y	—	1.0	0.7	0.8	†
Stage 2 (200 $\leq$ CD4 $<$ 500)					
$\geq$ 15 y	34.0	—	—	—	‡
15-29 y	—	34.4	56.0	23.0	†
30-49 y	—	30.2	54.0	18.4	†
50-64 y	—	10.6	5.1	5.5	†
$\geq$ 65 y	—	1.1	0.4	0.4	†
Stage 3 (AIDS; CD4 $<$ 200)					
$\geq$ 15 y	37.0	—	—	—	‡
15-29 y	—	95.9	98.2	97.9	†
30-49 y	—	96.8	98.4	98.3	†
50-64 y	—	92.7	97.4	96.9	†
$\geq$ 65 y	—	28.0	1.41	16.6	†
Undiagnosed HIV, % of MSM PLWH	13.5	—	—	—	[16] (Table 2)
Infection stage, % undiagnosed PLWH					
Stage 1 (CD4 $\geq$ 500)	41.3	—	—	—	[21]
Stage 2 (200 $\leq$ CD4 $<$ 500)	50.3	—	—	—	[21]
Stage 3 (CD4 $<$ 200)	8.4	—	—	—	[21]
Viral suppression rate, % of diagnosed PLWH					
$\geq$ 15 y	—	44.0	56.0	59.0	‡
15-29 y	40.0	8.0	11.0	12.0	Calibration, ‡
30-49 y	54.0	8.0	8.0	12.0	Calibration, ‡
50-64 y	62.0	21.0	21.0	22.0	Calibration, ‡
$\geq$ 65 y	63.0	7.0	7.0	8.0	Calibration, ‡
PrEP coverage in 2011, %	0.0	—	—	—	[13]
Annual PrEP uptake rate, %					
2012-2013	0.037	—	—	—	[17; 25]
2014-2016	0.478	—	—	—	[17; 25]
2017-Present	2.413	—	—	—	[17; 25]
PrEP discontinuation, %	59.0	—	—	—	[35; 34]
PrEP adherence levels, %					
Low	20.0	—	—	—	[22]
Medium	10.0	—	—	—	[22]
High	70.0	—	—	—	[22]
Relative risk of HIV infection, by PrEP adherence					
Low (reference)	1.00	—	—	—	[7; 39; 28; 19]

Continued on next page

Table S6: Initial state values in 2011, and model input parameter values. (continued from previous page)

Parameter	Total	Black	Hispanic	White	Source
Medium	0.42	—	—	—	[7; 39; 28; 19]
High	0.10	—	—	—	[7; 39; 28; 19]
HIV progression probability, %					
Virally suppressed					
Stage 1 (CD4 $\geq$ 500) to Stage 2 (200 $\leq$ CD4 $<$ 500)	0.040	—	—	—	Calibration
Stage 2 (200 $\leq$ CD4 $<$ 500) to Stage 3 (CD4 $<$ 200)	0.045	—	—	—	Calibration
Not virally suppressed					
Stage 1 (CD4 $\geq$ 500) to Stage 2 (200 $\leq$ CD4 $<$ 500)	0.340	—	—	—	Calibration
Stage 2 (200 $\leq$ CD4 $<$ 500) to Stage 3 (CD4 $<$ 200)	0.150	—	—	—	Calibration
Probability of viral rebound	—	0.009	0.010	0.003	Calculation, [18] (Table 1 & 2)
Transmission coefficient	—	0.019	0.0095	0.0057	Calibration
Transmission coefficient multiplier for ages 15-24 y	1.43	—	—	—	Calibration
Treated PLWH with high adherence, %	95.0	—	—	—	[32]
Transmissibility multiplier with high adherence	0	—	—	—	[32]
Average number of sexual partners					§
15-19 y	8	—	—	—	§
20-24 y	12	—	—	—	§
25-34 y	12	—	—	—	§
35-44 y	8	—	—	—	§
45-54 y	12	—	—	—	§
55-74 y	8	—	—	—	§
$\geq$ 75 y	0	—	—	—	§
Entry of new MSM, % of total MSM population	0.019	—	—	—	Calculation
Entry of new MSM, % of total new entrants	—	10.0	57.0	33.0	[41; 36]
Age group-specific probability of death	Varies	Varies	Varies	Varies	[8] (Life table for men)
Relative risk of AIDS-caused mortality with ART	0.78	—	—	—	[20]
Age group mortality risk multipliers					
15-29 y	2.00	—	—	—	Calibration
30-46 y	3.00	—	—	—	Calibration
50-64 y	1.75	—	—	—	Calibration
$\geq$ 65 y	1.00	—	—	—	Calibration

Abbreviations: HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome; PrEP, pre-exposure prophylaxis; LAC, Los Angeles County; MSM, men who have sex with men; PLWH, persons living with HIV.
Notes:
† Calculation, using data from LAC Department of Public Health
‡ LAC Department of Public Health
§ LA LGBT Center

4.2 Population Growth

Population growth in the model accounts for entry of new cohorts of young men (age 15) in the population, as they mature. We assume that any population growth that would occur via migrations of MSM into LAC after age 15 (immigration) is sufficiently low or is fully offset by migrations of MSM out of LAC (emigrations). This assumption is consistent with those made in other HIV models with age stratification [21].

We assume that the number of new men entering the population each year is equivalent to the proportion of 15-year old in the initial population (1.9%). This approach ensures temporal stability in the share of the 15-year old in the population. Thus, in all years of the simulations, 1.9% of the prior year's population enter the model as a cohort of 15-year old individuals, prior to any simulated transitions.

All new entrants are considered susceptible (uninfected) and not being treated with PrEP. The race and ethnicity distribution of these new entrants is assumed to be that of susceptible individuals in the initial population.

4.3 Probability of Infection

Key parameters involved in the calculation of the annual probability of infection are provided in Table S6.

4.3.1 Prevalence of Infectious Cases

With the availability of highly efficacious ART drugs, infected individuals can achieve viral suppression, a state in which they virtually no longer transmit HIV to others. Hence, when modeling HIV transmission, it is critical to take this into consideration. To calculate the likelihood of HIV acquisition by a susceptible individual, we only consider the prevalence of infectious HIV cases in the population. This prevalence is dynamic, changing year to year as individuals move between health states – new individuals can become virally suppressed, and previously virally suppressed individuals can experience viral rebound. We dynamically estimate this prevalence in the model in each period, by summing up the number of men in any of the infectious health states ($\boldsymbol{P}$, $\boldsymbol{P^P}$, $\boldsymbol{P^D}$, $\boldsymbol{I}$, $\boldsymbol{I^P}$, $\boldsymbol{I^D}$, $\boldsymbol{A}$, $\boldsymbol{A^P}$, and $\boldsymbol{A^D}$).

4.3.2 Transmissibility Risk

The transmissibility risk parameters are calibrated via our dynamic dynamic formulation of the annual probability of infection for specific demographic groups.

4.3.3 Protective Efficacy of PrEP

While PrEP has been shown to be a highly efficacious and cost-effective HIV prevention tool, its protective efficacy depends on the level of adherence to treatment. In our model, we consider three levels of adherence among PrEP users: (1) low adherence (20% of users), medium adherence (10% of users), high adherence (70% of users) [22]. At low adherence, PrEP is considered to have no effect, while at high adherence, 90% of PrEP users would be protected [7]. At medium adherence, 58% of the users would be protected [22].

4.3.4 Efficacy of ART for Achieving Viral Suppression

The clinical efficacy of ART at reducing viral load and preventing the depletion of CD4 cell counts depends on the individual's level of adherence to the treatment regimen. In our model, we consider individuals indicated to have viral suppression by the end of the year to have ART adherence levels that are either low (5% of treated individuals) or high (95% of treated individuals).

Following information from the PARTNER2 Study, high level users are considered not infectious while low level users remain infectious [32].

4.3.5 Average Annual Number of Sexual Partners

It is also important to consider the average annual number of partners an individual may have. Using data from the LA LGBT center's survey on sexual partnerships, we estimated that men in the $15-19$, $20-24$, $25-34$, $35-44$, $45-54$, and $55-74$ age groups had, respectively, 8, 12, 12, 8, 12, and 8 sexual partners on average during a three-months period. We assumed no partnerships after age 75. We did not observe significant racial and ethnic differences in the number of partners from these data.

4.3.6 Sexual Partnership Patterns: Sexual Mixing Matrix

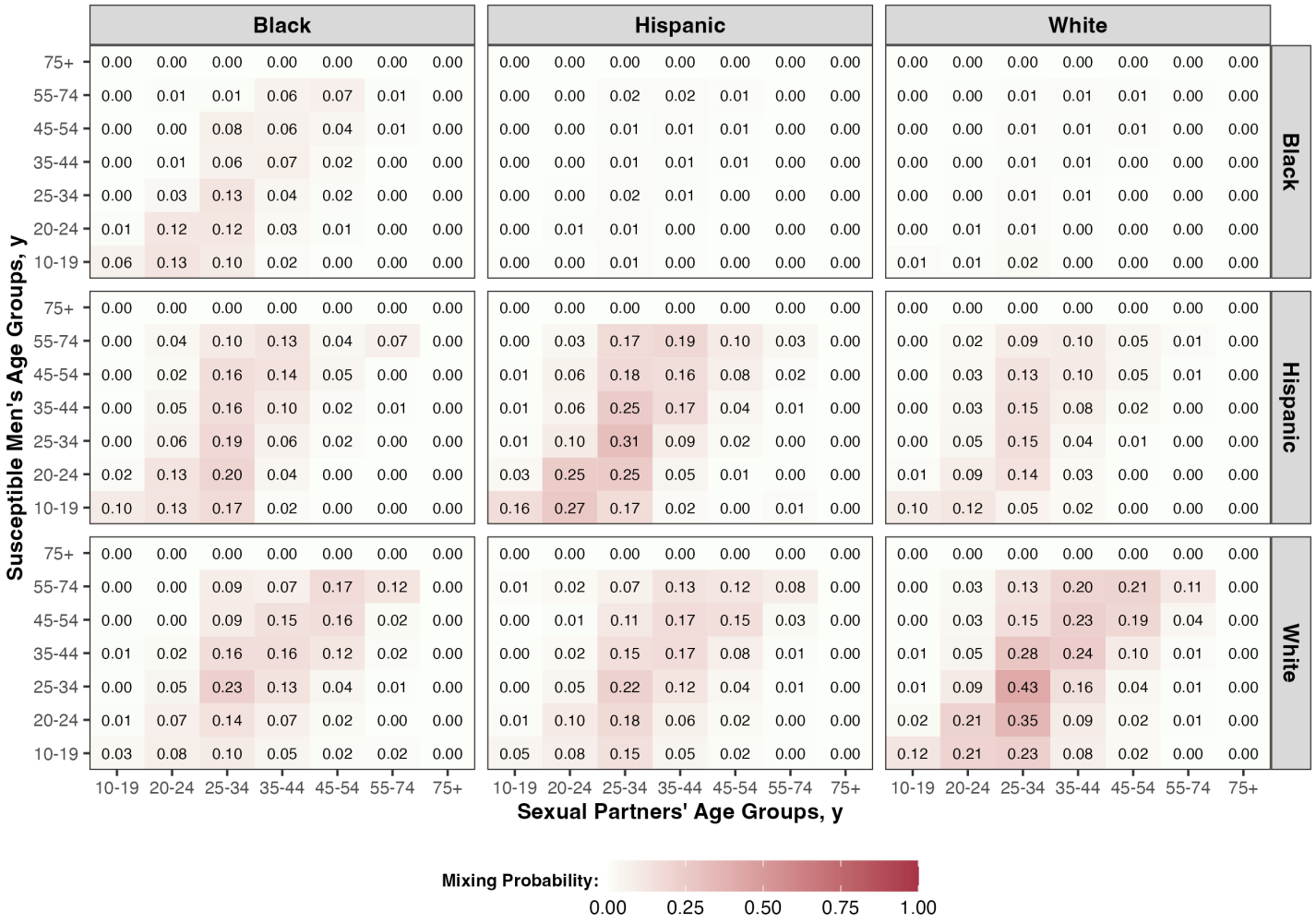
Group sexual mixing patterns are also important to HIV transmission. Prior studies suggest that MSM mix sexually along the sociodemographic characteristics of age and race and ethnicity. To adequately account for these dynamics requires stratification along specific relevant characteristics. Hence, models that are not stratified

by age or race and ethnicity are unable to appropriately account for partnership patterns with respect to these characteristics. These models often assume purely non-assortative partnerships that assign equal the likelihood for any individual in the simulation to form a sexual partnership, irrespective of their age or race and ethnicity.

An alternative approach is to use empirical preferential partnership patterns. Under the empirical sexual mixing approach, an individual's likelihood of forming a sexual partnership with another one depends not only on their own age and race and ethnicity, but also on the age and race and ethnicity of that potential partner. In our simulation, we identify the likelihood of a transmissible contact and average number of sexual partners based on an individual's race and ethnicity and age group. These probabilities, organized into a sexual mixing (or sexual partnership) matrix, are used to determine the annual probability of infection for different race and ethnicity and age groups each year, as the size of the infectious population – thus the risk that any random sexual partner is infectious – changes over time for each race and ethnicity and age group.

We model partnerships using a partnership matrix, $\boldsymbol{M}$, that captures the age, as well as racial and ethnic sexual partnership patterns of MSM in LAC. The matrix is informed from empirical data collected by a Los Angeles Lesbian, Gay, Bisexual, and Transgender (LGBT) Center. We identify three race and ethnicity groups (non-Hispanic Black, Hispanic, non-Hispanic White) and seven age groups ($15-19$ y, $20-24$ y, $25-34$ y, $35-44$ y, $45-54$ y, $55-74$ y, ≥ 75 y). Under these categorizations, each MSM could assume one of 21 different demographic characterizations for which we define partnership preferences. Entries of the sexual mixing matrix, $\boldsymbol{M^E}$, depicted in Figure S5, specify the probability that an individual in a specific age category and race and ethnic group (rows), forms a sexual partnership with another individual in a specific age category and race and ethnicity group (column). By construction, the mixing matrix is a square matrix where rows represent demographic characteristics of the reference individual, and the columns represent the demographic characteristics of possible partners. Under this structure, the entries in each row of the sexual mixing must sum to one.

Figure S5: Empirical sexual mixing matrix, $\mathbf{M^E}$.



Abbreviations: y, year.
Notes: Estimated from data of the LA LGBT Center's survey of sexual partnerships. Rows represent the age and race and ethnicity of the susceptible individual, and columns the age and race and ethnicity of the possible partner.

4.4 State Transition Probabilities

The state transition probabilities, summarized in Table S5, define the annual probability that an individual moves from one health state to another. These probabilities can be specific to a particular population subgroup, depending on data availability (e.g., different probabilities for diagnosis, treatment, and PrEP use between non-Hispanics and Hispanics, etc.). This is one way in which the model can capture potential differences in behaviors between different race and ethnicity and age groups.

In this model, we assume that all age and race and ethnicity subgroups have the same natural disease progression risk through the three stages of HIV infection (with or without viral suppression) and the same likelihood of PrEP uptake and discontinuation. However, while PrEP uptake is assumed to be the same across all subgroups, the likelihood of being prescribed PrEP varies from 2014 to 2017 to reflect the increase in PrEP adoption over time reflected in prior studies [17].

The risk of viral rebound is assumed to vary by race and ethnicity – but not age. Other parameters, such as the probability of achieving viral suppression and the probability of HIV/AIDS diagnosis at each stage of infection, are assumed to vary by age and race and ethnicity.

We are unable to estimate all transition probabilities by race and ethnicity and age groups, due to a lack of data. While some transition probabilities are identified through the clinical and economic literature, others are derived through calibration. We use a quadratic programming minimization problem to identify the probability of an undiagnosed HIV positive individual becoming diagnosed, based on their race and ethnicity, age, and HIV stage. We use new diagnosis estimates (year 2012) by race and ethnicity, age, and HIV stage (independently), derived from the LA county surveillance data, and estimates of the number of undiagnosed HIV infected individuals (year 2011) by HIV stage, race and ethnicity, and age group ($15-29$ y, $30-49$ y, $50-64$ y, and ≥ 65 y) as inputs into the model, and we solve for parameter values that minimize the sum of weighted squared errors between the model's outputs and observed values. Similar to the diagnosed population count optimization problem described above, we solve the optimization problem using the CVX package in MATLAB. We ensure that no HIV stage, race and ethnic group, and age category, has a zero probability of diagnosed cases. While our input data suffer from measurement errors, they are the best available evidence to help guide HIV policy in LAC, until more robust data become widely available.

4.5 Death Probabilities

Death probabilities in the simulation are age specific and are derived from the 2016 CDC life table for males [8]. They are assumed to not vary by race and ethnicity. All individuals who have not progressed to the AIDS stage are therefore assigned an annual mortality risk from all other causes, based on their age. For those with AIDS, a life table is derived from the CDC mortality data for 2016. We assume that this life table applies to those treated with ART. A prior modeling study estimated that the mortality risk for chronic HIV/AIDS individuals treated with ART was 0.58 times the risk for those not treated with ART [20], suggesting a relative mortality risk ratio of 0.58. This suggests that we can use a multiplier of 1.72 (i.e., 1/0.58) to adjust all probabilities of death for those with AIDS who are not treated with ART. A set of calibration constants are also applied to all AIDS related deaths by age. We apply scalar multipliers of 2, 3, 1.75, and 1 for the $15-29$ y, $30-46$ y, $50-64$ y, and ≥ 65 y, respectively. This is done for calibration purposes to reflect local mortality patterns based on the AIDS death data.

5 Model Calibration

Model calibration helps ensure that the model's predictions are realistic and consistent with observed outcomes. Here, we calibrated the our microsimulation model using a hierarchical process. First, we identified calibration targets from the LA County surveillance data. We prioritized aggregate-level calibration targets over stratified targets (i.e., age-, race and ethnicity-, HIV stage-specific). We prioritized targets relating to new HIV/AIDS diagnoses over those pertaining to total diagnosed PLWH because our outcomes of interest are more related to new infections and new diagnosis than total PLWH. Further, among our stratified targets, race and ethnicity-specific targets were prioritized over age group-specific targets, which were in turn prioritized over HIV stage-specific targets. We use this approach because the measures relating to race and ethnicity and age group in the surveillance data are more likely to be accurate than HIV stage data, as HIV stage varies over time in a less predictable fashion than age. Diagnosed AIDS deaths are our lowest priority calibration target under this approach. The prioritization of calibration targets is summarized in Table S7.

To calibrate the model, we changed uncertain values (calibration parameters) to align model output with trends observed in the LA County Department of Public Health surveillance data. Uncertain input parameters that required calibration include attainment of viral suppression by race and ethnicity, age group, and HIV stage. Further, we introduced three calibration constants: (1) a multiplier used to represent the transmissibility risk parameter in the derivation of the annual probability of infection; this parameter is assumed to vary by race and ethnicity [10; 29], (2) a multiplier that scales up the risk of infection among individuals under age 24, as HIV incidence rates and engagement in risky behaviors (e.g., low HIV testing rates, substance use, and low rates of

condom use) are higher in that demographic group [3; 6], and (3) a multiplier that adjusts AIDS-related death probabilities, as these values were derived from national data and are not specific to LAC.

We varied these inputs to obtain model outputs that were consistent with the observed data across the pre-specified calibration targets. We used an optimization routine to first identify calibration parameter values that produced outcomes within an acceptable range (±15%) of the values of the calibration targets. We used a large range in our assessment because of uncertainty in the surveillance data. All calibration targets were annual counts estimated from LA County surveillance data from 2012-2016 (Table S7).

All calibration parameters were unconstrained. The calibration constants were unbounded but tuned to reach calibration targets. Calibrated transition probabilities were bounded between 0 and 1. We calibrated transition probabilities that were unavailable from the literature because of the levels of stratification considered, consistent with approaches used in prior studies [20].

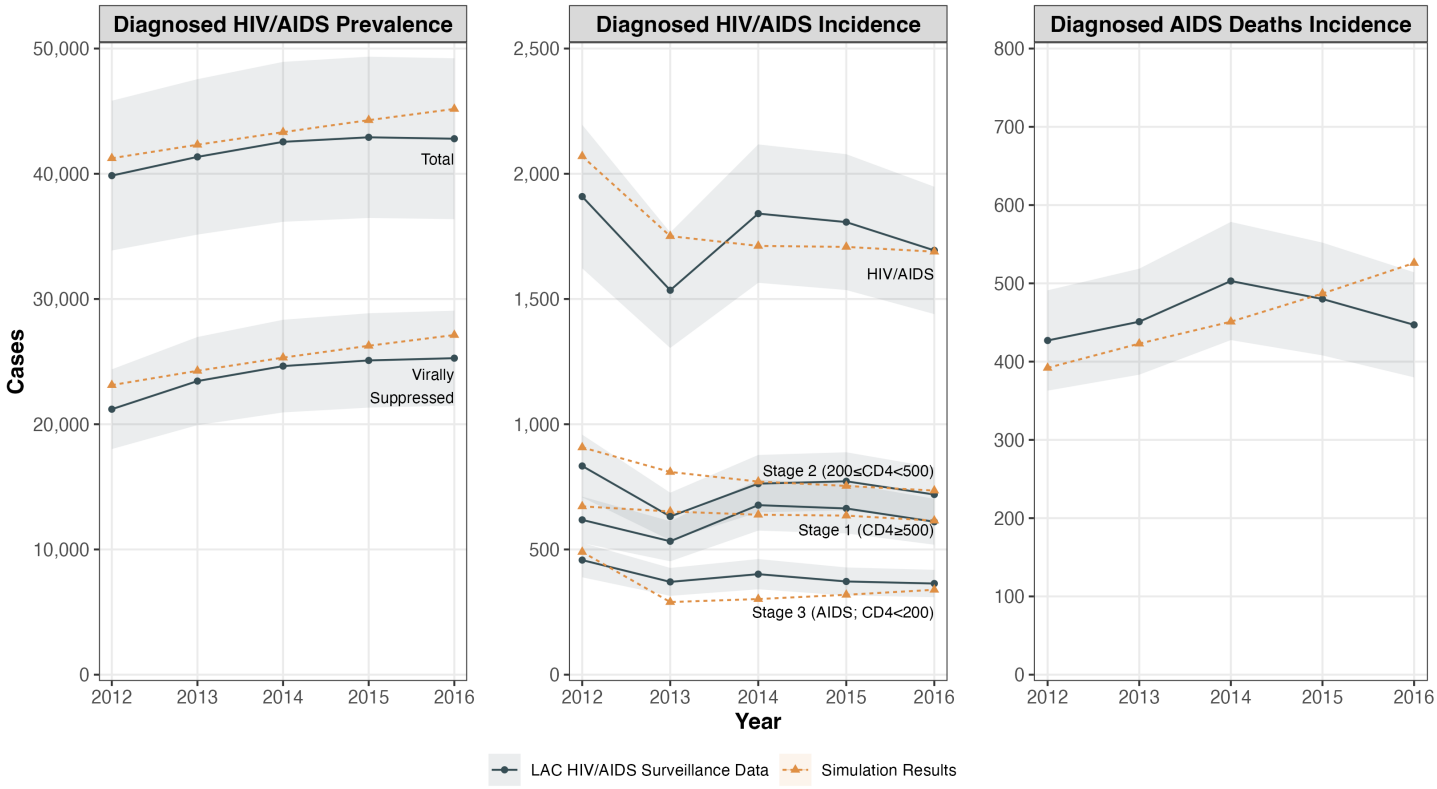
Results suggest that the model is reasonably well calibrated (see Figures S6, S7 and S8). We additionally report values for the root mean squared errors (RMSE) for each calibration target over all calibration years (Table S8). Values are generally below 15% for most calibration targets. Our calibrated model outputs lie within 10% of the RMSE for the number of PLWH, new HIV/AIDS diagnoses, viral suppression, and AIDS-related deaths, over the calibration period for the entire population. We accepted larger deviations for age-, race and ethnicity-, and HIV stage-specific calibration targets, as subgroup data often had small values, leading a single case to represent a larger percentage.

Table S7: Model calibration parameters and calibration targets.

Calibration Parameter	Calibration Targets	Priority Level
Racial and ethnic group-specific transmission coefficients, β_j	Diagnosed HIV/AIDS incidence, overall ($\sum_{j\in\mathcal{D}}\sum_X \tilde{X}_{j,t}$) and AIDS-specific ($\sum_{j\in\mathcal{D}}\sum_{X\in\mathcal{A}} \tilde{X}_{j,t}$)	High
	Diagnosed HIV/AIDS prevalence ($\sum_{j\in\mathcal{D}}\sum_X X_{j,t}$)	High
Age group-specific multipliers for AIDS-caused mortality probabilities	Incidence of diagnosed AIDS deaths ($\sum_{j\in\mathcal{D}}\sum_{X\in\mathcal{A}} \tilde{X}_{j,t}$)	High
Age and racial and ethnic group-specific viral suppression rates	Prevalence of (diagnosed) viral suppression ($\sum_{j\in\mathcal{D}}\sum_X X^{VS}_{j,t}$)	High
Racial and ethnic group-specific transmission coefficients (β_j) + Age and racial and ethnic group-specific viral suppression rates	Diagnosed HIV/AIDS incidence, by race and ethnicity ($\sum_X \tilde{X}_{j,t},\ \forall j \in \mathcal{D}_r$)	Medium
Younger age group ($\leq$ 24 y) multiplier, γ, for the group-specific transmission coefficients, β_j	Diagnosed HIV/AIDS incidence, by age group ($\sum_X \tilde{X}_{j,t},\ \forall j \in \mathcal{D}_a$)	Medium
Probabilities of HIV progression, by viral suppression status	Diagnosed HIV/AIDS incidence, by HIV stage ($\sum_{j\in\mathcal{D}}\sum_{X\in X^{VS}} \tilde{X}_{j,t}$ and $\sum_{j\in\mathcal{D}}\sum_{X\in X^{D}} \tilde{X}_{j,t}$)	Medium
Age and racial and ethnic group-specific viral suppression rates	Diagnosed HIV/AIDS prevalence among the treated, by race and ethnicity ($\sum_{j\in\mathcal{D}_r}\sum_{X\in X^D\cup X^{VS}} X_{j,t}$)	Medium
	Diagnosed HIV/AIDS prevalence among the treated, by age group ($\sum_{j\in\mathcal{D}_a}\sum_{X\in X^D\cup X^{VS}} X_{j,t}$)	Medium
Age and racial and ethnic group-specific viral suppression rates + Racial and ethnic group-specific transmission coefficients, β_j	Diagnosed HIV/AIDS prevalence, by race and ethnicity ($\sum_{j\in\mathcal{D}_r}\sum_{X\in X^D\cup X^{VS}} X_{j,t}$)	Medium
Younger age group ($\leq$ 24 y) multiplier, γ, for the group-specific transmission coefficients, β_j	Diagnosed HIV/AIDS prevalence, by age group ($\sum_{j\in\mathcal{D}_a}\sum_{X\in X^D\cup X^{VS}} X_{j,t}$)	Medium
Age group-specific multipliers for AIDS-caused mortality probabilities	Incidence of diagnosed AIDS deaths, by race and ethnicity ($\sum_{j\in\mathcal{D}_r}\sum_{X\in\mathcal{A}} \tilde{X}_{j,t}$)	Low
	Incidence of diagnosed AIDS deaths, by age group ($\sum_{j\in\mathcal{D}_a}\sum_{X\in\mathcal{A}} \tilde{X}_{j,t}$)	Low

Abbreviations: HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome; PLWH, persons living with HIV; LAC, Los Angeles County.
Notes: $\tilde{X}$ denotes incident cases in state X; $\mathcal{D} = \mathcal{D}_a \times \mathcal{D}_r$ denotes the set of all pairs of demographic characteristics.

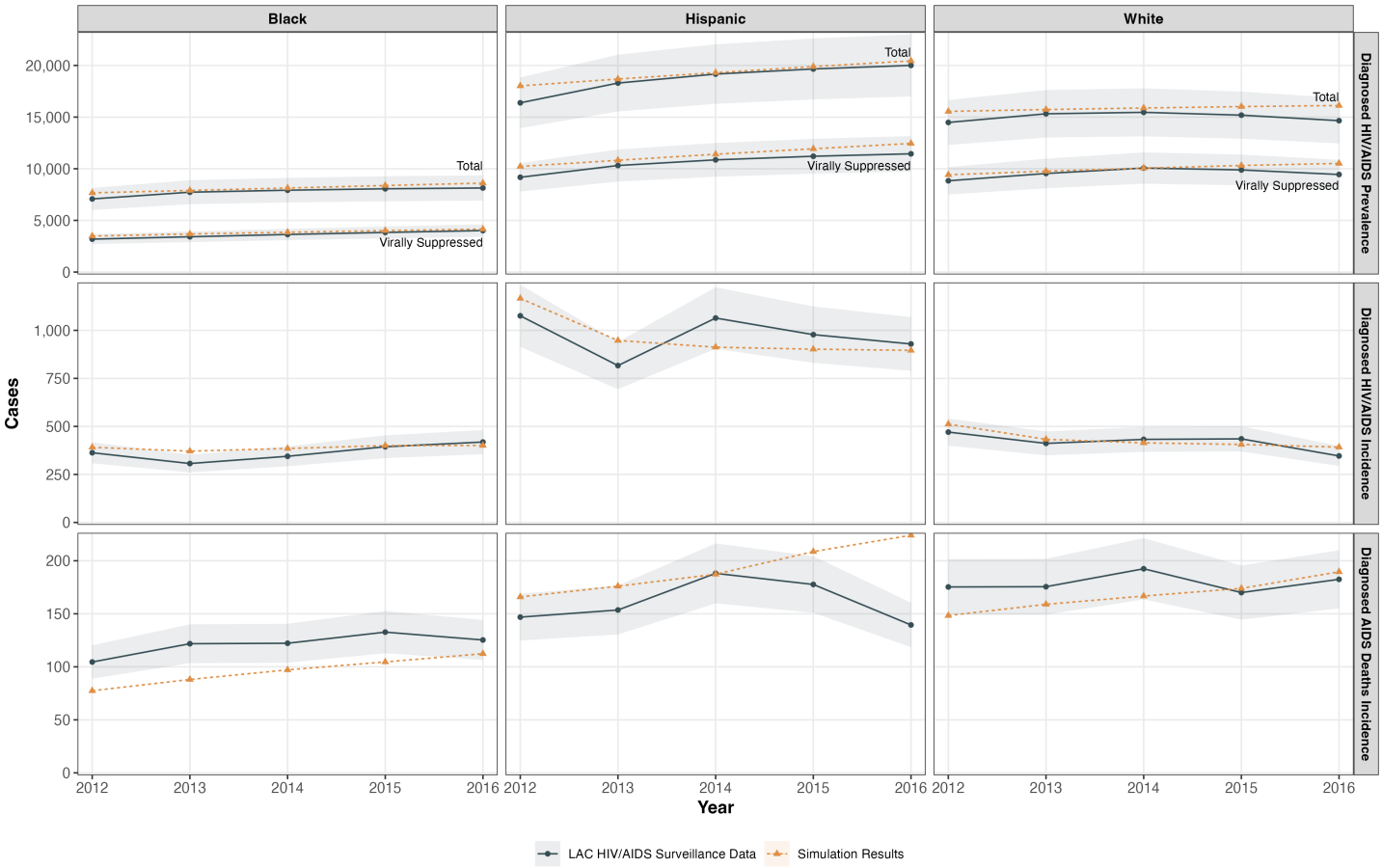
Figure S6: Results from the model's calibration to the epidemic surveillance data (2012-2016), overall.



Abbreviations: HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome; PLWH, persons living with HIV; LAC, Los Angeles County.

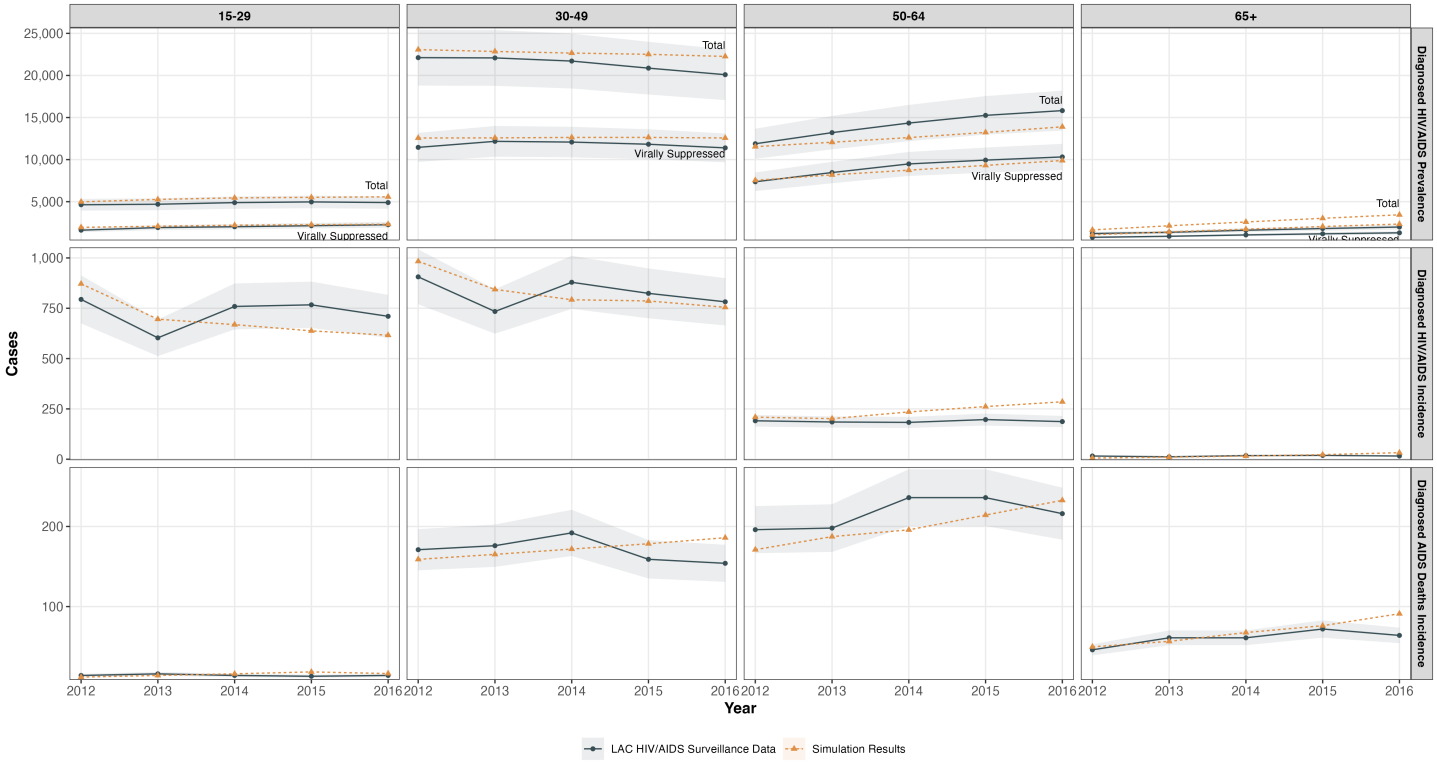
Notes: The model's aggregate predicted outcomes for each year are compared with reported estimates for the same outcomes in the LAC HIV surveillance data. The shaded bands represent the ±15% uncertainty ranges around the point estimates.

Figure S7: Results from the model's calibration to the epidemic surveillance data (2012-2016), by race and ethnicity.



Abbreviations: HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome; PLWH, persons living with HIV; LAC, Los Angeles County.
Notes: The model's aggregate predicted outcomes for each year and race and ethnic group are compared with reported estimates for the same outcomes in the LAC HIV surveillance data. The shaded bands represent the ±15% uncertainty ranges around the point estimates.

Figure S8: Results from the model's calibration to the epidemic surveillance data (2012-2016), by age group.



Abbreviations: HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome; PLWH, persons living with HIV; LAC, Los Angeles County.

Notes: The model's aggregate predicted outcomes for each year and age group are compared with reported estimates for the same outcomes in the LAC HIV surveillance data. The shaded bands represent the ±15% uncertainty ranges around the point estimates.

Table S8: RMSE of the model's predicted outcomes against the calibration targets, overall, and by demographic characteristics and HIV stage.

Characteristics	Calibration Targets			
	Diagnosed HIV/AIDS Prevalence	**Diagnosed HIV/AIDS Incidence**	**Virally Suppressed**	**Deaths**
Overall	0.035	0.090	0.060	0.084
Age group, y				
15-29 y	0.114	0.132	0.112	0.229
30-49 y	0.068	0.088	0.075	0.125
50-64 y	0.105	0.292	0.052	0.112
$\geq$ 65 y	0.602	0.536	0.647	0.203
Race and ethnicity				
White	0.063	0.084	0.063	0.102
Black	0.051	0.117	0.067	0.220
Hispanic	0.047	0.100	0.077	0.295
HIV stage				
CD4 $\geq$ 500	—	0.101	—	—
200 $\leq$ CD4 $\leq$ 499	—	0.132	—	—
CD4 $\leq$ 200	—	0.168	—	—

Abbreviations: RMSE, root mean square errors; HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome; PLWH, persons living with HIV; LAC, Los Angeles County; PrEP, pre-exposure prophylaxis; MSM, men who have sex with men; y, years.
Notes: The RMSE is the standard deviation of the residuals (prediction errors) and measures how spread out these residuals are.

6 Model Validation

6.1 Internal Validation

Estimates derived from the Los Angeles County HIV/AIDS Strategy for 2020 and Beyond report were used for the internal validation of the model for counts of undiagnosed PLWH, viral suppression, new diagnoses, and total PLWH in 2016 [25]. Estimates derived from the HIV Surveillance Annual Report, 2019 were used to internally validate the predicted diagnosis rates, incidence rates, HIV status awareness, and viral suppression in LAC for different race and ethnic groups [26].

6.2 External Validation

We externally validated the model by comparing its outputs against estimates of PLWH, viral suppression, and new diagnoses in LAC, derived from various reports [25; 35]. We externally validated the prevalence and incidence outcomes against comparable estimates derived from the CDC fact sheet for HIV Among Gay and Bisexual Men, adjusting for differences between LAC and the national estimates of the proportion of new diagnoses among MSM [32]. While this approach can add additional uncertainty, it allows us to benchmark our model's outcomes to comparable nationally reported outcomes. We externally validates our estimated incidence and prevalence rates (per 100,000) against estimated national MSM population count ($n = 4,503,800$) reported in Grey et al. (2016) [15; 41]. Given that MSM only account for $\sim$ 62% of the HIV positive population at the national level, but $\sim$ 84% in LAC [25; 32], we scaled the calculated rates by 1.35 (84/62)to account for potential difference

in expected incidence for LAC. We also validated PrEP coverage outcomes against estimates derived from the published literature [38; 1].

For all validation, we apply ±10% deviations to determine ranges when only single values were presented. Table S9 summarizes the derivation of the values and ranges used in our validation. Table S10 summarizes key validation results for the model, including HIV outcome measures and their uncertainty ranges, as predicted by our model, as well as similar outcomes derived from the literature, along with their associated uncertainty ranges. Whenever the ranges for a given outcome were not reported in the literature, we defined the defined the lower bound (LB) and upper bound (UB) to be 10% deviations from the reported point estimate.

Table S9: Derivation of the validation ranges.

HIV/AIDS Outcomes	Min	Max	Source
INTERNAL VALIDATION			
Living HIV/AIDS cases (2016), PLWH			
Undiagnosed, n	$0.90 \times (8,654 \times 0.84) \approx 6,500$	$1.10 \times (8,654 \times 0.84) \approx 8,000$	[25], Assumption
Undiagnosed, % of PLWH	$0.90 \times (8,654/60,946) \approx 0.13$	$1.10 \times (8,654/60,946) \approx 0.16$	[25]
Virally suppressed, % of PLWH	$0.90 \times 0.60 = 0.54$	$1.10 \times 0.60 = 0.66$	[25]
Diagnosed HIV/AIDS (2016)			
Incidence	$1,700 \times 0.84 = 1,470$	$2,000 \times 0.84 = 1,680$	[25]
Prevalence	$0.90 \times 59,446 \times 0.84 \approx 45,000$	$1.10 \times 59,446 \times 0.84 \approx 55,000$	[25]
Relative risk of HIV/AIDS diagnosis (2018)			
Black	$0.90 \times (91/37) = 2.21$	$1.10 \times (91/37) = 2.70$	[26]
Hispanic	Reference	Reference	[26]
White	$0.90 \times (23/37) = 0.56$	$1.10 \times (23/37) = 0.68$	[26]
HIV/AIDS incidence rate ratio (2018)			
Black	$0.90 \times (54/21) = 2.31$	$1.10 \times (54/21) = 2.83$	[26]
Hispanic	Reference	Reference	[26]
White	$0.90 \times (12/21) = 0.51$	$1.10 \times (12/21) = 0.63$	[26]
HIV serostatus awareness (2018), % of group's PLWH			
Black	$0.90 \times 0.74 = 0.66$	$1.10 \times 0.74 = 0.81$	[26]
Hispanic	$0.90 \times 0.77 = 0.69$	$1.10 \times 0.77 = 0.85$	[26]
White	0.90	1.00	[26]
Virally suppressed (2018), % of group's PLWH			
Black	$0.90 \times 0.55 = 0.50$	$1.10 \times 0.55 = 0.61$	[26]
Hispanic	$0.90 \times 0.61 = 0.56$	$1.10 \times 0.61 = 0.67$	[26]
White	$0.90 \times 0.62 = 0.56$	$1.10 \times 0.62 = 0.68$	[26]
EXTERNAL VALIDATION			
Incidence rate per 100,000 (2016)	$0.90 \times (84/62) \times \left(\frac{26,400+1,200}{4,503,800-648,500-58,600}\right) \approx 890$	$1.10 \times (84/62) \times \left(\frac{26,400+1,200}{4,503,800-648,500-58,600}\right) \approx 1,100$	[15; 25; 5]
PLWH Rate pre 100,000 (2016)	$0.90 \times \left(\frac{84}{62}\right) \times \left(\frac{648,500+58,600}{4,503,800}\right) \approx 19,100$	$1.10 \times \left(\frac{84}{62}\right) \times \left(\frac{648,500+58,600}{4,503,800}\right) \approx 23,400$	[15; 25; 5]
% PrEP coverage (2017)	-	-	[37]*

Abbreviations: HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome; PLWH, persons living with HIV; LAC, Los Angeles County; PrEP, pre-exposure prophylaxis; MSM, men who have sex with men; y, years.

Notes:

* No calculation was needed for the PrEP coverage range. Instead, we used the reported range in literature, which is for total proportion of population that has ever used PrEP [37]. Because we only determine PrEP coverage for a given year, we expect our value to be on the lower end of this metric because discontinuation rates for PrEP are high.

Table S10: External validation of the model: Comparison of the model's predicted estimates with reported estimates in the literature.

	Model's Predictions	Literature	
HIV/AIDS Outcomes	**Est. (95% CI)**	**Est. (LB - UB)**	**Source**
Estimated number of PLWH (2016), n	52,136 (52,090-52,182)	49,935 (45,000- 55,000)	[25], Table S9
HIV/AIDS prevalence rate (2016), per 100,000 MSM	20,291 (20,274-20,308)	21,271 (19,100-23,400)	[15; 25; 5], Table S9
HIV incidence rate (2016), per 100,000 MSM	968 (960-977)	985 (890-1,100)	[15; 25; 5], Table S9
Undiagnosed HIV/AIDS prevalence (2016)			
Number of MSM, n	6,960 (6,930-6,990)	7,269 (6,500-8,000)	[25], Table S9
As % of total MSM PLWH, %	13.3 (13.2-13.4)	14.0 (13.0-16.0)	[25], Table S9
New HIV/AIDS diagnoses (2016), n	1,689 (1,672-1,706)	1,575 (1,470-1,680)	[25], Table S9
Virally suppressed, %	60.0 (59.9-60.1)	60.0 (54.0-66.0)	[25], Table S9
Relative risk of HIV/AIDS diagnosis (2018)			
Black	2.83 (2.76-2.89)	2.45 (2.205-2.695)	[26]
Hispanic	Reference	Reference	[26]
White	0.67 (0.66-0.68)	0.62 (0.56-0.68)	[26]
HIV/AIDS incidence rate ratio (2018)			
Black	2.59 (2.54-2.64)	2.57 (2.31-2.83)	[26]
Hispanic	Reference	Reference	[26]
White	0.61 (0.60-0.62)	0.57 (0.51-0.63)	[26]
Serostatus awareness (2018), % of race group's PLWH			
Black	84.6 (84.5-84.7)	74.0 (66.0-81.0)	[26]
Hispanic	85.8 (85.7-85.9)	77.0 (69.0-85.0)	[26]
White	88.9 (88.8-88.9)	100.0	[26]
Virally suppressed (2018), % of race group's PLWH			
Black	49.2 (49.1-49.4)	55.0 (50.0-61.0)	[26]
Hispanic	62.2 (62.1-62.4)	61.0 (56.0-67.0)	[26]
White	66.6 (66.5-66.7)	62.0 (56.0-68.0)	[26]
PrEP coverage and use			
PrEP coverage (2017), %	2.62 (2.61-2.63)	5.50 (2.00-9.00)	[37]
Number of PrEP users (2018), n	6,878 (6,849-6,907)	8,350	[1; 38]

Abbreviations: HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome; PLWH, persons living with HIV; LAC, Los Angeles County; PrEP, pre-exposure prophylaxis; MSM, men who have sex with men; Est., estimate; CI, confidence interval; LB, lower bound; UB, upper bound.
Notes: When the literature reported only a point estimate for a given outcome, the lower and upper bound values were as ±10% deviations from the point estimate. When only a range was reported in the literature, with no point estimate, the point estimate was defined as the midpoint of the range.

7 Model Application: Intervention Strategies

The policies implemented allocated different quantities of PrEP to different race groups. For the single race/ethnicity policies, all PrEP is allocated to the single race/ethnicity group. For the distributed policies, the PrEP is spread among the race/ethnicity groups. In the table A12, we present the specific quantities of PrEP allocated to each race/ethnicity group under different allocation schemes. We test our polices at the 3000, 6000, and 9000 additional annual prescriptions levels. We restrict the maximum annual PrEP increase to 9000 because higher values will result in an oversaturation of PrEP for the Black MSM group under certain allocation schemes by the end of the simulated intervention period, making these scenarios unsuitable for comparison with others.

The Equal allocation scheme distributes PrEP equally to each racial/ethnic group. The count policy distributes proportionally to racial distribution of HIV among PLWH (21% non-Hispanic Black, 47% Hispanic, 32% non-Hispanic White). The rate policy distributes proportionally to the new diagnosis rates in each race/ethnicity group (63% non-Hispanic Black, 24% Hispanic, 13% non-Hispanic White). These approximations align with the total PLWH by race in 2018 and new diagnoses by race in 2016 outlined in the 2018 LAC HIV surveillance report.34

In Figure 2 of the main manuscript, we presented cumulative infections averted for the 3000, 6000, and 9000 PrEP coverage levels for all allocation schemes. Presented in table A13 are the standard errors associated with the

total cumulative infections averted.

Table S11: Distribution of the annual additional PrEP units across race and ethnic groups, by PrEP allocation strategy and PrEP coverage level.

Race and Ethnic Groups	PrEP Allocation Strategy					
	Black*	**Hispanic†**	**White‡**	**Equal§**	**Count¶**	**Rate††**
	PrEP Coverage: 3,000 PrEP Units					
Black	3,000	0	0	1,000	632	1,883
Hispanic	0	3,000	0	1,000	1,421	726
White	0	0	3,000	1,000	947	391
	PrEP Coverage: 6,000 PrEP Units					
Black	6,000	0	0	2,000	1,263	3,766
Hispanic	0	6,000	0	2,000	2,842	1,452
White	0	0	6,000	2,000	1,895	781
	PrEP Coverage: 9,000 PrEP Units					
Black	9,000	0	0	3,000	1,895	5,649
Hispanic	0	9,000	0	3,000	4,263	2,179
White	0	0	9,000	3,000	2,842	1,172

Abbreviations: PrEP, pre-exposure prophylaxis; MSM, men who have sex with men.

Notes: An annual additional 1,000 PrEP units represents approximately a 20-22% increase in PrEP coverage, relative to the baseline coverage in 2020.

* All additional annual PrEP units above the Status-quo coverage level are allocated to non-Hispanic Black MSM only.

† All additional annual PrEP units are allocated to Hispanic MSM only.

‡ All additional annual PrEP units above the Status-quo coverage level are allocated to non-Hispanic White MSM only.

§ The additional annual PrEP units above the Status-quo coverage level are allocated equally to each race and ethnic group.

¶ The additional annual PrEP units above the Status-quo coverage level are allocated to each race and ethnic group, based the group's diagnosed HIV/AIDS prevalence (cases).

†† The additional annual PrEP units above the Status-quo coverage level are allocated to each race and ethnic group, proportionally to the diagnosed HIV/AIDS incidence rate in each race and ethnic group.

Table S12: Distributions of the 15-year (2020-2035) cumulative infections averted by alternative PrEP allocation strategies, relative to Status-quo, at different annual PrEP coverage levels.

Statistic	PrEP Allocation Strategy					
	Black*	**Hispanic†**	**White‡**	**Equal§**	**Count¶**	**Rate††**
			PrEP Coverage: 3,000 PrEP Units			
Mean	1,019.5	320.3	336.5	669.4	534.9	753.8
SE	85.4	81.1	82.5	78.3	93.0	91.2
95% CI	(852.2 - 1,186.8)	(161.4 - 479.3)	(174.7 - 498.2)	(515.9 - 822.9)	(352.6 - 717.2)	(574.9 - 932.6)
			PrEP Coverage: 6,000 PrEP Units			
Mean	2,185.6	896.0	580.1	1,265.8	1,159.2	1,648.5
SE	81.2	80.1	84.5	74.2	84.6	85.5
95% CI	(2,026.5 - 2,344.7)	(739.0 - 1,053.0)	(414.5 - 745.8)	(1,120.3 - 1,411.3)	(993.5 - 1,325.0)	(1,480.9 - 1,816.2)
			PrEP Coverage: 9,000 PrEP Units			
Mean	3,143.2	1,420.0	938.9	1,869.4	1,695.9	2,503.8
SE	82.2	76.4	88.2	84.1	75.1	85.6
95% CI	(2,982.1 - 3,304.3)	(1,270.2 - 1,569.7)	(766.0 - 1,111.9)	(1,704.5 - 2,034.4)	(1,548.6 - 1,843.2)	(2,335.9 - 2,671.6)

Abbreviations: PrEP, pre-exposure prophylaxis; MSM, men who have sex with men.

Notes: An annual additional 1,000 PrEP units represents approximately a 20-22% increase in PrEP coverage, relative to the baseline coverage in 2020.

* All additional annual PrEP units above the Status-quo coverage level are allocated to non-Hispanic Black MSM only.

† All additional annual PrEP units are allocated to Hispanic MSM only.

‡ All additional annual PrEP units above the Status-quo coverage level are allocated to non-Hispanic White MSM only.

§ The additional annual PrEP units above the Status-quo coverage level are allocated equally to each race and ethnic group.

¶ The additional annual PrEP units above the Status-quo coverage level are allocated to each race and ethnic group, based the group's diagnosed HIV/AIDS prevalence (cases).

†† The additional annual PrEP units above the Status-quo coverage level are allocated to each race and ethnic group, proportionally to the diagnosed HIV/AIDS incidence rate in each race and ethnic group.

8 Measuring Inequality in the Distribution of Health

We assessed the impacts of alternative PrEP allocation strategies on racial and ethnic inequities in the distribution of HIV outcomes, after 15 years (2021-2035) of program implementation. To do this, we calculated the Gini index, using the predicted HIV/AIDS incidence rate for different race and ethnic groups in 2035. In sensitivity analyses, we also assess how potential inequalities in HIV outcomes, using alternative measures of inequality, such as the Atkinson index and the Kolm index. We present these values alongside the Gini index for alternative PrEP allocation strategies and levels of PrEP coverage.

8.1 Gini index

The Gini index, G is a summary measure of inequality inequality in some relevant outcome of interest to a decision-maker (e.g., HIV outcomes in our case). The Gini index incorporates the detailed subgroup share data into a single statistic, which summarizes the dispersion of the outcome of interest across the entire outcome distribution. The Gini coefficient ranges from 0, indicating perfect equality (where everyone receives an equal share), to 1, indicating perfect inequality (where only one recipient or group of recipients receives all the income). The Gini is based on the difference between the Lorenz curve (the observed cumulative income distribution) and the notion of a perfectly equal income distribution [4; 33]. Its equation is as follows:

$$G_j = \frac{1}{2\bar{h}_j}\sum_{i=1}^{n}\sum_{k=1}^{n}\omega_i\omega_k|h_{j,i}-h_{j,k}|, \tag{11}$$

where ω_x denotes the proportion of the population in subgroup x, $h_{j,x}$ denotes, the incidence rate of HIV/AIDS in subgroups x under intervention j, n is the number of population subgroups, and $\bar{h}_j = \sum_{i=1}^{n}\omega_i h_{j,i}$ is the population level mean value of the outcome of interest (overall HIV incidence rate across all groups), under intervention j. When the values, h_j, are ranked, say in ascending order, such that each h_j has rank i and $h_j < h_{j+1}$, then the expression in equation (11) can be considerably simplified for faster computation:

$$G_j = 1 - \frac{1}{\bar{h}_j}\sum_{i=1}^{n}\omega_i(S_{j,i-1}+S_{j,i}), \tag{12}$$

where $S_{j,i} = \sum_{k=1}^{i}\omega_k h_{j,k}$, and $S_{j,0} = 0$. In addition, when $\omega_i = \omega_k\,, \forall i \neq k \in J$, that is, when all population subgroups are of equal size, the expression in equation (11) can be rewritten as follows:

$$G_j = \frac{1}{2n^2\bar{h}_j}\sum_{i}^{n}\sum_{k}^{n}|h_{j,i}-h_{j,k}|. \tag{13}$$

In that case, when the values, $h_{j,x}$, are ranked, say in ascending order, such that each $h_{j,i}$ has rank i, the expression in equation (13) can be considerably simplified for faster computation:

$$G_j = \frac{2}{n^2\bar{h}_j}\sum_{i}^{n} i(h_{j,i}-\bar{h}_j) = \frac{\sum_i^n(2i-n-1)h_{j,i}}{n\sum_i^n h_{j,i}}. \tag{14}$$

Although there are no universally-defined standard cut-off values for the Gini index, it is commonly recognized that $G < 0.2$ corresponds with perfect equality; $0.2 \leq G < 0.3$ corresponds with relative equality; $0.3 \leq G < 0.4$ corresponds with a relatively reasonable outcome gap; $0.4 \leq G < 0.5$ corresponds with high disparity; and $G \geq 0.5$ corresponds with severe disparity [40].

Because the small sample variance properties of G are unknown, and large sample approximations to its variance

are poor [30; 14; 11], confidence intervals for G are calculated via bootstrap re-sampling methods [12].

The Gini index is often criticized for lacking three properties: (i) subgroup consistency, and (ii) sensitivity to the inequality in the lower end of distribution. Subgroup consistency is the property that if inequality declines in one subgroup (region, ethnic group, etc.) and remains unchanged in the rest of population, then the overall inequality declines. By its construction, the Gini index puts equal weights to the entire distribution.

8.2 Atkinson index

The Atkinson index is another measure of inequality, used to determine which end of the distribution contributed most to some level of observed inequality between groups [2]. The index can transformed into a normative measure by incorporating a coefficient to weight outcomes. We can impose greater weights on changes in a given portion of the outcome distribution by selecting appropriate values of this coefficient, also known as the inequality aversion parameter. The mathematical expression of the Atkinson index is as follows:

$$A_j(\epsilon) = 1 - \frac{\bar{h}_j^*(\epsilon)}{\bar{h}_j}, \tag{15}$$

where:

$$\bar{h}_j^*(\epsilon) = \begin{cases} \left[\sum_{i=1}^{n} \omega_i h_{j,i}^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}, & \text{if } 0 \leq \epsilon \text{ and } \epsilon \neq 1\ , \\ \prod_{i=1}^{n} h_{j,i}^{\omega_i}, & \text{if } \epsilon = 1 \end{cases} \tag{16}$$

denotes the **equally distributed equivalent (EDE)** level of the outcome, under intervention j. The parameter ω_i denotes the proportion of the population in subgroup i, n is the total number of population subgroups, $h_{j,i}$ represents incidence rate of HIV/AIDS in subgroup i under intervention j, and ϵ denotes the constant parameter of relative inequality aversion. When $\omega_i = \omega_k\ , \forall i \neq k \in J$, that is, when all population subgroups are of equal size, the expression in equation (16) can be rewritten as follows:

$$\bar{h}_j^*(\epsilon) = \begin{cases} \left[\frac{1}{n}\sum_{i=1}^{n} h_{j,i}^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}, & \text{if } 0 \leq \epsilon \neq 1 \\ \prod_{i=1}^{n} h_{j,i}^{1/n}, & \text{if } \epsilon = 1. \end{cases} \tag{17}$$

The Atkinson index becomes more sensitive to changes at the lower end of the outcome distribution as ϵ approaches 1, and more sensitive to changes at the upper end of the outcome distribution as ϵ approaches 0. Thus, unlike the Gini index, the Atkinson index inequality measure has the properties of subgroup consistency, and sensitivity to the inequality in the lower end of distribution, as it puts more weight to the lower end of the outcome distribution.

When $A_j(\epsilon)$ is multiplied by the average health across groups, $\bar{h}_j$, the resulting expression is the difference between average health across groups and the EDE level of health:

$$\bar{h}_j A_j(\epsilon) = \bar{h}_j - \bar{h}_j^*(\epsilon). \tag{18}$$

8.3 Kolm index

The Kolm index is a concentration index used to measure the concentration of an outcome along the outcome distribution [23; 24]. Similar to the Atkinson index, it too can be modified into normative measure by incorporating a coefficient to weight outcomes. This coefficient, known also as the constant parameter of **absolute inequality aversion**, can be used to impose greater or smaller weights on changes in a given portion of the outcome distribution, by selecting appropriate values. The mathematical expression of the Kolm index is as follows:

$$K_j(\alpha) \quad = \quad \frac{1}{\alpha}\log\left\{\sum_{i=1}^{n}\omega_i e^{\alpha(\bar{h}_j - h_{j,i})}\right\} = \bar{h}_j - \bar{h}_j^*(\alpha), \quad \forall\alpha > 0 \tag{19}$$

where ω_i denotes the proportion of the population in subgroup i, n denotes the number of population subgroups, $h_{j,i}$ represents the incidence rate of HIV/AIDS in subgroup i under intervention j, $\alpha > 0$ is the constant parameter of absolute inequality aversion, and $\bar{h}_j^*(\alpha) = \bar{h}_j - K_j(\alpha)$ is the EDE. Hence, $K_j(\alpha)$ is the difference between average health across groups and the EDE level of health. When $\omega_i = \omega_k\,, \forall i \neq k \in J$, the expression in equation (19) can be rewritten as follows:

$$K_j(\alpha) \quad = \quad \frac{1}{\alpha}\log\left(\sum_{i=1}^{n}\frac{1}{n}e^{\alpha(\bar{h}_j - h_{j,i})}\right), \quad \forall\alpha > 0. \tag{20}$$

Table S13: Inequalities in the distribution of the health benefits of PrEP in year 2035, by inequality measures, degrees of inequality aversion, and PrEP allocation strategies, and levels of PrEP coverage.

		PrEP Allocation Strategies					
Indices	**Status-quo***	**Black****	**Hispanic**†	**White**‡	**Equal**§	**Count**¶	**Rate**††
PrEP Coverage: 3,000 PrEP Units							
Gini Index	0.24	0.20	0.24	0.25	0.23	0.23	0.22
Atkinson Index							
$\epsilon = 1$	0.11	0.08	0.11	0.12	0.10	0.10	0.09
$\epsilon = 7$	0.34	0.31	0.32	0.38	0.34	0.33	0.32
$\epsilon = 30$	0.42	0.40	0.40	0.46	0.42	0.41	0.40
Kolm Index							
$\alpha = 0.025$	252.70	217.20	238.16	268.45	239.86	236.67	226.77
$\alpha = 0.50$	292.16	256.80	277.65	307.85	279.36	276.14	266.33
PrEP Coverage: 6,000 PrEP Units							
Gini Index	0.24	0.16	0.23	0.26	0.22	0.23	0.20
Atkinson Index							
$\epsilon = 1$	0.11	0.05	0.11	0.12	0.09	0.10	0.07
$\epsilon = 7$	0.34	0.27	0.31	0.39	0.32	0.33	0.30
$\epsilon = 30$	0.42	0.36	0.39	0.47	0.40	0.41	0.38
Kolm Index							
$\alpha = 0.025$	252.70	181.27	217.65	269.94	218.50	227.47	200.88
$\alpha = 0.50$	292.16	221.06	257.17	309.29	258.06	267.03	240.55
PrEP Coverage: 9,000 PrEP Units							
Gini Index	0.24	0.13	0.24	0.27	0.21	0.22	0.17
Atkinson Index							
$\epsilon = 1$	0.11	0.04	0.11	0.14	0.08	0.10	0.06
$\epsilon = 7$	0.34	0.24	0.30	0.42	0.32	0.33	0.27
$\epsilon = 30$	0.42	0.34	0.39	0.50	0.40	0.41	0.36
Kolm Index							
$\alpha = 0.025$	252.70	156.86	205.16	279.61	210.09	214.84	176.87
$\alpha = 0.50$	292.16	196.77	244.61	318.92	249.69	254.40	216.62

Abbreviations: PrEP, pre-exposure prophylaxis; MSM, men who have sex with men.

Notes: An annual additional 1,000 PrEP units represents approximately a 20-22% increase in PrEP coverage, relative to the baseline coverage in 2020. The parameters ϵ and α denote the inequality aversion parameters, respectively for the Atkinson index and the Kolm index.

* Denotes scenario with no additional annual PrEP units.

** All additional annual PrEP units above the Status-quo coverage level are allocated to non-Hispanic Black MSM only.

† All additional annual PrEP units are allocated to Hispanic MSM only.

‡ All additional annual PrEP units above the Status-quo coverage level are allocated to non-Hispanic White MSM only.

§ The additional annual PrEP units above the Status-quo coverage level are allocated equally to each race and ethnic group.

¶ The additional annual PrEP units above the Status-quo coverage level are allocated to each race and ethnic group, based the group's diagnosed HIV/AIDS prevalence (cases).

†† The additional annual PrEP units above the Status-quo coverage level are allocated to each race and ethnic group, proportionally to the diagnosed HIV/AIDS incidence rate in each race and ethnic group.

9 Sensitivity Analysis

In our base case model, we assumed an empirical mixing matrix, $\boldsymbol{M^E}$, estimated from the LA LGBT Center survey data (see Figure S5). However, the choice of this empirical mixing matrix may result in biased model estimates, given that the surveyed sample is not representative of the LAC MSM population. In fact, individuals that visited the LA LGBT Center, where the survey was administered, receive clients predominantly White and in different sociodemographic and socioeconomic groups as the broader MSM population in LAC.

To assess the impact of alternative assumptions about the mixing matrix on outcomes, we conducted sensitivity analyses of our results against alternative assumptions about the sexual mixing matrix, including, an assortative sexual mixing and a uniform sexual mixing. In our application, the assortative mixing pattern was characterised by a mixing matrix, $\boldsymbol{M^A}$, where each race and ethnic group only formed sexual partnerships with (had partnership preferences) within their own race and ethnic group, with equal probabilities of partnerships for all age groups. We characterized the uniform mixing pattern by a matrix, $\boldsymbol{M^U}$, where individuals in any race and ethnic group equally formed sexual partnerships with all race and ethnic groups, with equal probabilities of partnerships for all age groups. In all mixing matrices, we assume that sexual mixing among the ≥ 75 y age group is negligible. Figures S9-S10 depict the heat-maps of the assortative and uniform sexual mixing matrices, respectively.

Results, depicted in Figure S11, suggest that under the assumption of an assortative mixing, all calibration targets, but new diagnoses by race and ethnicity, were hit within reasonable ranges of estimates obtained from the empirical mixing assumption. These findings were expected, given that the assortative mixing pattern assumes that individuals in different racial and ethnic groups only form partnerships with others from their own race and ethnic group. This therefore results in increased incidence rates among racial and ethnic groups most burdened by HIV/AIDS, such as non-Hispanic Black MSM. Under the assumption of a uniform mixing, all calibration targets, but new diagnosis among Hispanic MSM, were also hit within reasonable ranges of estimates obtained from the empirical mixing assumption. New HIV/AIDS diagnoses were higher among Hispanic MSM under the uniform mixing assumption, compared to the empirical mixing assumption.

Figure S12 depicts the trends in HIV/AIDS incidence rates among different race and ethnicity, for the Status-quo strategy, under alternative assumptions about the mixing patterns. The results suggest that the incidence rates are sensitive to assumptions about the mixing patterns. Outcomes for Black MSM were worse under the assortative mixing assumption. While outcomes improved over time for all race and ethnic groups under the empirical mixing assumption, they worsened for Black MSM under the assortative mixing assumption, and worsened for both Blacks and Hispanics under the uniform mixing assumption.

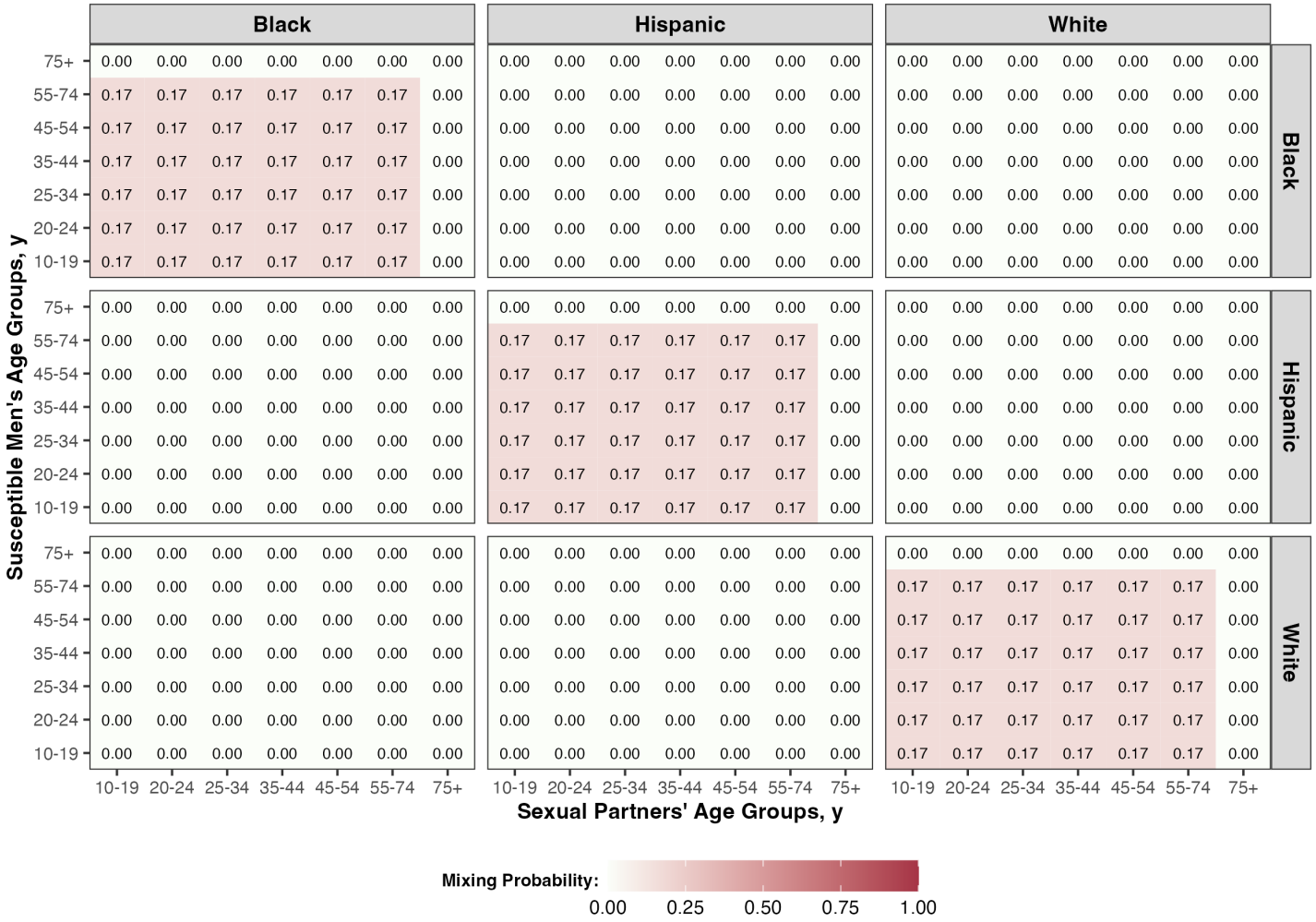
The cumulative infections averted relative to Status-quo under alternative PrEP allocation strategies, with a PrEP coverage level of $9,000$ additional annual PrEP units above the Status-quo level were similar to the empirical mixing results, with policies that prioritize PrEP allocation to Black MSM averting the most cases (Figure S13). The benefits of the intervention were more evenly distributed across groups under uniform mixing and less so under assortative mixing. Differences in averted cases across mixing scenarios were driven by differences in incidence rates under Status-quo. Incidence rates were $1.5 - 4$ times higher for non-Hispanic Black MSM under the assortative mixing assumption compared to the empirical mixing assumption; similarly, incidence rates were $1.25 - 2.0$ times higher for Hispanic MSM under uniform mixing assumption.

Table S14 summarizes the impacts of alternative PrEP allocation strategies on health inequality, as measured by the Gini index, for different levels of PrEP coverage and assumptions about the sexual mixing patterns. Results indicate that although alternative mixing assumptions result in differences in the inequality measures, the patterns of the effects are consistent across mixing patterns.

The Black only and Rate Strategies produce the largest reductions inequalities in the health benefits of PrEP (e.g., reductions in Gini index of 39%-53% and 28%-33%, respectively, at the PrEP coverage level of $9,000$ units per year above Status-quo level). The Equal and Count Strategies resulted in small reductions in inequalities in the distribution of the health benefits of PrEP (e.g., reductions in the Gini index of 11%-13% and 6%-9%, respectively). The Hispanic only and White only PrEP allocation Strategies consistently maintained or exacerbated inequities in

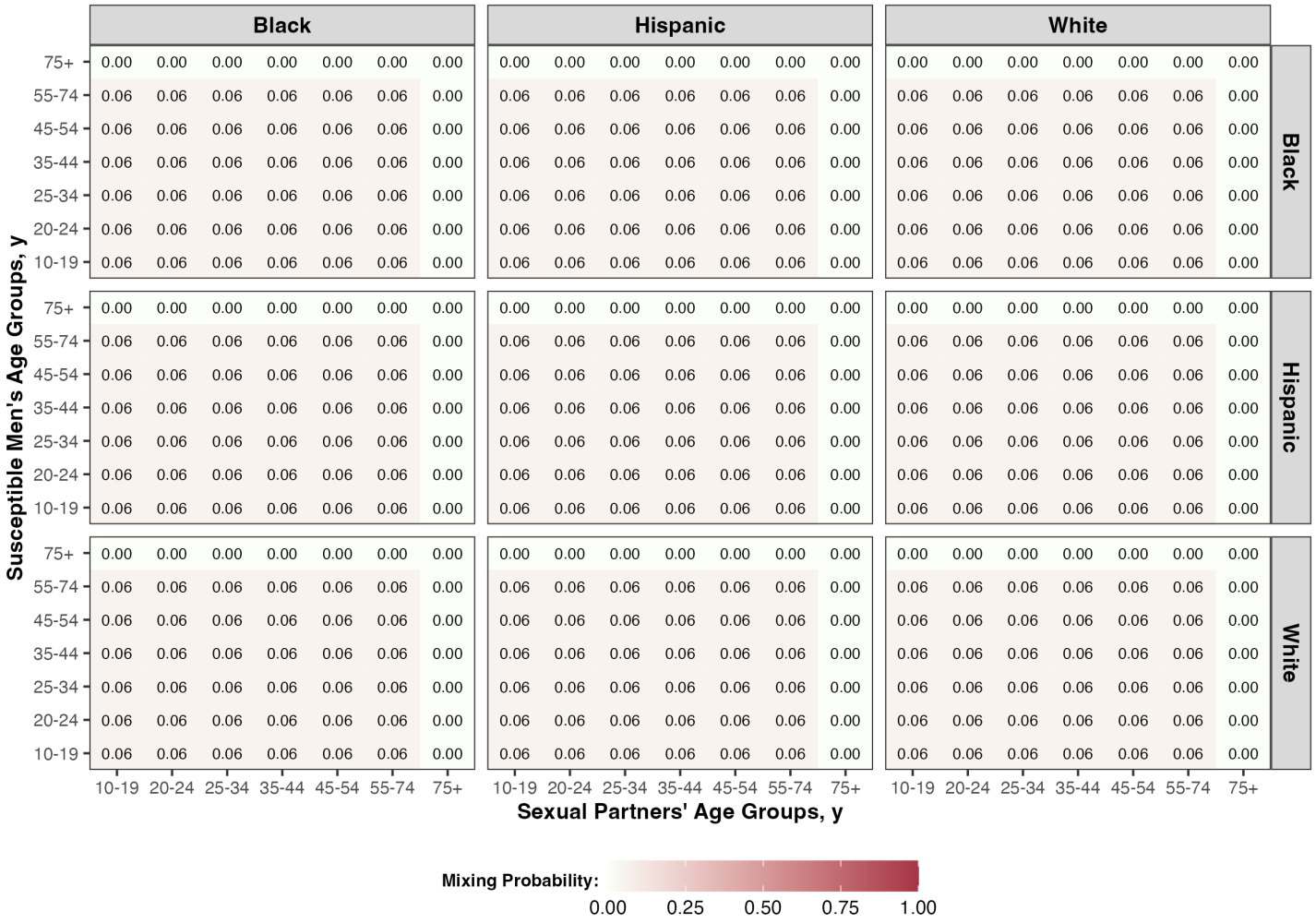
the distribution of the health benefits of PrEP. Note that individual Gini index values should only be compared to those under the same mixing matrix.

Figure S9: Assortative sexual mixing matrix, $\mathbf{M^A}$.



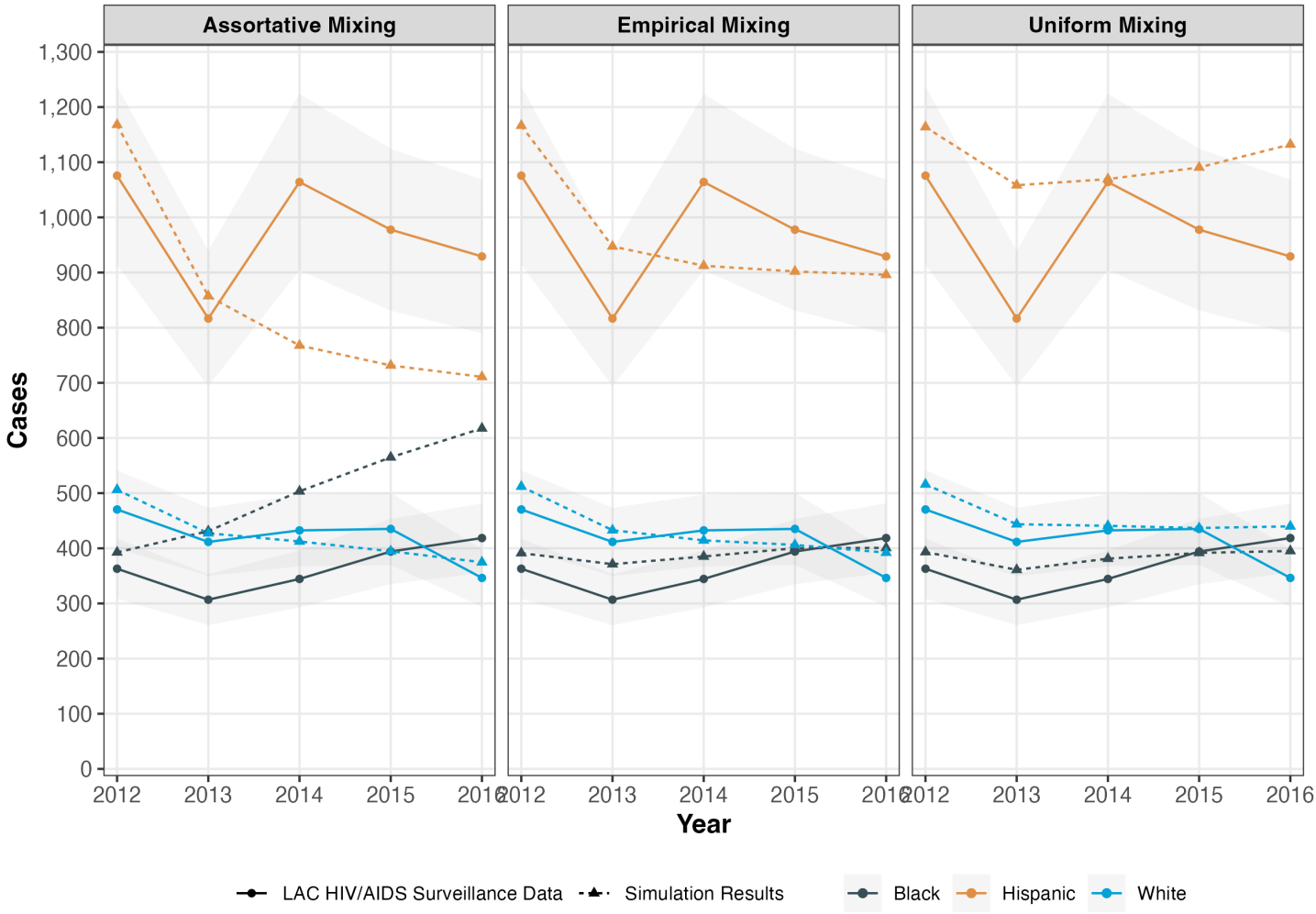
Abbreviations: y, year.
Notes: Rows represent the age and race and ethnicity of the susceptible individual, and columns the age and race and ethnicity of the possible partner.

Figure S10: Uniform sexual mixing matrix, $\mathbf{M^U}$.



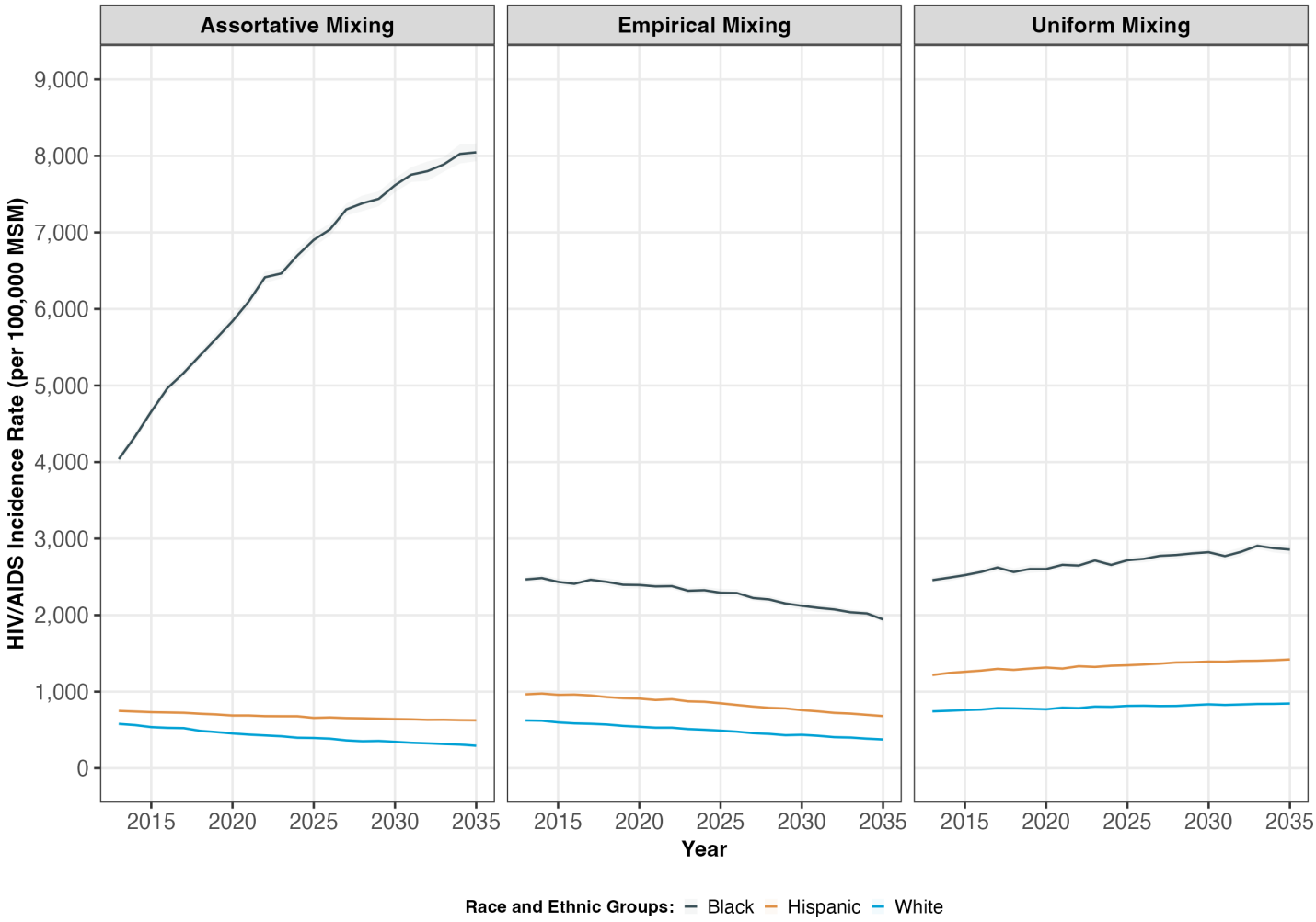
Abbreviations: y, year.
Notes: Rows represent the age and race and ethnicity of the susceptible individual, and columns the age and race and ethnicity of the possible partner.

Figure S11: Calibration results of the simulated incident diagnosed HIV/AIDS cases in different race and ethnic groups against the LAC HIV/AIDS surveillance estimates, under alternative assumptions about the sexual mixing patterns: Status-quo Strategy.



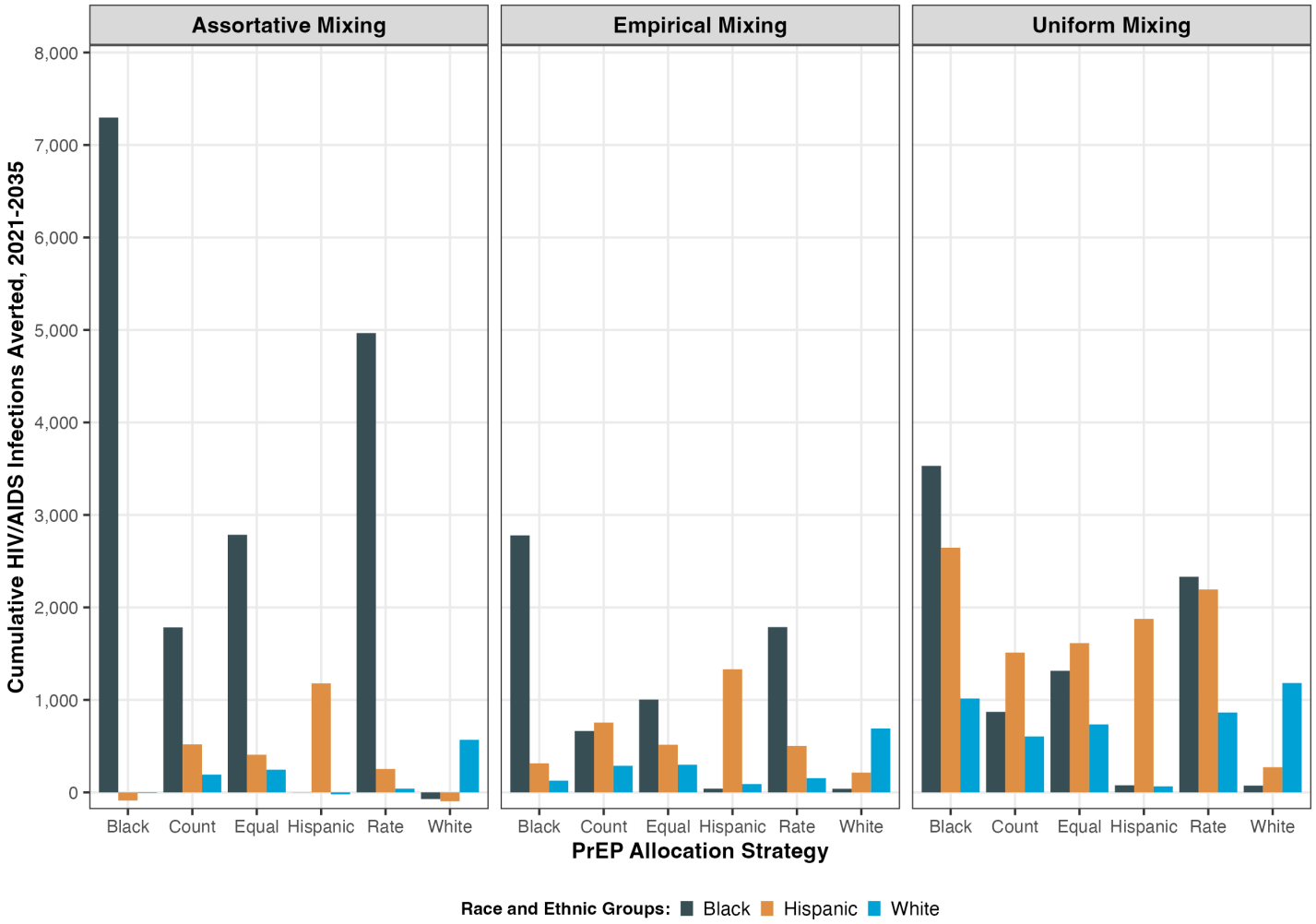
Abbreviations: HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome; PrEP, pre-exposure prophylaxis.
Notes: Estimates are for Status-quo coverage level.

Figure S12: Annual trends in HIV/AIDS incidence rate (per 100,000 MSM) among different race and ethnic groups, under alternative assumptions about the sexual mixing patterns: Status-quo Strategy.



Abbreviations: HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome; PrEP, pre-exposure prophylaxis.
Notes: Estimates are for Status-quo coverage level.

Figure S13: Cumulative HIV/AIDS infections averted during 2021-2035, by race and ethnicity, and assumptions about the sexual mixing patterns.



Abbreviations: HIV, human immunodeficiency virus; AIDS, acquired immunodeficiency syndrome; PrEP, pre-exposure prophylaxis.
Notes: Estimates are for the PrEP coverage level of 9,000 PrEP units per year above the Status-quo coverage level.

Table S14: Sensitivity analysis of the Gini index to assumptions about the sexual mixing patterns: empirical, assortative, and uniform mixing.

Sexual Mixing Pattern	PrEP Allocation Strategies						
	Status-quo*	Black**	Hispanic†	White‡	Equal§	Count¶	Rate††
PrEP Coverage: 3,000 PrEP units							
Empirical	0.24	0.20	0.24	0.25	0.23	0.23	0.22
Assortative	0.45	0.38	0.45	0.46	0.43	0.44	0.41
Uniform	0.18	0.16	0.18	0.19	0.17	0.18	0.16
PrEP Coverage: 6,000 PrEP units							
Empirical	0.24	0.16	0.23	0.26	0.22	0.23	0.20
Assortative	0.45	0.30	0.45	0.47	0.40	0.43	0.35
Uniform	0.18	0.12	0.17	0.19	0.17	0.17	0.15
PrEP Coverage: 9,000 PrEP units							
Empirical	0.24	0.13	0.24	0.27	0.21	0.22	0.17
Assortative	0.45	0.21	0.46	0.48	0.39	0.41	0.30
Uniform	0.18	0.11	0.17	0.21	0.16	0.17	0.13

Abbreviations: PrEP, pre-exposure prophylaxis.

Notes: An annual additional 1,000 PrEP units represents approximately a 20-22% increase in PrEP coverage, relative to the baseline coverage in 2020.

* Denotes scenario with no additional annual PrEP units.

** All additional annual PrEP units above the Status-quo coverage level are allocated to non-Hispanic Black MSM only.

† All additional annual PrEP units are allocated to Hispanic MSM only.

‡ All additional annual PrEP units above the Status-quo coverage level are allocated to non-Hispanic White MSM only.

§ The additional annual PrEP units above the Status-quo coverage level are allocated equally to each race and ethnic group.

¶ The additional annual PrEP units above the Status-quo coverage level are allocated to each race and ethnic group, based the group's diagnosed HIV/AIDS prevalence (cases).

†† The additional annual PrEP units above the Status-quo coverage level are allocated to each race and ethnic group, proportionally to the diagnosed HIV/AIDS incidence rate in each race and ethnic group.

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