PROJECTED IMPACT OF EXPANDED LONG-ACTING INJECTABLE PREP USE ON LOCAL HIV EPIDEMICS

Technical Supplement

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April 18, 2022

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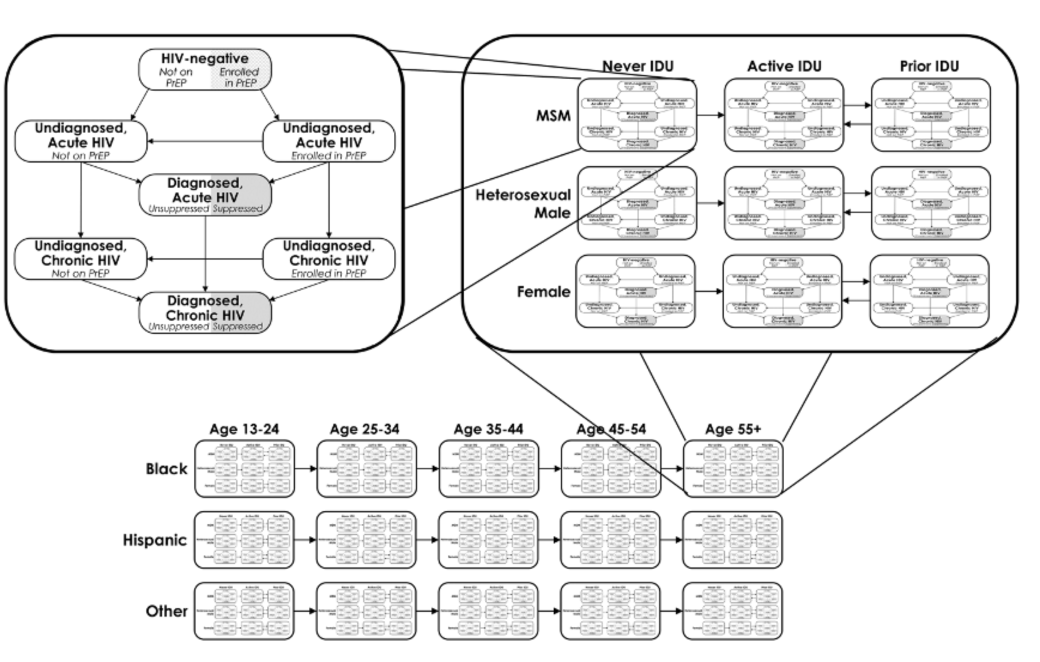
All code for this work is publicly available at https://github.com/tfojo1/ending_hiv

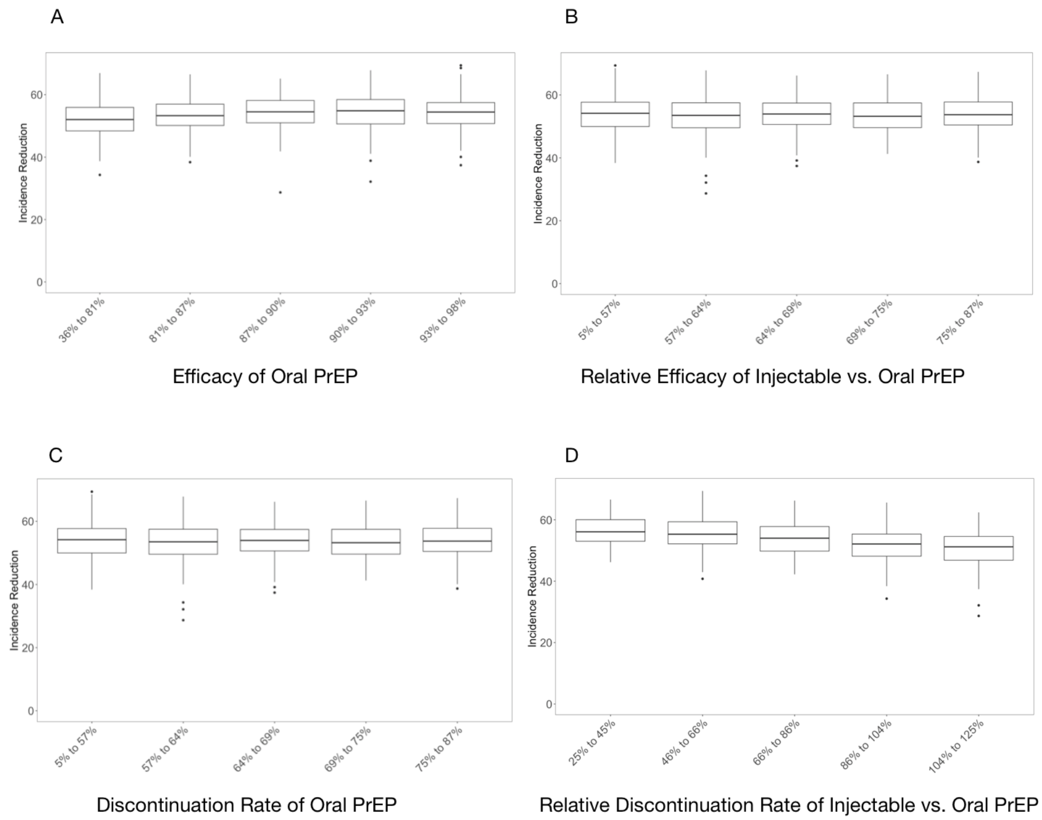
1 Supplemental Figures

Figure S1: Model Structure



The upper left panel shows model populations (compartments) defined by HIV disease state and the continuum of care. Each uninfected population has a proportion who are enrolled in a PrEP program. As people in the model become infected, they first enter the acute HIV phase ? which lasts 2.9 months ? where transmissibility is high, before progressing to chronic HIV. People who become infected with HIV while enrolled in a PrEP program are diagnosed at an average rate of once every 3 months. People with HIV (PWH) who are unaware of their diagnosis and not in a PrEP program are diagnosed according to testing rates that depend on their age, race/ethnicity, sex/sexual behavior, IV drug use (IDU) status, location, and calendar year. All populations of PWH who are aware of their diagnosis have a proportion who are virally suppressed and do not transmit HIV. Each population is further stratified by sex/sexual behavior and IV drug use status (top right), and by age and race/ethnicity (bottom) (Adapted from Fojo et al., 2021[?]). All interventions presented in this study are focused on the MSM subgroups.

Figure S2: Impact of Efficacy and Persistence for Oral and Long-Acting Injectable PrEP on Projected Reduction in HIV Incidence among MSM



For each of the 1,000 simulations per city, we calculated the reduction in total incidence among MSM from 2020 to 2030 across all 32 cities for the 25% additional uptake of LAI with a baseline of oral PrEP intervention. For each of the four parameters governing PrEP effects A) efficacy of oral PrEP, B) Relative efficacy of injectable vs oral PrEP, C) Discontinuation rate of oral PrEP, D) Relative discontinuation rate of injectable vs oral PrEP), we divided simulations into five groups of 200 simulations each, from low to high values of each parameter. For each group, we present a boxplot of the distribution in incidence reduction: the horizontal line represents the median reduction, the box represents the interquartile range, the whiskers represent the 95% credible interval, and dots represent outliers.

Figure S3: Differences Between Projected and Observed Reported Diagnoses among MSM, 2010-2018

	Total	Race/Ethnicity			Risk Factor	
		Black	Hispanic	Other	MSM†	MSM-PWID
New York-Newark-Jersey City, NY-NJ-PA	87 (4%)	46 (6%)	53 (6%)	80 (12%)	92 (4%)	14 (20%)
Miami-Fort Lauderdale-Pompano Beach, FL	91 (7%)	25 (7%)	58 (8%)	43 (12%)	94 (7%)	6 (25%)
Los Angeles-Long Beach-Anaheim, CA	123 (7%)	39 (11%)	70 (8%)	66 (10%)	124 (7%)	10 (16%)
Atlanta-Sandy Springs-Alpharetta, GA	56 (5%)	50 (6%)	23 (19%)	32 (15%)	57 (5%)	7 (25%)
Houston-The Woodlands-Sugar Land, TX	58 (6%)	31 (8%)	26 (7%)	34 (15%)	55 (6%)	8 (24%)
Dallas-Fort Worth-Arlington, TX	72 (7%)	34 (9%)	26 (9%)	50 (16%)	73 (8%)	10 (27%)
Chicago-Naperville-Elgin, IL-IN-WI	62 (6%)	37 (8%)	24 (10%)	40 (13%)	61 (6%)	7 (20%)
Washington-Arlington-Alexandria, DC-VA-MD-WV	52 (7%)	36 (9%)	16 (13%)	25 (14%)	50 (7%)	7 (26%)
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	32 (7%)	28 (10%)	13 (16%)	17 (13%)	31 (7%)	5 (27%)
Orlando-Kissimmee-Sanford, FL	30 (8%)	17 (16%)	19 (16%)	19 (14%)	29 (8%)	4 (30%)
San Francisco-Oakland-Berkeley, CA	34 (6%)	14 (12%)	20 (11%)	28 (10%)	36 (7%)	11 (19%)
Phoenix-Mesa-Chandler, AZ	32 (8%)	11 (17%)	16 (10%)	23 (12%)	31 (8%)	8 (28%)
Tampa-St. Petersburg-Clearwater, FL	27 (7%)	15 (13%)	13 (19%)	22 (14%)	28 (8%)	6 (40%)
Riverside-San Bernardino-Ontario, CA	26 (7%)	9 (16%)	19 (11%)	19 (13%)	28 (8%)	6 (33%)
Detroit-Warren-Dearborn, MI	23 (6%)	20 (8%)	6 (28%)	17 (17%)	23 (6%)	3 (24%)
Baltimore-Columbia-Towson, MD	22 (7%)	23 (11%)	5 (29%)	14 (19%)	25 (9%)	13 (105%)
Las Vegas-Henderson-Paradise, NV	21 (7%)	13 (16%)	13 (11%)	17 (12%)	19 (7%)	8 (35%)
Boston-Cambridge-Newton, MA-NH	24 (9%)	10 (20%)	12 (17%)	19 (14%)	24 (10%)	6 (39%)
San Diego-Chula Vista-Carlsbad, CA	29 (8%)	8 (21%)	17 (10%)	17 (10%)	29 (8%)	9 (41%)
Charlotte-Concord-Gastonia, NC-SC	27 (10%)	18 (12%)	8 (25%)	15 (20%)	24 (9%)	4 (39%)
San Antonio-New Braunfels, TX	23 (8%)	8 (22%)	19 (11%)	13 (20%)	22 (8%)	7 (44%)
Jacksonville, FL	17 (10%)	13 (14%)	6 (37%)	12 (21%)	17 (10%)	1 (25%)
New Orleans-Metairie, LA	30 (12%)	18 (12%)	7 (31%)	16 (24%)	28 (12%)	3 (30%)
Memphis, TN-MS-AR	33 (18%)	39 (24%)	4 (51%)	8 (29%)	33 (17%)	3 (77%)
Seattle-Tacoma-Bellevue, WA	39 (16%)	10 (24%)	12 (25%)	45 (32%)	40 (19%)	6 (26%)
Austin-Round Rock-Georgetown, TX	24 (10%)	8 (22%)	15 (17%)	15 (13%)	23 (10%)	5 (43%)
Indianapolis-Carmel-Anderson, IN	18 (12%)	17 (22%)	6 (33%)	11 (18%)	19 (14%)	3 (32%)
Cincinnati, OH-KY-IN	16 (11%)	10 (15%)	4 (55%)	14 (20%)	16 (12%)	2 (33%)
Columbus, OH	17 (9%)	11 (14%)	5 (48%)	16 (20%)	17 (10%)	4 (43%)
Baton Rouge, LA	22 (15%)	17 (15%)	NA	7 (26%)	19 (14%)	3 (42%)
Cleveland-Elyria, OH	18 (13%)	6 (19%)	9 (22%)	13 (18%)	17 (13%)	4 (47%)
Sacramento-Roseville-Folsom, CA	13 (8%)	12 (12%)	6 (44%)	11 (20%)	13 (8%)	3 (37%)
Total§	**520 (3%)**	**137 (2%)**	**159 (3%)**	**446 (8%)**	**536 (3%)**	**105 (16%)**

The top number in each cell represents the mean, across 1,000 simulations and 9 years (2010-2018), of the absolute value of the difference between projected and observed diagnoses among MSM. The number in parentheses is the mean absolute percent error. †MSM = men who have sex with men who do not inject drugs. MSM+PWID = men who have sex with men who are also people who inject drugs. Total = the errors are calculated by subtracting the sum of observed values across MSAs from the sum of projections

Figure S4: Differences Between Projected and Observed Prevalence of Diagnosed HIV among MSM, 2010-2018

	Total	Race/Ethnicity			Risk Factor	
		Black	Hispanic	Other	MSM†	MSM-PWID
New York-Newark-Jersey City, NY-NJ-PA	2,079 (4%)	1,309 (8%)	1,734 (8%)	957 (4%)	1,691 (3%)	575 (11%)
Miami-Fort Lauderdale-Pompano Beach, FL	1,174 (5%)	398 (7%)	931 (9%)	396 (4%)	1,241 (5%)	126 (8%)
Los Angeles-Long Beach-Anaheim, CA	2,382 (6%)	461 (7%)	1,224 (7%)	1,275 (7%)	2,227 (6%)	263 (8%)
Atlanta-Sandy Springs-Alpharetta, GA	1,901 (10%)	1,026 (9%)	255 (18%)	868 (14%)	1,745 (10%)	183 (13%)
Houston-The Woodlands-Sugar Land, TX	928 (6%)	338 (6%)	269 (6%)	535 (10%)	926 (6%)	84 (7%)
Dallas-Fort Worth-Arlington, TX	967 (6%)	331 (6%)	258 (7%)	597 (8%)	1,016 (6%)	192 (16%)
Chicago-Naperville-Elgin, IL-IN-WI	1,251 (10%)	559 (11%)	380 (14%)	633 (11%)	1,166 (10%)	201 (15%)
Washington-Arlington-Alexandria, DC-VA-MD-WV	952 (6%)	522 (6%)	203 (10%)	534 (9%)	853 (6%)	147 (13%)
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	674 (9%)	399 (11%)	177 (16%)	305 (9%)	601 (9%)	168 (17%)
Orlando-Kissimmee-Sanford, FL	488 (8%)	229 (13%)	117 (8%)	255 (9%)	509 (9%)	65 (15%)
San Francisco-Oakland-Berkeley, CA	1,242 (7%)	268 (10%)	265 (7%)	1,009 (8%)	1,103 (7%)	224 (8%)
Phoenix-Mesa-Chandler, AZ	435 (5%)	70 (10%)	182 (8%)	339 (7%)	418 (6%)	90 (10%)
Tampa-St. Petersburg-Clearwater, FL	325 (5%)	132 (8%)	96 (10%)	236 (6%)	342 (5%)	95 (16%)
Riverside-San Bernardino-Ontario, CA	1,016 (13%)	86 (13%)	256 (11%)	742 (16%)	954 (14%)	135 (19%)
Detroit-Warren-Dearborn, MI	265 (4%)	177 (5%)	54 (22%)	150 (7%)	268 (5%)	61 (16%)
Baltimore-Columbia-Towson, MD	364 (6%)	411 (11%)	89 (27%)	159 (9%)	318 (6%)	131 (16%)
Las Vegas-Henderson-Paradise, NV	282 (6%)	79 (8%)	97 (7%)	216 (8%)	249 (5%)	75 (16%)
Boston-Cambridge-Newton, MA-NH	535 (8%)	90 (8%)	158 (13%)	381 (9%)	458 (8%)	106 (18%)
San Diego-Chula Vista-Carlsbad, CA	657 (7%)	87 (9%)	228 (7%)	454 (9%)	598 (7%)	125 (13%)
Charlotte-Concord-Gastonia, NC-SC	273 (7%)	203 (10%)	65 (19%)	132 (9%)	258 (7%)	64 (25%)
San Antonio-New Braunfels, TX	254 (6%)	44 (10%)	208 (8%)	84 (7%)	295 (7%)	77 (23%)
Jacksonville, FL	246 (8%)	218 (15%)	51 (27%)	111 (9%)	299 (11%)	74 (28%)
New Orleans-Metairie, LA	307 (8%)	191 (9%)	33 (13%)	149 (9%)	336 (9%)	50 (12%)
Memphis, TN-MS-AR	235 (7%)	237 (9%)	38 (40%)	122 (15%)	220 (7%)	61 (35%)
Seattle-Tacoma-Bellevue, WA	487 (7%)	80 (12%)	113 (13%)	434 (9%)	487 (8%)	112 (14%)
Austin-Round Rock-Georgetown, TX	345 (8%)	63 (11%)	109 (8%)	220 (10%)	373 (10%)	87 (21%)
Indianapolis-Carmel-Anderson, IN	251 (7%)	105 (9%)	51 (21%)	196 (10%)	225 (7%)	89 (30%)
Cincinnati, OH-KY-IN	313 (13%)	124 (12%)	41 (47%)	164 (12%)	255 (11%)	65 (39%)
Columbus, OH	266 (8%)	98 (9%)	54 (33%)	183 (8%)	241 (7%)	65 (30%)
Baton Rouge, LA	144 (7%)	128 (9%)	22 (54%)	56 (10%)	136 (8%)	84 (34%)
Cleveland-Elyria, OH	236 (8%)	49 (11%)	64 (12%)	169 (9%)	195 (8%)	121 (31%)
Sacramento-Roseville-Folsom, CA	220 (7%)	95 (6%)	87 (32%)	127 (9%)	167 (6%)	88 (37%)
Total§	**4,467 (1%)**	**3,544 (3%)**	**3,464 (4%)**	**3,848 (3%)**	**4,470 (1%)**	**3,213 (11%)**

The top number in each cell represents the mean, across 1,000 simulations and 9 years (2010-2018), of the absolute value of the difference between projected and observed prevalence of diagnosed HIV. The number in parentheses is the mean absolute percent error. †MSM = men who have sex with men who do not inject drugs. MSM+PWID = men who have sex with men who are also people who inject drugs.Total = the errors are calculated by subtracting the sum of observed values across MSAs from the sum of projections.

Figure S5: Ratio of Incident Cases per Population Black MSM vs Non Black Non-Hispanic MSM

Year	2019	2030	2030	2030	2030	2030	2030	2030	2030	2030
Additional PrEP Uptake (Target Group)	NA	0%	0%	10% All Oral (All MSM)	10% All LAI (All MSM)	10% All LAI (All MSM)	25% All Oral (All MSM)	25% All LAI (All MSM)	25% All LAI (Black Hispanic MSM)	25% All LAI (All MSM)
Type of Base PrEP*	NA	Oral	LAI	Oral	Oral	LAI	Oral	Oral	LAI	LAI
New York-Newark-Jersey City, NY-NJ-PA	3.4	3.4	3.4	3.5	3.5	3.5	3.5	3.5	3.5	2.4
Miami-Fort Lauderdale-Pompano Beach, FL	2.3	2.3	2.3	2.3	2.3	2.2	2.2	2.2	2.2	1.6
Los Angeles-Long Beach-Anaheim, CA	3.1	3.1	3.1	3.1	3.1	3.2	3.2	3.2	3.2	2.3
Atlanta-Sandy Springs-Alpharetta, GA	5.0	5.0	5.1	5.1	5.1	5.2	5.3	5.3	5.3	3.9
Houston-The Woodlands-Sugar Land, TX	4.5	4.5	4.5	4.5	4.6	4.6	4.6	4.6	4.6	3.4
Dallas-Fort Worth-Arlington, TX	4.3	4.4	4.4	4.4	4.4	4.4	4.5	4.5	4.5	3.3
Chicago-Naperville-Elgin, IL-IN-WI	5.1	5.2	5.2	5.2	5.3	5.4	5.4	5.5	5.5	3.7
Washington-Arlington-Alexandria, DC-VA-MD-WV	5.1	5.1	5.0	5.0	5.1	5.0	5.0	5.0	5.0	3.6
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	5.7
Orlando-Kissimmee-Sanford, FL	2.9	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.2
San Francisco-Oakland-Berkeley, CA	2.9	2.9	2.9	2.9	2.9	2.9	3.0	3.0	3.0	2.1
Phoenix-Mesa-Chandler, AZ	3.6	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	2.7
Tampa-St. Petersburg-Clearwater, FL	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	2.8
Riverside-San Bernardino-Ontario, CA	1.9	1.9	1.9	1.9	2.0	2.0	2.0	2.0	2.0	1.4
Detroit-Warren-Dearborn, MI	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	5.3	3.7
Baltimore-Columbia-Towson, MD	6.8	6.8	6.8	6.8	6.8	6.7	6.7	6.7	6.7	4.9
Las Vegas-Henderson-Paradise, NV	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3	2.5
Boston-Cambridge-Newton, MA-NH	2.0	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.4
San Diego-Chula Vista-Carlsbad, CA	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.3
Charlotte-Concord-Gastonia, NC-SC	3.9	3.9	4.0	4.0	4.0	4.1	4.1	4.1	4.1	2.9
San Antonio-New Braunfels, TX	3.0	3.0	3.0	3.0	3.0	3.1	3.1	3.1	3.1	2.3
Jacksonville, FL	3.1	3.1	3.1	3.1	3.1	3.2	3.2	3.2	3.2	2.3
New Orleans-Metairie, LA	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.1
Memphis, TN-MS-AR	12.6	12.6	12.6	12.7	12.7	12.6	12.6	12.6	12.6	9.7

Seattle-Tacoma-Bellevue, WA	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.9
Austin-Round Rock-Georgetown, TX	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	1.7
Indianapolis-Carmel-Anderson, IN	5.9	5.9	5.9	5.9	6.0	5.9	5.9	6.0	6.0	4.3
Cincinnati, OH-KY-IN	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.3	3.3	2.5
Columbus, OH	3.3	3.3	3.3	3.3	3.3	3.2	3.2	3.2	3.2	2.3
Baton Rouge, LA	10.2	10.2	10.5	10.5	10.6	10.8	10.9	10.9	10.9	8.1
Cleveland-Elyria, OH	2.1	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	1.6
Sacramento-Roseville-Folsom, CA	7.7	7.7	7.7	7.6	7.7	7.5	7.5	7.5	7.5	5.5

Each cell shows the ratio of incident HIV cases per population between Black MSM and non-black non-Hispanic MSM for a given intervention and year. The ratio value in each cell represents the mean across 1,000 simulations, with ratios ranging from ¡1 to 13.

Figure S6: Ratio of Incident Cases per Population Hispanic MSM vs Non Black Non-Hispanic MSM

Year	2019	2030	2030	2030	2030	2030	2030	2030	2030	2030
Additional PrEP Uptake (Target Group)	NA	0%	0%	10% All Oral (All MSM)	10% All LAI (All MSM)	10% All LAI (All MSM)	25% All Oral (All MSM)	25% All LAI (All MSM)	25% All LAI (All MSM)	25% All LAI (Black Hispanic MSM)
Type of Base PrEP*	NA	Oral	LAI	Oral	Oral	LAI	Oral	Oral	LAI	LAI
New York-Newark-Jersey City, NY-NJ-PA	4.3	4.1	4.1	4.1	4.1	4.1	4.0	4.0	4.1	2.8
Miami-Fort Lauderdale-Pompano Beach, FL	4.4	4.0	4.0	3.9	3.9	4.0	3.9	3.9	3.9	2.8
Los Angeles-Long Beach-Anaheim, CA	1.9	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.3
Atlanta-Sandy Springs-Alpharetta, GA	2.4	2.2	2.2	2.2	2.2	2.2	2.3	2.3	2.3	1.7
Houston-The Woodlands-Sugar Land, TX	3.1	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.1
Dallas-Fort Worth-Arlington, TX	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.5
Chicago-Naperville-Elgin, IL-IN-WI	3.0	2.9	2.9	2.9	2.9	2.9	3.0	3.0	3.0	2.0
Washington-Arlington-Alexandria, DC-VA-MD-WV	4.3	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	3.0
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	6.2	6.1	6.1	6.1	6.1	6.1	6.0	6.0	6.0	4.4
Orlando-Kissimmee-Sanford, FL	3.9	3.6	3.7	3.7	3.7	3.7	3.7	3.7	3.7	2.6
San Francisco-Oakland-Berkeley, CA	2.8	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	1.9
Phoenix-Mesa-Chandler, AZ	2.6	2.6	2.6	2.6	2.6	2.6	2.5	2.5	2.5	1.8
Tampa-St. Petersburg-Clearwater, FL	2.7	2.6	2.6	2.5	2.5	2.5	2.5	2.5	2.5	1.8
Riverside-San Bernardino-Ontario, CA	1.8	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.2
Detroit-Warren-Dearborn, MI	2.7	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.8
Baltimore-Columbia-Towson, MD	3.5	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	2.5
Las Vegas-Henderson-Paradise, NV	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.5
Boston-Cambridge-Newton, MA-NH	3.7	3.5	3.4	3.4	3.4	3.4	3.3	3.3	3.2	2.5
San Diego-Chula Vista-Carlsbad, CA	2.3	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	1.6
Charlotte-Concord-Gastonia, NC-SC	1.9	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.3
San Antonio-New Braunfels, TX	3.5	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	2.5
Jacksonville, FL	1.3	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.9
New Orleans-Metairie, LA	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.4

Memphis, TN-MS-AR	1.7	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.2
Seattle-Tacoma-Bellevue, WA	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.7
Austin-Round Rock-Georgetown, TX	2.5	2.5	2.5	2.4	2.4	2.4	2.4	2.4	2.4	1.7
Indianapolis-Carmel-Anderson, IN	2.7	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.9
Cincinnati, OH-KY-IN	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0	0.8
Columbus, OH	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.1
Baton Rouge, LA	1.8	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.4
Cleveland-Elyria, OH	2.5	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	1.6
Sacramento-Roseville-Folsom, CA	2.9	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.1

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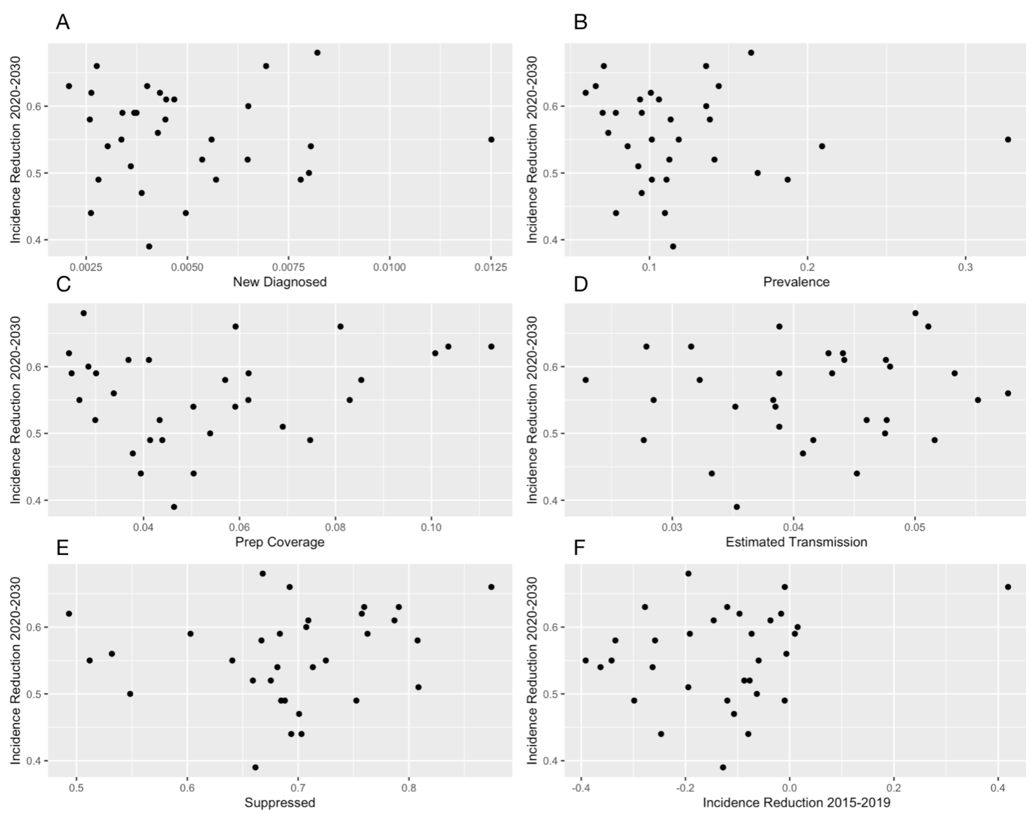
Each cell shows the ratio of incident HIV cases per population between Hispanic MSM and non-black non-Hispanic MSM for a given intervention and year. The ratio value in each cell represents the mean across 1,000 simulations, with ratios ranging from ¡1 to 13.

Figure S7: Relationship Between Incidence Reduction and Aspects of the Underlying HIV Epidemic



Scatterplot of the relationship between variables underlying the HIV epidemic including A) The number of newly diagnosed patients per population B) The prevalence of HIV per population C) Base PrEP coverage D) The ratio of newly diagnosed patients to HIV prevalence (Estimated Transmission) E) The proportion of virally suppressed individuals F) The incidence reduction between 2015-2019 on the incidence reduction between 2020-2030. Each individual point represents the average for each variables across all 1000 simulations for an individual MSA.

2 Model Parameters and Their Prior Distributions

Table S1: Model Parameters and Sampling Distributions.

Parameter	Estimate	Uncertainty Range	Symbol/ Section	References
HIV TRANSMISSION MULTIPLIERS**				
Male-to-male Sexual Transmission *(A composite of number of sexual encounters and rate of transmission per encounter)*				
Black, 2000	1	[0.003 - 354]	$\omega^{(MSM)}$ 8.2	
Black, ratio of rate by 2010 to 2000 rate	1	[0.257 - 3.891]		
Black, ratio of rate by 2020 to 2010 rate	1	[0.507 - 1.972]		
Hispanic, 2000	1	[0.003 - 354]		
Hispanic, ratio of rate by 2010 to 2000 rate	1	[0.257 - 3.891]		
Hispanic, ratio of rate by 2020 to 2010 rate	1	[0.507 - 1.972]		
Non-Black/Non-Hispanic, 2000	1	[0.003 - 354]		
Non-Black/Non-Hispanic, ratio of rate by 2010 to 2000 rate	1	[0.257 - 3.891]		
Non-Black/Non-Hispanic, ratio of rate by 2020 to 2010 rate	1	[0.507 - 1.972]		
Ratio of rate before 1980 to rate by 2000 (All Races)	3.1	[0.404 - 23.790]		HIV Atlas?
Heterosexual Transmission *(A composite of number of sexual encounters and rate of transmission per encounter)*				
Black, 2000	1	[0.003 - 354]	$\omega^{(het)}$ 8.2	
Black, ratio of rate by 2010 to 2000 rate	1	[0.257 - 3.891]		
Black, ratio of rate by 2020 to 2010 rate	1	[0.507 - 1.972]		
Hispanic, 2000	1	[0.003 - 354]		
Hispanic, ratio of rate by 2010 to 2000 rate	1	[0.257 - 3.891]		
Hispanic, ratio of rate by 2020 to 2010 rate	1	[0.507 - 1.972]		
Non-Black/Non-Hispanic, 2000	1	[0.003 - 354]		
Non-Black/Non-Hispanic, ratio of rate by 2010 to 2000 rate	1	[0.257 - 3.891]		
Non-Black/Non-Hispanic, ratio of rate by 2020 to 2010 rate	1	[0.507 - 1.972]		
Ratio of rate before 1980 to rate by 2000 (All Races)	2.2	[0.287 - 16.883]		HIV Atlas?
Transmission via Needle Sharing *(A composite of number of needle-sharing encounters and rate of transmission per encounter)*				
Black	1	[0.003 - 354]	$\omega^{(IDU)}$ 8.2	
Black, ratio of rate by 2010 to 2000 rate	1	[0.257 - 3.891]		
Black, ratio of rate by 2020 to 2010 rate	1	[0.507 - 1.972]		
Hispanic	1	[0.003 - 354]		
Hispanic, ratio of rate by 2010 to 2000 rate	1	[0.257 - 3.891]		
Hispanic, ratio of rate by 2020 to 2010 rate	1	[0.507 - 1.972]		
Non-Black/Non-Hispanic, 2000	1	[0.003 - 354]		
Non-Black/Non-Hispanic, ratio of rate by 2010 to 2000 rate	1	[0.257 - 3.891]		
Non-Black/Non-Hispanic, ratio of rate by 2020 to 2010 rate	1	[0.507 - 1.972]		
Ratio of rate before 1980 to rate by 2000 (All Races)	4.7	[0.612 - 36.068]		HIV Atlas?
**Uncertainty Range represents the 95% confidence interval for a Lognormal distribution unless otherwise indicated*				

Table S1 (Model Parameters) continued				
Parameter	**Estimate**	**Uncertainty Range**	**Symbol/ Section**	**References**
SUSCEPTIBILTY TO HIV INFECTION BY AGE				
via Male-to-male Sexual Contact *(A composite of probability of being sexually active, number of encounters, and rate of transmission per encounter)*				
Age 13-24 prior to 2010 (relative to age 35-44)	0.67	[0.48 - 0.94]	$\omega^{(A)}$ (8.2)	Twenge 2017[?] Abma 2017[?]
Age 13-24 by 2020 (relative to age 35-44)	0.67	[0.48 - 0.94]		
Age 25-34 prior to 2010 (relative to age 35-44)	1.11	[0.79 - 1.56]		
Age 25-34 by 2020 (relative to age 35-44)	1.11	[0.79 - 1.56]		
Age 45-54 (relative to age 35-44)	0.72	[0.51 - 1.01]		
Age 55+ (relative to age 35-44)	0.35	[0.25 - 0.49]		
via Heterosexual Contact *(A composite of probability of being sexually active, number of encounters, and rate of transmission per encounter)*				
Age 13-24 (relative to age 35-44)	0.67	[0.48 - 0.94]	$\omega^{(A)}$ (8.2)	Twenge 2017[?] Abma 2017[?]
Age 25-34 (relative to age 35-44)	1.11	[0.79 - 1.56]		
Age 45-54 (relative to age 35-44)	0.72	[0.51 - 1.01]		
Age 55+ (relative to age 35-44)	0.35	[0.25 - 0.49]		
via Needle Sharing *(A composite of number of needle-sharing encounters and rate of transmission per encounter)*				
Age 13-24 (relative to age 35-44)	1.04	[0.74 - 1.46]	$\omega^{(A)}$ (8.2)	HIV Surveillance #24[?]
Age 25-34 (relative to age 35-44)	1.06	[0.75 - 1.49]		
Age 45-54 (relative to age 35-44)	0.84	[0.60 - 1.18]		
Age 55+ (relative to age 35-44)	0.70	[0.50 - 0.98]		
RELATIVE SUSCEPTIBILITY TO HIV ACQUISITION				
via needle sharing, MSM-IDU vs heterosexual male prior to 1990	3.30	[1.67 - 6.51]		Strathdee 1997[?]
via needle sharing, MSM-IDU vs heterosexual male by 2000	3.30	[1.67 - 6.51]		
via needle sharing, MSM-IDU vs heterosexual male by 2010	3.30	[1.67 - 6.51]		
via needle sharing, MSM-IDU vs heterosexual male by 2020	3.30	[1.67 - 6.51]		
via needle sharing, female vs heterosexual male	1.10	[0.56 - 2.17]		HIV Surveillance #24[?]
via heterosexual contact, male vs female	0.75	[0.38 - 1.48]		Shah 2016,[?] NHBS Report #19[?]
TRANSMISSIBILITY OF HIV BY HIV NATURAL HISTORY AND CARE/TREATMENT ENGAGEMENT				
Relative Risk of Transmission for Acute vs Chronic HIV	12	[8.54 - 16.85]		Shah 2016[?]
Relative Risk of Transmission by PWH with diagnosed vs undiagnosed HIV	0.3	[0.21 - 0.42]		Marks 2005,[?] Marks 2006[?]
Relative Risk of Transmission by PWH virally suppressed vs unsuppressed	0	*Not Sampled*		Eisinger 2019[?]
SEXUAL ASSORTATIVITY				
Proportion of female sexual partnerships with MSM, relative to the proportion of MSM in the population	0.0895	[0.045 - 0.177]		Pathela 2006[?]
Proportion of heterosexual male partnerships with other males	0.004	[0.002 - 0.008]		Pathela 2006[?]
**Uncertainty Range represents the 95% confidence interval for a Lognormal distribution unless otherwise indicated*				

Table S1 (Model Parameters) continued				
Parameter	**Estimate**	**Uncertainty Range**	**Symbol/ Section**	**References**
Proportion of non-IDU sexual partnerships with active IDU, relative the the prevalence of active IDU in the population	0.2	[0.10 - 0.39]		Jenness 2010[?]
Proportion of Black sexual partnerships with Black partners, relative to the proportion Black in the population	3.76	[2.68 - 5.28]		Bohl 2011[?]
Proportion of Hispanic sexual partnerships with Hispanic partners, relative to the proportion Hispanic in the population	2.19	[1.56 - 3.08]		Mutanski 2014[?]
Proportion of Non-Black/Non-Hispanic sexual partnerships with Non-Black/Non-Hispanic partners, relative to the proportion Other in the population	1.55	[1.10 - 2.18]		Fujimoto 2015,[?] Hamilton 2015[?]
Dispersion of age of sexual partnerships	*Sex- and age-specific*	[0.71 - 1.40] $\times$ estimate		Chow 2016[?]
Ratio of proportion of 13yo who are sexually active to 20-24yo proportion	0.101	*Not Sampled*		Abma 2017[?]
Ratio of proportion of 14yo who are sexually active to 20-24yo proportion	0.144	*Not Sampled*		
Ratio of proportion of 15yo who are sexually active to 20-24yo proportion	0.173	*Not Sampled*		
Ratio of proportion of 16yo who are sexually active to 20-24yo proportion	0.346	*Not Sampled*		
Ratio of proportion of 17yo who are sexually active to 20-24yo proportion	0.546	*Not Sampled*		
Ratio of proportion of 18yo who are sexually active to 20-24yo proportion	0.733	*Not Sampled*		
Ratio of proportion of 19yo who are sexually active to 20-24yo proportion	0.906	*Not Sampled*		
Ratio of proportion of 65-74yo who are sexually active to 55-64yo proportion	0.721	*Not Sampled*		Lindau 2007[?]
Ratio of proportion of 75+yo who are sexually active to 55-64yo proportion	0.366	*Not Sampled*		
NEEDLE SHARING ASSORTATIVITY				
Proportion of Black needle-sharing partnerships with Black partners, relative to the proportion Black in the population	9.12	*Not Sampled*		Smith 2018[?]
Proportion of Hispanic needle-sharing partnerships with Hispanic partners, relative to the proportion Hispanic in the population	1.05	*Not Sampled*		
Proportion of Non-Black/Non-Hispanic needle-sharing partnerships with Non-Black/Non-Hispanic partners, relative to the proportion of Non-Black/Non-Hispanic in the population	1.05	*Not Sampled*		
Proportion of MSM needle-sharing partnerships with MSM partners, relative to the proportion MSM in the population	5.29	*Not Sampled*		Glick 2018[?]
Proportion of heterosexual male needle-sharing partnerships with heterosexual male partners, relative to the proportion heterosexual males in the population	0.82	*Not Sampled*		
**Uncertainty Range represents the 95% confidence interval for a Lognormal distribution unless otherwise indicated*				

Table S1 (Model Parameters) continued				
Parameter	**Estimate**	**Uncertainty Range**	**Symbol/ Section**	**References**
Proportion of female needle-sharing partnerships with female partners, relative to the proportion female in the population	0.51	*Not Sampled*		
Dispersion of age of sexual partnerships	Estimated based on sex and age	*Not Sampled*		Smith 2018[?]
Ratio of proportion of 13-14yo who share injection equipment to 19-24yo proportion	0.02	*Not Sampled*		
Ratio of proportion of 15-18yo who share injection equipment to 19-24yo proportion	0.18	*Not Sampled*		NSDUH 2015-2018[?]
Ratio of proportion of 65+ yo who share injection equipment to 55-64yo proportion	0.193	*Not Sampled*		NSDUH 2015 and 2016[?]
PROBABILITY OF RECEIVING HIV TEST WITHIN PAST YEAR				
MSM, 2010 Odds	0.67	[0.17 - 2.61]	β (8.5)	NHBS 2011-2018[?,?,?,?,?,?,?,?] BRFSS 2013-2017[?]
MSM, OR for every year after 2010	1.133	[0.989 - 1.298]		
Heterosexual, 2010 Odds	0.148	[0.04 - 0.58]		
Heterosexual, OR for every year after 2010	1.063	[0.928 - 1.218]		
IDU, 2010 Odds	0.369	[0.09 - 1.44]		
IDU, OR for every year after 2010	1.03	[0.899 - 1.180]		
MSM-IDU, 2010 Odds	0.67	[0.17 - 2.61]		
MSM-IDU, OR for every year after 2010	1.133	[0.989 - 1.298]		
Black vs Non-Black/Non-Hispanic, OR 2010	1.215	[0.31 - 4.73]		
Black vs Non-Black/Non-Hispanic, OR for every year after 2010	1.005	*Not Sampled*		
Hispanic vs Non-Black/Non-Hispanic, OR 2010	0.853	[0.22 - 3.32]		
Hispanic vs Non-Black/Non-Hispanic, OR for every year after 2010	1.015	*Not Sampled*		
Age 13-24 vs Age 35-44, OR 2010	1.267	[0.33 - 4.93]		
Age 13-24 vs Age 35-44, OR for every year after 2010	0.971	*Not Sampled*		
Age 25-34 vs Age 35-44, OR 2010	1.345	[0.35 - 5.23]		
Age 25-34 vs Age 35-44, OR for every year after 2010	0.983	*Not Sampled*		
Age 45-54 vs Age 35-44, OR 2010	0.836	[0.21 - 3.25]		
Age 45-54 vs Age 35-44, OR for every year after 2010	0.994	*Not Sampled*		
Age 55+ vs Age 35-44, OR 2010	0.749	[0.19 - 2.91]		
Age 55+ vs Age 35-44, OR for every year after 2010	0.991	*Not Sampled*		
Female vs Heterosexual Male, OR 2010	1.27	*Not Sampled*		
Female vs Heterosexual Male OR for every year after 2010	0.981	*Not Sampled*		
Relative Probability 1993 vs 2010	0.5	[0.36 - 0.70]		
PROBABILITY OF ACHIEVING VIRAL SUPPRESSION				
MSM, 2010 Odds	1.16	[0.30 - 4.51]	8.4	HIV Surveillance #18-2[?]
MSM, OR for every year after 2010	1.17	[1.021 - 1.340]		HIV Surveillance #18-5[?]
Heterosexual, 2010 Odds	0.885	[0.23 - 3.44]		HIV Surveillance #19-3[?]
Heterosexual, OR for every year after 2010	1.149	[1.003 - 1.316]		HIV Surveillance #20-2[?]

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Table S1 (Model Parameters) continued				
Parameter	**Estimate**	**Uncertainty Range**	**Symbol/ Section**	**References**
IDU, 2010 Odds	0.703	[0.18 - 2.74]		HIV Surveillance #21-4[?]
IDU, OR for every year after 2010	1.143	[0.998 - 1.309]		HIV Surveillance #22-2[?]
MSM-IDU, 2010 Odds	0.975	[0.25 - 3.79]		HIV Surveillance #23-4[?]
MSM-IDU, OR for every year after 2010	1.179	[1.029 - 1.351]		HIV Surveillance #24-3[?]
Black vs. Non-Black/Non-Hispanic, OR 2010	0.543	[0.14 - 2.11]		HIV Surveillance #25-2[?]
Black vs. Non-Black/Non-Hispanic, OR for every year after 2010	0.997	[0.870 - 1.142]		
Hispanic vs. Non-Black/Non-Hispanic, OR 2010	0.759	[0.20 - 2.95]		
Hispanic vs. Non-Black/Non-Hispanic, OR for every year after 2010	0.985	[0.860 - 1.128]		
Age 13-24 vs Age 35-44, OR 2010	0.531	[0.14 - 2.07]		
Age 13-24 vs Age 35-44, OR for every year after 2010	1.059	[0.924 - 1.213]		
Age 25-34 vs Age 35-44, OR 2010	0.73	[0.19 - 2.84]		
Age 25-34 vs Age 35-44, OR for every year after 2010	1.028	[0.897 - 1.178]		
Age 45-54 vs Age 35-44, OR 2010	1.194	[0.31 - 4.65]		
Age 45-54 vs Age 35-44, OR for every year after 2010	1.007	[0.879 - 1.154]		
Age 55+ vs Age 35-44, OR 2010	1.301	[0.33 - 5.06]		
Age 55+ vs Age 35-44, OR for every year after 2010	0.999	[0.872 - 1.144]		
Female vs Male, Heteroexual, OR 2010	1.062	*Not Sampled*		
Female vs Male OR, Heterosexual, for every year after 2010	1.018	*Not Sampled*		
Female vs Male, IDU OR 2010	1.154	*Not Sampled*		
Female vs Male OR, IDU for every year after 2010	1.02	*Not Sampled*		
Additional OR for every year after 2020, all subgroups	1.05	[1.007 - 1.095]		
PrEP COVERAGE AMONG AT-RISK INDIVIDUALS				
Among Non-Black/Non-Hispanic MSM age 35-44 in 2014, proportion	0.005	[0.00 - 0.228]†		Finlayson 2019,[?] Holloway 2017,[?] HIV Surveillance #22[?]
Yearly increase among Non-Black/Non-Hispanic MSM age 35-44 in 2014, proportion	0.0045	[0.00 - 0.210]†		
Among Non-Black/Non-Hispanic Heterosexual Men age 35-44 in 2014, proportion	0.0009	[0.00 - 0.014]†		HIV Surveillance #19[?]
Yearly increase among Non-Black/Non-Hispanic Heterosexual Men age 35-44 in 2014, proportion	0.0002	[0.00 - 0.003]†		
Among Non-Black/Non-Hispanic PWID age 35-44 in 2014, proportion	0.0001	[0.00 - 0.002]†		HIV Surveillance #24[?]
Yearly increase among Non-Black/Non-Hispanic PWID age 35-44 in 2014, proportion	0.0002	[0.00 - 0.003]†		
Odds ratio of 2014 Coverage, Black vs. Non-Black/Non-Hispanic	0.5203	[0.336 - 0.806]		Finlayson 2019[?]
Odds ratio of Yearly Increase Black vs. Non-Black/Non-Hispanic	0.6559	[0.424 - 1.016]		Holloway 2017[?]
Odds ratio of 2014 Coverage, Hispanic vs. Non-Black/Non-Hispanic	0.4133	[0.267 - 0.640]		HIV Surveillance #22[?]
**Uncertainty Range represents the 95% confidence interval for a Lognormal distribution unless otherwise indicated*				

Table S1 (Model Parameters) continued

Parameter	**Estimate**	**Uncertainty Range**	**Symbol/ Section**	**References**
Odds ratio of Yearly Increase Hispanic vs. Non-Black/Non-Hispanic	0.7675	[0.496 - 1.189]		
Odds ratio of 2014 Coverage and Yearly Increase, age 13-24 vs 35-44	0.6886	[0.177 - 2.679]		HIV Surveillance #24[?]
Odds ratio of 2014 Coverage and Yearly Increase, age 25-34 vs 35-44	1.1511	[0.296 - 4.478]		HIV Surveillance #22[?]
Odds ratio of 2014 Coverage and Yearly Increase, age 45-54 vs 35-44	0.6217	[0.160 - 2.419]		
Odds ratio of 2014 Coverage and Yearly Increase, age 55+ vs 35-44	0.2048	[0.053 - 0.797]		
Odds ratio of 2014 Coverage and Yearly Increase, Female vs. Male	1.5411	*Not Sampled*		HIV Surveillance #24,[?] HIV Surveillance #22[?]
Adherence to PrEP	0.56	*Not sampled*		Coy 2019[?]
Relative risk of acquiring HIV, PrEP vs no PrEP, male-to-male sexual contact	0.14	*Not sampled*		McCormack 2016[?]
Relative risk of acquiring HIV, PrEP vs no PrEP, heterosexual contact	0.25	*Not sampled*		Baeten 2012[?]
Relative risk of acquiring HIV, PrEP vs no PrEP, needle-sharing	0.51	*Not sampled*		Choopanya 2013[?]
Frequency of HIV Screening while on PrEP	3mo	*Not sampled*		
DISTRIBUTION OF MSM IN THE POPULATION				
Total Proportion of Males who are MSM	*Location-specific*	[0.84 - 1.19] × estimate		Grey 2016[?]
Relative Proportion of Males who are MSM, Black vs. Non-Black/Non-Hispanic	1.28	*Not Sampled*		Lansky 2015[?]
Relative Proportion of Males who are MSM, Hispanic vs. Non-Black/Non-Hispanic	0.96	*Not Sampled*		
MORTALITY OF UNSUPPRESSED HIV				
Excess mortality rate among PWH with unsuppressed HIV before 1994	0.15	[0.71 - 1.40]	$\theta^{(HIV)}$	Bhaskaran 2008[?]
Excess mortality rate among PWH with unsuppressed HIV by 2000	0.036	[0.026 - 0.051]	(8.9)	
Excess mortality rate among PWH with unsuppressed HIV by 2010	0.023	[0.016 - 0.032]		
PROPORTION IN AGE BRACKET WHO WILL AGE UP TO NEXT BRACKET, per year				
MSM and MSM-IDU				
Age 13-24	0.27	[0.19 - 0.38]	$\alpha^{(H)}$	HIV Surveillance #24-5[?]
Age 25-34 prior to 2000	0.18	[0.09 - 0.36]	(8.8)	HIV Surveillance #14[?]
Age 25-34 after 2010	0.13	[0.07 - 0.26]		HIV Surveillance #23[?]
Age 35-44 prior to 2000	0.10	*Not Sampled*		
Age 35-44 after 2010	0.14	[0.07 - 0.28]		HIV Surveillance #23[?]
Age 45-54 prior to 2000	0.10	*Not Sampled*		
Age 45-54 after 2010	0.08	*Not Sampled*		
Heterosexual				
Age 13-24	0.25	[0.18 - 0.35]	$\alpha^{(H)}$	HIV Surveillance #24-5[?]
Age 25-34 prior to 2000	0.18	[0.09 - 0.36]	(8.8)	HIV Surveillance #14[?]
Age 25-34 after 2010	0.13	[0.07 - 0.26]		HIV Surveillance #23[?]
Age 35-44 prior to 2000	0.10	*Not Sampled*		

**Uncertainty Range represents the 95% confidence interval for a Lognormal distribution unless otherwise indicated*

Table S1 (Model Parameters) continued				
Parameter	**Estimate**	**Uncertainty Range**	**Symbol/ Section**	**References**
Age 35-44 after 2010	0.14	[0.07 - 0.28]		HIV Surveillance #23[?]
Age 45-54 prior to 2000	0.10	*Not Sampled*		
Age 45-54 after 2010	0.08	*Not Sampled*		
PWID				
Age 13-24	0.32	[0.23 - 0.45]	$\alpha^{(H)}$ (8.8)	HIV Surveillance #24-5[?]
Age 25-34 prior to 2000	0.18	[0.09 - 0.36]		HIV Surveillance #14[?]
Age 25-34 after 2010	0.13	[0.07 - 0.26]		HIV Surveillance #23[?]
Age 35-44 prior to 2000	0.10	*Not Sampled*		
Age 35-44 after 2010	0.14	[0.07 - 0.28]		HIV Surveillance #23[?]
Age 45-54 prior to 2000	0.10	*Not Sampled*		
Age 45-54 after 2010	0.08	*Not Sampled*		
INJECTION DRUG USE				
Excess mortality rate among active IDU	0.0166	*Not Sampled*		Mathers 2014[?]
Incidence of IV Drug Use, base estimate	Location- and stratum-specific	-	8.7	NSDUH 2015-2018[?]
Multiplier, Incidence of IV Drug Use, Black, before 2000	1	[0.51 - 1.97]		
Multiplier,Incidence of IV Drug Use, Black, by 2020	1	[0.51 - 1.97]		
Multiplier,Incidence of IV Drug Use, Hispanic before 2000	1	[0.51 - 1.97]		
Multiplier,Incidence of IV Drug Use, Hispanic by 2020	1	[0.51 - 1.97]		
Multiplier,Incidence of IV Drug Use, Non-Black/Non-Hispanic before 2000	1	[0.51 - 1.97]		
Multiplier,Incidence of IV Drug Use, Non-Black/Non-Hispanic by 2020	1	[0.51 - 1.97]		
Multiplier,Incidence of IV Drug Use, MSM before 2000	1	[0.51 - 1.97]		
Multiplier,Incidence of IV Drug Use, MSM by 2020	1	[0.51 - 1.97]		
Rate of Remission of IV Drug Use	Location- and stratum-specific	[0.51 - 1.97] $\times$ estimate		
Rate of Relapse of IV Drug Use	Location- and stratum-specific	[0.51 - 1.97] $\times$ estimate		
FUTURE UNCERTAINTY				
Continued changes in MSM tranmission rates from 2020-2030, as proportion of changes from 2010-2020	0.1	[0.03 - 0.39]	p_2 (8.1.2.2)	
Continued changes in heterosexual tranmission rates from 2020-2030, as proportion of changes from 2010-2020	0.1	[0.03 - 0.39]		
Continued changes in IDU tranmission rates from 2020-2030, as proportion of changes from 2010-2020	0.1	[0.03 - 0.39]		
Improvements in testing continue until year	uniform on [2020-2025]			
**Uncertainty Range represents the 95% confidence interval for a Lognormal distribution unless otherwise indicated*				

Table S1 (Model Parameters) continued				
Parameter	**Estimate**	**Uncertainty Range**	**Symbol/ Section**	**References**
Improvements in viral suppression continue until year	uniform on [2020-2025]			
Improvements in PrEP coverage continue until year	uniform on [2020-2025]			

**HIV Transmission Multipliers are relative to the Global Transmission Rate, or the average number of infections generated by one, unsuppressed PWH per year, which is calibrated to match local epidemics

3 Calibration Targets

Table S2: Model Calibration Targets

	Target	Years	Level of Stratification	Data Source
1.	Reported diagnoses	2009 to 2017	sex, age, race, risk factor, sex*age, sex*race, sex*race, sex*risk, race*risk	CDC MSA reports[?,?,?,?,?,?,?,?]
2.	Estimated number of diagnosed PWH	2008 to 2016	sex, age, race, and risk factor sex*age, sex*race, sex*race, sex*risk, race*risk	CDC MSA reports[?,?,?,?,?,?,?,?]
3.	Mortality in PWH	2009 to 2016	sex	CDC MSA reports[?,?,?,?,?,?,?]
4.	The proportion of PWH aware of their diagnosis (state-level)	2010 to 2018	total	HIV Atlas[?]
5.	The proportion of diagnosed PWH who were virally suppressed	2010 to 2018	total + age, race, sex, risk factor (when available)	local health departments
6.	The number of individuals receiving a prescription for emtricitabine/tenofovir for PrEP	2010 to 2018	sex, race	AIDSVu[?]
7.	The proportion receiving an HIV test	2013 to 2017	age, sex, race	BRFSS[?]
8.	The prevalence of injection drug use (sub-state estimates)	2014 to 2016	age	NSDUH[?]
9.	Cumulative AIDS mortality	up to 2002	age, race, sex, risk factor	AIDS Public Information Dataset[?]
10.	Reported AIDS diagnoses	1998 to 2002	total	AIDS Public Information Dataset[?]

4 Projected Outcomes Under Different Scenarios for How COVID-19 Pandemic Affects HIV Transmission

4.1 Projected Incidence in 2020, 2021, and 2025

Table S3: Projected Incidence in 2020 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2020	Prolonged Barriers to Care, 2020	Rapid Resumption of Care, 2020
New York-Newark-Jersey City, NY-NJ-PA	2,169 [1,883 to 2,446]	2,183 [1,450 to 3,092]	2,182 [1,452 to 3,086]
Miami-Fort Lauderdale-Pompano Beach, FL	1,680 [1,267 to 2,075]	1,460 [956 to 2,104]	1,460 [955 to 2,103]
Los Angeles-Long Beach-Anaheim, CA	1,846 [1,598 to 2,090]	1,645 [1,136 to 2,230]	1,645 [1,140 to 2,233]
Atlanta-Sandy Springs-Alpharetta, GA	1,413 [1,242 to 1,618]	1,256 [904 to 1,697]	1,256 [903 to 1,697]
Houston-The Woodlands-Sugar Land, TX	1,246 [1,037 to 1,478]	1,080 [755 to 1,496]	1,080 [756 to 1,494]
Dallas-Fort Worth-Arlington, TX	1,108 [926 to 1,293]	1,007 [687 to 1,415]	1,007 [687 to 1,415]
Chicago-Naperville-Elgin, IL-IN-WI	1,123 [968 to 1,306]	966 [676 to 1,311]	966 [678 to 1,306]
Washington-Arlington-Alexandria, DC-VA-MD-WV	565 [475 to 686]	555 [369 to 797]	555 [368 to 799]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	564 [468 to 676]	512 [354 to 713]	511 [353 to 712]
Orlando-Kissimmee-Sanford, FL	537 [430 to 678]	471 [313 to 670]	470 [312 to 671]
San Francisco-Oakland-Berkeley, CA	448 [348 to 565]	434 [271 to 642]	434 [272 to 637]
Phoenix-Mesa-Chandler, AZ	444 [339 to 576]	393 [258 to 577]	392 [259 to 573]
Tampa-St. Petersburg-Clearwater, FL	451 [345 to 605]	398 [262 to 578]	398 [261 to 578]
Riverside-San Bernardino-Ontario, CA	495 [352 to 686]	427 [262 to 662]	427 [261 to 664]
Detroit-Warren-Dearborn, MI	416 [321 to 526]	377 [243 to 561]	377 [243 to 559]
Baltimore-Columbia-Towson, MD	265 [206 to 331]	249 [167 to 350]	249 [166 to 350]
Las Vegas-Henderson-Paradise, NV	365 [296 to 444]	308 [208 to 425]	308 [208 to 425]
Boston-Cambridge-Newton, MA-NH	517 [335 to 809]	541 [316 to 846]	541 [318 to 850]
San Diego-Chula Vista-Carlsbad, CA	264 [209 to 335]	252 [162 to 374]	252 [161 to 374]
Charlotte-Concord-Gastonia, NC-SC	313 [251 to 384]	275 [188 to 393]	275 [188 to 390]
San Antonio-New Braunfels, TX	310 [253 to 380]	276 [187 to 403]	276 [187 to 403]
Jacksonville, FL	269 [197 to 366]	238 [152 to 356]	238 [151 to 357]
New Orleans-Metairie, LA	235 [185 to 295]	214 [140 to 305]	214 [141 to 307]
Memphis, TN-MS-AR	235 [176 to 301]	209 [138 to 299]	209 [138 to 299]
Seattle-Tacoma-Bellevue, WA	361 [219 to 530]	345 [182 to 574]	345 [182 to 569]
Austin-Round Rock-Georgetown, TX	208 [167 to 257]	193 [123 to 287]	193 [123 to 287]
Indianapolis-Carmel-Anderson, IN	226 [179 to 282]	202 [134 to 290]	202 [134 to 289]
Cincinnati, OH-KY-IN	319 [242 to 442]	298 [199 to 442]	297 [199 to 444]
Columbus, OH	168 [127 to 225]	154 [99 to 232]	154 [99 to 233]
Baton Rouge, LA	160 [118 to 224]	145 [95 to 212]	145 [95 to 212]
Sacramento-Roseville-Folsom, CA	187 [140 to 239]	161 [103 to 235]	161 [104 to 235]
Cleveland-Elyria, OH	111 [85 to 141]	103 [67 to 151]	103 [66 to 151]
Total	19,020 [18,159 to 20,091]	17,329 [12,411 to 23,467]	17,321 [12,459 to 23,501]

Table S4: Projected Incidence in 2021 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2021	Prolonged Barriers to Care, 2021	Rapid Resumption of Care, 2021
New York-Newark-Jersey City, NY-NJ-PA	2,016 [1,713 to 2,329]	2,525 [1,651 to 3,571]	2,098 [1,506 to 2,833]
Miami-Fort Lauderdale-Pompano Beach, FL	1,579 [1,137 to 1,999]	1,605 [1,057 to 2,335]	1,452 [950 to 2,090]
Los Angeles-Long Beach-Anaheim, CA	1,786 [1,537 to 2,053]	1,876 [1,335 to 2,536]	1,685 [1,232 to 2,223]
Atlanta-Sandy Springs-Alpharetta, GA	1,375 [1,190 to 1,593]	1,423 [1,074 to 1,867]	1,293 [1,010 to 1,658]
Houston-The Woodlands-Sugar Land, TX	1,202 [968 to 1,450]	1,210 [856 to 1,677]	1,100 [791 to 1,503]
Dallas-Fort Worth-Arlington, TX	1,053 [859 to 1,245]	1,146 [789 to 1,612]	1,009 [728 to 1,391]
Chicago-Naperville-Elgin, IL-IN-WI	1,107 [941 to 1,304]	1,095 [796 to 1,443]	1,010 [753 to 1,312]
Washington-Arlington-Alexandria, DC-VA-MD-WV	506 [409 to 631]	623 [402 to 908]	520 [363 to 730]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	530 [424 to 648]	568 [387 to 793]	505 [357 to 691]
Orlando-Kissimmee-Sanford, FL	505 [396 to 652]	523 [349 to 754]	469 [325 to 664]
San Francisco-Oakland-Berkeley, CA	413 [307 to 540]	500 [301 to 766]	420 [267 to 613]
Phoenix-Mesa-Chandler, AZ	415 [304 to 567]	436 [278 to 648]	388 [250 to 571]
Tampa-St. Petersburg-Clearwater, FL	426 [314 to 605]	442 [283 to 654]	397 [260 to 584]
Riverside-San Bernardino-Ontario, CA	476 [320 to 704]	487 [279 to 788]	431 [253 to 704]
Detroit-Warren-Dearborn, MI	395 [290 to 520]	437 [266 to 670]	378 [238 to 576]
Baltimore-Columbia-Towson, MD	239 [177 to 310]	273 [176 to 387]	235 [161 to 329]
Las Vegas-Henderson-Paradise, NV	339 [267 to 417]	331 [228 to 456]	306 [210 to 424]
Boston-Cambridge-Newton, MA-NH	500 [312 to 794]	630 [372 to 971]	564 [331 to 876]
San Diego-Chula Vista-Carlsbad, CA	241 [189 to 312]	286 [179 to 430]	242 [159 to 358]
Charlotte-Concord-Gastonia, NC-SC	303 [236 to 382]	312 [215 to 444]	280 [199 to 392]
San Antonio-New Braunfels, TX	298 [238 to 374]	315 [208 to 469]	280 [192 to 408]
Jacksonville, FL	261 [181 to 373]	269 [169 to 410]	241 [153 to 365]
New Orleans-Metairie, LA	217 [165 to 282]	239 [157 to 345]	210 [140 to 294]
Memphis, TN-MS-AR	220 [156 to 290]	232 [153 to 331]	206 [138 to 296]
Seattle-Tacoma-Bellevue, WA	354 [197 to 566]	436 [202 to 802]	357 [174 to 646]
Austin-Round Rock-Georgetown, TX	191 [150 to 244]	222 [137 to 342]	188 [122 to 284]
Indianapolis-Carmel-Anderson, IN	217 [167 to 279]	231 [151 to 329]	205 [138 to 290]
Cincinnati, OH-KY-IN	314 [230 to 442]	331 [221 to 489]	311 [207 to 459]
Columbus, OH	159 [116 to 220]	173 [113 to 262]	154 [101 to 233]
Baton Rouge, LA	150 [107 to 218]	159 [106 to 234]	144 [98 to 209]
Sacramento-Roseville-Folsom, CA	185 [134 to 243]	184 [111 to 282]	165 [103 to 249]
Cleveland-Elyria, OH	99 [72 to 132]	113 [71 to 168]	97 [64 to 145]
Total	18,072 [16,869 to 19,487]	19,632 [14,136 to 26,582]	17,342 [13,128 to 22,724]

Table S5: Projected Incidence in 2025 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2025	Prolonged Barriers to Care, 2025	Rapid Resumption of Care, 2025
New York-Newark-Jersey City, NY-NJ-PA	1,720 [1,303 to 2,158]	1,775 [1,338 to 2,277]	1,732 [1,311 to 2,209]
Miami-Fort Lauderdale-Pompano Beach, FL	1,322 [813 to 1,862]	1,347 [847 to 1,858]	1,316 [825 to 1,817]
Los Angeles-Long Beach-Anaheim, CA	1,656 [1,305 to 2,043]	1,680 [1,328 to 2,097]	1,643 [1,311 to 2,029]
Atlanta-Sandy Springs-Alpharetta, GA	1,314 [1,044 to 1,585]	1,315 [1,035 to 1,596]	1,307 [1,024 to 1,582]
Houston-The Woodlands-Sugar Land, TX	1,112 [796 to 1,464]	1,124 [780 to 1,505]	1,102 [766 to 1,467]
Dallas-Fort Worth-Arlington, TX	935 [684 to 1,191]	949 [691 to 1,203]	929 [676 to 1,178]
Chicago-Naperville-Elgin, IL-IN-WI	1,093 [861 to 1,366]	1,092 [861 to 1,352]	1,078 [854 to 1,337]
Washington-Arlington-Alexandria, DC-VA-MD-WV	398 [264 to 567]	410 [278 to 570]	401 [274 to 555]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	457 [310 to 635]	462 [325 to 638]	454 [320 to 626]
Orlando-Kissimmee-Sanford, FL	431 [295 to 596]	437 [296 to 597]	427 [286 to 582]
San Francisco-Oakland-Berkeley, CA	337 [216 to 505]	353 [228 to 530]	339 [222 to 500]
Phoenix-Mesa-Chandler, AZ	356 [211 to 561]	361 [216 to 579]	352 [211 to 556]
Tampa-St. Petersburg-Clearwater, FL	370 [227 to 609]	377 [231 to 606]	367 [227 to 586]
Riverside-San Bernardino-Ontario, CA	433 [225 to 796]	442 [241 to 810]	423 [231 to 764]
Detroit-Warren-Dearborn, MI	358 [221 to 543]	372 [230 to 562]	357 [222 to 533]
Baltimore-Columbia-Towson, MD	189 [115 to 281]	192 [121 to 284]	189 [118 to 280]
Las Vegas-Henderson-Paradise, NV	282 [187 to 386]	285 [190 to 391]	279 [186 to 383]
Boston-Cambridge-Newton, MA-NH	428 [254 to 681]	432 [267 to 678]	428 [260 to 674]
San Diego-Chula Vista-Carlsbad, CA	194 [134 to 279]	202 [138 to 285]	195 [133 to 274]
Charlotte-Concord-Gastonia, NC-SC	287 [197 to 404]	291 [199 to 408]	284 [195 to 395]
San Antonio-New Braunfels, TX	277 [193 to 375]	280 [199 to 382]	274 [195 to 370]
Jacksonville, FL	244 [144 to 411]	248 [147 to 411]	241 [144 to 395]
New Orleans-Metairie, LA	181 [116 to 261]	185 [122 to 265]	181 [120 to 259]
Memphis, TN-MS-AR	190 [113 to 273]	192 [115 to 275]	189 [112 to 272]
Seattle-Tacoma-Bellevue, WA	326 [135 to 677]	352 [146 to 732]	325 [139 to 659]
Austin-Round Rock-Georgetown, TX	154 [105 to 214]	161 [109 to 229]	155 [105 to 220]
Indianapolis-Carmel-Anderson, IN	198 [132 to 277]	202 [130 to 275]	197 [128 to 270]
Cincinnati, OH-KY-IN	297 [189 to 437]	302 [190 to 440]	298 [190 to 434]
Columbus, OH	139 [90 to 210]	142 [91 to 215]	139 [89 to 212]
Baton Rouge, LA	132 [83 to 210]	135 [87 to 204]	133 [86 to 202]
Sacramento-Roseville-Folsom, CA	186 [114 to 283]	189 [117 to 281]	180 [112 to 264]
Cleveland-Elyria, OH	78 [46 to 118]	80 [47 to 121]	78 [46 to 119]
Total	16,073 [13,150 to 19,076]	16,362 [13,422 to 19,537]	15,992 [13,215 to 18,896]

4.2 Projected Reported Diagnoses in 2020, 2021, and 2025

Table S6: Projected Reported Diagnoses in 2020 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2020	Prolonged Barriers to Care, 2020	Rapid Resumption of Care, 2020
New York-Newark-Jersey City, NY-NJ-PA	2,492 [2,264 to 2,730]	2,098 [1,648 to 2,568]	2,098 [1,647 to 2,564]
Miami-Fort Lauderdale-Pompano Beach, FL	1,877 [1,643 to 2,112]	1,548 [1,206 to 1,928]	1,548 [1,206 to 1,927]
Los Angeles-Long Beach-Anaheim, CA	1,878 [1,659 to 2,097]	1,549 [1,183 to 1,937]	1,548 [1,182 to 1,938]
Atlanta-Sandy Springs-Alpharetta, GA	1,460 [1,308 to 1,634]	1,208 [944 to 1,496]	1,208 [944 to 1,498]
Houston-The Woodlands-Sugar Land, TX	1,259 [1,124 to 1,418]	1,036 [794 to 1,296]	1,036 [794 to 1,296]
Dallas-Fort Worth-Arlington, TX	1,187 [1,024 to 1,343]	983 [749 to 1,245]	984 [749 to 1,245]
Chicago-Naperville-Elgin, IL-IN-WI	1,131 [1,003 to 1,275]	930 [728 to 1,152]	929 [727 to 1,152]
Washington-Arlington-Alexandria, DC-VA-MD-WV	721 [630 to 827]	608 [471 to 755]	608 [471 to 754]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	651 [573 to 738]	542 [421 to 678]	542 [421 to 678]
Orlando-Kissimmee-Sanford, FL	590 [501 to 698]	486 [361 to 630]	486 [361 to 630]
San Francisco-Oakland-Berkeley, CA	513 [436 to 607]	430 [327 to 550]	430 [327 to 550]
Phoenix-Mesa-Chandler, AZ	501 [417 to 596]	414 [308 to 532]	414 [308 to 532]
Tampa-St. Petersburg-Clearwater, FL	481 [404 to 574]	397 [296 to 514]	397 [296 to 513]
Riverside-San Bernardino-Ontario, CA	512 [415 to 622]	420 [305 to 547]	420 [305 to 547]
Detroit-Warren-Dearborn, MI	418 [355 to 485]	346 [262 to 442]	346 [262 to 441]
Baltimore-Columbia-Towson, MD	338 [292 to 387]	283 [216 to 353]	283 [216 to 353]
Las Vegas-Henderson-Paradise, NV	403 [346 to 465]	330 [252 to 418]	330 [252 to 417]
Boston-Cambridge-Newton, MA-NH	488 [376 to 650]	416 [287 to 587]	416 [288 to 586]
San Diego-Chula Vista-Carlsbad, CA	316 [263 to 377]	263 [195 to 344]	263 [195 to 344]
Charlotte-Concord-Gastonia, NC-SC	319 [273 to 367]	262 [196 to 337]	262 [196 to 337]
San Antonio-New Braunfels, TX	313 [273 to 361]	259 [197 to 326]	259 [197 to 326]
Jacksonville, FL	279 [234 to 334]	230 [172 to 302]	230 [172 to 302]
New Orleans-Metairie, LA	256 [223 to 292]	212 [160 to 266]	212 [160 to 266]
Memphis, TN-MS-AR	274 [235 to 315]	226 [172 to 285]	226 [172 to 285]
Seattle-Tacoma-Bellevue, WA	369 [263 to 478]	308 [207 to 429]	308 [208 to 429]
Austin-Round Rock-Georgetown, TX	228 [194 to 267]	190 [143 to 243]	190 [143 to 243]
Indianapolis-Carmel-Anderson, IN	218 [183 to 254]	180 [136 to 229]	180 [136 to 229]
Cincinnati, OH-KY-IN	270 [224 to 320]	223 [166 to 288]	223 [166 to 289]
Columbus, OH	178 [149 to 213]	147 [111 to 190]	147 [111 to 190]
Baton Rouge, LA	177 [154 to 209]	147 [111 to 190]	147 [111 to 190]
Sacramento-Roseville-Folsom, CA	180 [144 to 219]	148 [111 to 197]	148 [110 to 197]
Cleveland-Elyria, OH	135 [115 to 158]	113 [86 to 142]	113 [86 to 142]
Total	20,411 [19,635 to 21,212]	16,930 [13,517 to 20,306]	16,930 [13,514 to 20,319]

Table S7: Projected Reported Diagnoses in 2021 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2021	Prolonged Barriers to Care, 2021	Rapid Resumption of Care, 2021
New York-Newark-Jersey City, NY-NJ-PA	2,307 [2,050 to 2,590]	2,121 [1,583 to 2,722]	2,334 [1,908 to 2,834]
Miami-Fort Lauderdale-Pompano Beach, FL	1,778 [1,483 to 2,082]	1,491 [1,133 to 1,897]	1,673 [1,332 to 2,050]
Los Angeles-Long Beach-Anaheim, CA	1,814 [1,574 to 2,067]	1,533 [1,147 to 1,944]	1,715 [1,384 to 2,066]
Atlanta-Sandy Springs-Alpharetta, GA	1,413 [1,252 to 1,594]	1,215 [928 to 1,528]	1,346 [1,099 to 1,643]
Houston-The Woodlands-Sugar Land, TX	1,214 [1,048 to 1,403]	1,009 [763 to 1,293]	1,131 [924 to 1,399]
Dallas-Fort Worth-Arlington, TX	1,129 [957 to 1,301]	978 [730 to 1,247]	1,085 [860 to 1,366]
Chicago-Naperville-Elgin, IL-IN-WI	1,108 [968 to 1,266]	925 [706 to 1,157]	1,031 [824 to 1,271]
Washington-Arlington-Alexandria, DC-VA-MD-WV	641 [541 to 753]	594 [450 to 775]	650 [519 to 824]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	606 [515 to 708]	532 [407 to 686]	587 [457 to 739]
Orlando-Kissimmee-Sanford, FL	562 [470 to 680]	475 [349 to 629]	529 [416 to 668]
San Francisco-Oakland-Berkeley, CA	473 [389 to 577]	427 [311 to 559]	471 [363 to 589]
Phoenix-Mesa-Chandler, AZ	472 [382 to 581]	401 [292 to 537]	447 [344 to 572]
Tampa-St. Petersburg-Clearwater, FL	458 [373 to 570]	386 [283 to 505]	431 [336 to 551]
Riverside-San Bernardino-Ontario, CA	494 [379 to 626]	416 [288 to 569]	461 [337 to 622]
Detroit-Warren-Dearborn, MI	398 [324 to 482]	343 [248 to 453]	380 [288 to 493]
Baltimore-Columbia-Towson, MD	302 [253 to 357]	271 [204 to 345]	298 [236 to 373]
Las Vegas-Henderson-Paradise, NV	380 [320 to 454]	313 [237 to 399]	352 [280 to 438]
Boston-Cambridge-Newton, MA-NH	488 [350 to 698]	476 [315 to 680]	522 [356 to 746]
San Diego-Chula Vista-Carlsbad, CA	289 [234 to 355]	255 [184 to 335]	283 [217 to 365]
Charlotte-Concord-Gastonia, NC-SC	308 [253 to 366]	258 [191 to 341]	288 [229 to 364]
San Antonio-New Braunfels, TX	301 [255 to 355]	257 [190 to 339]	285 [223 to 370]
Jacksonville, FL	269 [215 to 338]	228 [168 to 306]	254 [194 to 331]
New Orleans-Metairie, LA	237 [200 to 280]	205 [149 to 262]	228 [183 to 282]
Memphis, TN-MS-AR	255 [210 to 302]	217 [164 to 279]	242 [194 to 307]
Seattle-Tacoma-Bellevue, WA	368 [244 to 513]	337 [208 to 514]	366 [228 to 548]
Austin-Round Rock-Georgetown, TX	210 [175 to 251]	185 [133 to 248]	204 [157 to 261]
Indianapolis-Carmel-Anderson, IN	209 [170 to 249]	178 [130 to 231]	198 [155 to 250]
Cincinnati, OH-KY-IN	271 [219 to 340]	234 [171 to 303]	261 [199 to 336]
Columbus, OH	167 [136 to 208]	144 [105 to 191]	160 [124 to 206]
Baton Rouge, LA	165 [137 to 204]	140 [103 to 182]	157 [128 to 195]
Sacramento-Roseville-Folsom, CA	177 [138 to 220]	146 [106 to 197]	163 [123 to 214]
Cleveland-Elyria, OH	121 [99 to 146]	107 [79 to 139]	118 [91 to 151]
Total	19,383 [18,138 to 20,779]	16,796 [13,066 to 20,829]	18,652 [15,740 to 22,065]

Table S8: Projected Reported Diagnoses in 2025 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2025	Prolonged Barriers to Care, 2025	Rapid Resumption of Care, 2025
New York-Newark-Jersey City, NY-NJ-PA	1,831 [1,504 to 2,181]	1,981 [1,585 to 2,477]	1,884 [1,534 to 2,329]
Miami-Fort Lauderdale-Pompano Beach, FL	1,424 [981 to 1,804]	1,488 [1,034 to 1,945]	1,430 [989 to 1,840]
Los Angeles-Long Beach-Anaheim, CA	1,624 [1,369 to 1,901]	1,696 [1,380 to 2,040]	1,630 [1,346 to 1,941]
Atlanta-Sandy Springs-Alpharetta, GA	1,284 [1,067 to 1,504]	1,313 [1,080 to 1,548]	1,285 [1,053 to 1,512]
Houston-The Woodlands-Sugar Land, TX	1,078 [846 to 1,304]	1,113 [868 to 1,385]	1,075 [844 to 1,338]
Dallas-Fort Worth-Arlington, TX	935 [733 to 1,142]	977 [750 to 1,207]	940 [731 to 1,154]
Chicago-Naperville-Elgin, IL-IN-WI	1,063 [878 to 1,281]	1,084 [883 to 1,301]	1,055 [869 to 1,254]
Washington-Arlington-Alexandria, DC-VA-MD-WV	448 [333 to 592]	483 [349 to 635]	461 [335 to 602]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	484 [356 to 628]	503 [376 to 649]	486 [367 to 636]
Orlando-Kissimmee-Sanford, FL	453 [341 to 590]	472 [351 to 623]	453 [336 to 588]
San Francisco-Oakland-Berkeley, CA	363 [253 to 494]	397 [271 to 542]	373 [260 to 500]
Phoenix-Mesa-Chandler, AZ	377 [257 to 540]	393 [265 to 558]	377 [257 to 534]
Tampa-St. Petersburg-Clearwater, FL	376 [263 to 535]	393 [274 to 559]	377 [266 to 535]
Riverside-San Bernardino-Ontario, CA	426 [263 to 686]	446 [283 to 702]	420 [267 to 663]
Detroit-Warren-Dearborn, MI	346 [244 to 480]	370 [256 to 520]	349 [246 to 483]
Baltimore-Columbia-Towson, MD	214 [148 to 290]	225 [158 to 308]	217 [152 to 295]
Las Vegas-Henderson-Paradise, NV	296 [226 to 374]	305 [230 to 387]	295 [223 to 371]
Boston-Cambridge-Newton, MA-NH	430 [270 to 670]	459 [295 to 694]	444 [284 to 669]
San Diego-Chula Vista-Carlsbad, CA	216 [161 to 283]	234 [171 to 312]	221 [164 to 292]
Charlotte-Concord-Gastonia, NC-SC	281 [213 to 362]	291 [219 to 382]	280 [212 to 366]
San Antonio-New Braunfels, TX	264 [204 to 330]	273 [209 to 349]	263 [203 to 335]
Jacksonville, FL	236 [159 to 345]	245 [162 to 363]	236 [157 to 346]
New Orleans-Metairie, LA	185 [137 to 242]	195 [144 to 254]	187 [140 to 241]
Memphis, TN-MS-AR	201 [137 to 265]	209 [145 to 278]	202 [139 to 268]
Seattle-Tacoma-Bellevue, WA	327 [158 to 612]	366 [176 to 696]	331 [164 to 617]
Austin-Round Rock-Georgetown, TX	159 [123 to 204]	171 [127 to 226]	162 [121 to 210]
Indianapolis-Carmel-Anderson, IN	183 [135 to 234]	191 [135 to 245]	183 [131 to 234]
Cincinnati, OH-KY-IN	259 [187 to 344]	269 [197 to 360]	262 [191 to 350]
Columbus, OH	137 [102 to 185]	145 [108 to 194]	139 [102 to 186]
Baton Rouge, LA	132 [97 to 185]	139 [103 to 191]	135 [100 to 182]
Sacramento-Roseville-Folsom, CA	172 [118 to 236]	179 [122 to 249]	169 [116 to 235]
Cleveland-Elyria, OH	86 [61 to 118]	91 [63 to 127]	87 [61 to 121]
Total	16,288 [14,442 to 18,071]	17,097 [14,575 to 19,782]	16,408 [14,176 to 18,706]

4.3 Projected Prevalence in 2020, 2021, and 2025

Table S9: Projected Prevalence in 2020 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2020	Prolonged Barriers to Care, 2020	Rapid Resumption of Care, 2020
New York-Newark-Jersey City, NY-NJ-PA	138,248 [133,698 to 142,456]	138,204 [133,436 to 142,683]	138,203 [133,441 to 142,692]
Miami-Fort Lauderdale-Pompano Beach, FL	65,831 [61,957 to 69,630]	65,597 [61,813 to 69,323]	65,596 [61,813 to 69,331]
Los Angeles-Long Beach-Anaheim, CA	63,793 [57,128 to 69,729]	63,459 [57,432 to 69,437]	63,459 [57,439 to 69,438]
Atlanta-Sandy Springs-Alpharetta, GA	38,733 [35,353 to 42,450]	38,612 [34,940 to 42,365]	38,611 [34,939 to 42,370]
Houston-The Woodlands-Sugar Land, TX	38,488 [35,441 to 41,635]	38,326 [35,204 to 41,468]	38,326 [35,198 to 41,457]
Dallas-Fort Worth-Arlington, TX	34,407 [31,018 to 37,924]	34,268 [30,811 to 37,679]	34,268 [30,813 to 37,676]
Chicago-Naperville-Elgin, IL-IN-WI	33,705 [31,297 to 36,340]	33,538 [31,034 to 36,074]	33,538 [31,032 to 36,076]
Washington-Arlington-Alexandria, DC-VA-MD-WV	34,870 [32,367 to 37,210]	34,919 [32,589 to 37,264]	34,919 [32,588 to 37,262]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	26,191 [24,920 to 27,470]	26,127 [24,764 to 27,408]	26,127 [24,764 to 27,409]
Orlando-Kissimmee-Sanford, FL	15,571 [14,100 to 17,082]	15,459 [14,049 to 17,004]	15,459 [14,046 to 17,006]
San Francisco-Oakland-Berkeley, CA	26,203 [23,780 to 28,731]	26,171 [23,588 to 28,733]	26,171 [23,587 to 28,735]
Phoenix-Mesa-Chandler, AZ	14,956 [13,439 to 16,585]	14,887 [13,272 to 16,575]	14,886 [13,271 to 16,578]
Tampa-St. Petersburg-Clearwater, FL	15,448 [13,959 to 17,055]	15,390 [13,935 to 16,955]	15,390 [13,935 to 16,955]
Riverside-San Bernardino-Ontario, CA	12,545 [11,102 to 14,107]	12,433 [11,071 to 13,909]	12,433 [11,071 to 13,908]
Detroit-Warren-Dearborn, MI	12,086 [11,036 to 13,099]	12,008 [10,998 to 13,051]	12,008 [10,998 to 13,053]
Baltimore-Columbia-Towson, MD	18,343 [17,357 to 19,350]	18,297 [17,293 to 19,385]	18,297 [17,293 to 19,385]
Las Vegas-Henderson-Paradise, NV	10,256 [9,193 to 11,526]	10,184 [9,097 to 11,395]	10,184 [9,097 to 11,396]
Boston-Cambridge-Newton, MA-NH	15,496 [14,415 to 16,665]	15,518 [14,446 to 16,673]	15,518 [14,450 to 16,674]
San Diego-Chula Vista-Carlsbad, CA	13,995 [12,225 to 15,923]	13,980 [12,297 to 15,917]	13,980 [12,296 to 15,916]
Charlotte-Concord-Gastonia, NC-SC	9,809 [8,904 to 10,884]	9,728 [8,817 to 10,793]	9,728 [8,815 to 10,792]
San Antonio-New Braunfels, TX	9,020 [8,198 to 9,891]	8,986 [8,146 to 9,865]	8,986 [8,146 to 9,865]
Jacksonville, FL	8,936 [8,196 to 9,641]	8,893 [8,173 to 9,597]	8,893 [8,172 to 9,597]
New Orleans-Metairie, LA	9,516 [8,826 to 10,171]	9,482 [8,763 to 10,153]	9,482 [8,763 to 10,153]
Memphis, TN-MS-AR	8,599 [7,895 to 9,273]	8,561 [7,855 to 9,276]	8,561 [7,854 to 9,277]
Seattle-Tacoma-Bellevue, WA	10,915 [9,053 to 12,775]	10,865 [9,141 to 12,659]	10,865 [9,138 to 12,657]
Austin-Round Rock-Georgetown, TX	8,152 [7,278 to 9,117]	8,113 [7,248 to 9,062]	8,113 [7,247 to 9,061]
Indianapolis-Carmel-Anderson, IN	6,722 [5,874 to 7,564]	6,693 [5,897 to 7,567]	6,693 [5,897 to 7,568]
Cincinnati, OH-KY-IN	5,234 [4,571 to 5,912]	5,214 [4,590 to 5,918]	5,214 [4,589 to 5,913]
Columbus, OH	6,581 [5,753 to 7,337]	6,549 [5,706 to 7,358]	6,549 [5,705 to 7,357]
Baton Rouge, LA	6,314 [5,921 to 6,752]	6,289 [5,880 to 6,722]	6,288 [5,880 to 6,723]
Sacramento-Roseville-Folsom, CA	5,312 [4,586 to 6,082]	5,271 [4,608 to 6,003]	5,271 [4,608 to 6,003]
Cleveland-Elyria, OH	5,610 [5,138 to 6,144]	5,602 [5,104 to 6,138]	5,602 [5,104 to 6,138]
Total	729,886 [717,453 to 742,027]	727,625 [713,525 to 741,477]	727,619 [713,468 to 741,445]

Table S10: Projected Prevalence in 2021 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2021	Prolonged Barriers to Care, 2021	Rapid Resumption of Care, 2021
New York-Newark-Jersey City, NY-NJ-PA	138,423 [133,828 to 142,670]	138,777 [133,940 to 143,462]	138,414 [133,631 to 142,988]
Miami-Fort Lauderdale-Pompano Beach, FL	66,384 [62,237 to 70,341]	66,121 [61,879 to 70,153]	66,003 [61,835 to 70,030]
Los Angeles-Long Beach-Anaheim, CA	64,611 [57,954 to 70,718]	64,276 [58,043 to 70,339]	64,141 [57,964 to 70,277]
Atlanta-Sandy Springs-Alpharetta, GA	39,519 [36,102 to 43,363]	39,405 [35,697 to 43,189]	39,300 [35,622 to 43,060]
Houston-The Woodlands-Sugar Land, TX	39,121 [36,078 to 42,337]	38,921 [35,640 to 42,243]	38,840 [35,590 to 42,106]
Dallas-Fort Worth-Arlington, TX	34,932 [31,558 to 38,551]	34,833 [31,230 to 38,324]	34,728 [31,150 to 38,149]
Chicago-Naperville-Elgin, IL-IN-WI	34,314 [31,852 to 37,062]	34,119 [31,492 to 36,796]	34,045 [31,448 to 36,692]
Washington-Arlington-Alexandria, DC-VA-MD-WV	34,923 [32,411 to 37,256]	35,064 [32,691 to 37,481]	34,974 [32,582 to 37,360]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	26,249 [24,961 to 27,556]	26,198 [24,785 to 27,535]	26,151 [24,756 to 27,465]
Orlando-Kissimmee-Sanford, FL	15,823 [14,325 to 17,377]	15,707 [14,255 to 17,366]	15,667 [14,195 to 17,328]
San Francisco-Oakland-Berkeley, CA	26,211 [23,723 to 28,755]	26,227 [23,612 to 28,796]	26,170 [23,564 to 28,762]
Phoenix-Mesa-Chandler, AZ	15,149 [13,579 to 16,928]	15,083 [13,379 to 16,870]	15,045 [13,357 to 16,852]
Tampa-St. Petersburg-Clearwater, FL	15,579 [14,050 to 17,244]	15,508 [13,989 to 17,144]	15,481 [13,976 to 17,121]
Riverside-San Bernardino-Ontario, CA	12,812 [11,243 to 14,516]	12,690 [11,224 to 14,298]	12,648 [11,187 to 14,265]
Detroit-Warren-Dearborn, MI	12,268 [11,208 to 13,300]	12,210 [11,106 to 13,309]	12,164 [11,098 to 13,253]
Baltimore-Columbia-Towson, MD	18,277 [17,269 to 19,291]	18,238 [17,222 to 19,329]	18,217 [17,202 to 19,304]
Las Vegas-Henderson-Paradise, NV	10,416 [9,340 to 11,710]	10,326 [9,220 to 11,554]	10,308 [9,197 to 11,545]
Boston-Cambridge-Newton, MA-NH	15,770 [14,609 to 17,064]	15,900 [14,672 to 17,174]	15,846 [14,634 to 17,141]
San Diego-Chula Vista-Carlsbad, CA	14,037 [12,261 to 15,963]	14,050 [12,338 to 16,036]	14,017 [12,317 to 15,991]
Charlotte-Concord-Gastonia, NC-SC	9,961 [9,024 to 11,038]	9,877 [8,930 to 10,961]	9,852 [8,897 to 10,939]
San Antonio-New Braunfels, TX	9,166 [8,316 to 10,062]	9,134 [8,267 to 10,067]	9,109 [8,247 to 10,036]
Jacksonville, FL	9,035 [8,262 to 9,769]	8,985 [8,213 to 9,718]	8,967 [8,199 to 9,691]
New Orleans-Metairie, LA	9,554 [8,863 to 10,239]	9,525 [8,809 to 10,226]	9,506 [8,789 to 10,193]
Memphis, TN-MS-AR	8,672 [7,970 to 9,338]	8,633 [7,920 to 9,329]	8,615 [7,901 to 9,309]
Seattle-Tacoma-Bellevue, WA	11,111 [9,226 to 13,100]	11,112 [9,247 to 12,979]	11,052 [9,204 to 12,915]
Austin-Round Rock-Georgetown, TX	8,219 [7,340 to 9,197]	8,195 [7,326 to 9,141]	8,171 [7,303 to 9,114]
Indianapolis-Carmel-Anderson, IN	6,814 [5,933 to 7,668]	6,788 [5,980 to 7,687]	6,768 [5,962 to 7,678]
Cincinnati, OH-KY-IN	5,438 [4,739 to 6,169]	5,430 [4,748 to 6,198]	5,414 [4,733 to 6,170]
Columbus, OH	6,622 [5,801 to 7,403]	6,595 [5,741 to 7,421]	6,582 [5,727 to 7,400]
Baton Rouge, LA	6,345 [5,941 to 6,802]	6,318 [5,889 to 6,798]	6,309 [5,880 to 6,789]
Sacramento-Roseville-Folsom, CA	5,401 [4,631 to 6,180]	5,346 [4,651 to 6,102]	5,335 [4,641 to 6,090]
Cleveland-Elyria, OH	5,604 [5,118 to 6,129]	5,602 [5,095 to 6,137]	5,591 [5,087 to 6,123]
Total	736,763 [723,940 to 748,925]	735,191 [718,432 to 752,332]	733,431 [717,223 to 750,569]

Table S11: Projected Prevalence in 2025 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2025	Prolonged Barriers to Care, 2025	Rapid Resumption of Care, 2025
New York-Newark-Jersey City, NY-NJ-PA	137,940 [132,838 to 142,837]	138,666 [133,305 to 144,153]	138,028 [132,698 to 143,278]
Miami-Fort Lauderdale-Pompano Beach, FL	67,716 [62,376 to 72,729]	67,631 [62,230 to 72,863]	67,326 [61,901 to 72,450]
Los Angeles-Long Beach-Anaheim, CA	67,301 [60,321 to 73,604]	67,160 [60,723 to 73,551]	66,821 [60,406 to 73,113]
Atlanta-Sandy Springs-Alpharetta, GA	42,300 [38,612 to 46,403]	42,237 [38,384 to 46,477]	42,066 [38,262 to 46,274]
Houston-The Woodlands-Sugar Land, TX	41,253 [37,893 to 45,147]	41,152 [37,555 to 45,111]	40,941 [37,318 to 44,669]
Dallas-Fort Worth-Arlington, TX	36,569 [32,982 to 40,257]	36,591 [32,685 to 40,537]	36,366 [32,553 to 40,059]
Chicago-Naperville-Elgin, IL-IN-WI	36,536 [33,748 to 39,590]	36,386 [33,409 to 39,602]	36,224 [33,308 to 39,348]
Washington-Arlington-Alexandria, DC-VA-MD-WV	34,717 [32,134 to 37,271]	34,943 [32,486 to 37,480]	34,788 [32,364 to 37,369]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	26,208 [24,692 to 27,848]	26,209 [24,582 to 27,882]	26,106 [24,520 to 27,754]
Orlando-Kissimmee-Sanford, FL	16,572 [14,928 to 18,454]	16,512 [14,947 to 18,451]	16,410 [14,828 to 18,330]
San Francisco-Oakland-Berkeley, CA	25,977 [23,341 to 28,743]	26,095 [23,463 to 28,968]	25,959 [23,406 to 28,737]
Phoenix-Mesa-Chandler, AZ	15,713 [13,901 to 17,811]	15,694 [13,805 to 17,799]	15,600 [13,723 to 17,681]
Tampa-St. Petersburg-Clearwater, FL	15,914 [14,170 to 18,015]	15,894 [14,141 to 18,056]	15,811 [14,122 to 17,939]
Riverside-San Bernardino-Ontario, CA	13,717 [11,760 to 16,214]	13,672 [11,860 to 15,930]	13,525 [11,760 to 15,767]
Detroit-Warren-Dearborn, MI	12,841 [11,532 to 14,168]	12,873 [11,561 to 14,283]	12,743 [11,451 to 14,148]
Baltimore-Columbia-Towson, MD	17,842 [16,769 to 18,911]	17,834 [16,748 to 18,966]	17,788 [16,706 to 18,931]
Las Vegas-Henderson-Paradise, NV	10,865 [9,733 to 12,216]	10,806 [9,560 to 12,164]	10,752 [9,523 to 12,123]
Boston-Cambridge-Newton, MA-NH	16,620 [15,000 to 18,655]	16,846 [15,194 to 18,752]	16,734 [15,116 to 18,666]
San Diego-Chula Vista-Carlsbad, CA	14,042 [12,282 to 16,099]	14,108 [12,330 to 16,121]	14,034 [12,270 to 16,008]
Charlotte-Concord-Gastonia, NC-SC	10,483 [9,380 to 11,706]	10,429 [9,334 to 11,662]	10,368 [9,294 to 11,610]
San Antonio-New Braunfels, TX	9,661 [8,697 to 10,736]	9,660 [8,669 to 10,783]	9,599 [8,616 to 10,706]
Jacksonville, FL	9,360 [8,422 to 10,395]	9,338 [8,405 to 10,431]	9,284 [8,354 to 10,322]
New Orleans-Metairie, LA	9,586 [8,820 to 10,413]	9,589 [8,791 to 10,441]	9,543 [8,755 to 10,383]
Memphis, TN-MS-AR	8,845 [8,035 to 9,632]	8,833 [8,007 to 9,663]	8,791 [7,983 to 9,619]
Seattle-Tacoma-Bellevue, WA	11,780 [9,459 to 14,257]	11,940 [9,568 to 14,607]	11,734 [9,474 to 14,275]
Austin-Round Rock-Georgetown, TX	8,363 [7,490 to 9,366]	8,386 [7,460 to 9,412]	8,324 [7,424 to 9,301]
Indianapolis-Carmel-Anderson, IN	7,101 [6,150 to 8,103]	7,101 [6,177 to 8,074]	7,055 [6,124 to 8,025]
Cincinnati, OH-KY-IN	6,167 [5,292 to 7,248]	6,201 [5,274 to 7,330]	6,155 [5,258 to 7,272]
Columbus, OH	6,708 [5,860 to 7,600]	6,705 [5,821 to 7,579]	6,673 [5,807 to 7,546]
Baton Rouge, LA	6,404 [5,926 to 7,059]	6,395 [5,929 to 7,042]	6,375 [5,913 to 7,002]
Sacramento-Roseville-Folsom, CA	5,735 [4,864 to 6,679]	5,703 [4,888 to 6,588]	5,654 [4,846 to 6,516]
Cleveland-Elyria, OH	5,510 [5,007 to 6,075]	5,524 [5,007 to 6,096]	5,501 [4,983 to 6,056]
Total	756,345 [739,909 to 773,165]	757,111 [735,455 to 781,763]	753,075 [733,195 to 776,201]

4.4 Projected Knowledge of Status in 2020, 2021, and 2025

Table S12: Projected Knowledge of Status in 2020 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2020	Prolonged Barriers to Care, 2020	Rapid Resumption of Care, 2020
New York-Newark-Jersey City, NY-NJ-PA	95% [95 to 96%]	95% [94 to 96%]	95% [94 to 96%]
Miami-Fort Lauderdale-Pompano Beach, FL	91% [88 to 94%]	91% [88 to 94%]	91% [88 to 94%]
Los Angeles-Long Beach-Anaheim, CA	91% [90 to 93%]	91% [89 to 93%]	91% [89 to 93%]
Atlanta-Sandy Springs-Alpharetta, GA	92% [88 to 94%]	91% [88 to 94%]	91% [88 to 94%]
Houston-The Woodlands-Sugar Land, TX	88% [86 to 90%]	88% [85 to 90%]	88% [85 to 90%]
Dallas-Fort Worth-Arlington, TX	89% [87 to 92%]	89% [86 to 92%]	89% [86 to 92%]
Chicago-Naperville-Elgin, IL-IN-WI	93% [91 to 95%]	93% [91 to 95%]	93% [91 to 95%]
Washington-Arlington-Alexandria, DC-VA-MD-WV	96% [95 to 97%]	96% [94 to 97%]	96% [94 to 97%]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	95% [93 to 96%]	94% [93 to 96%]	94% [93 to 96%]
Orlando-Kissimmee-Sanford, FL	90% [87 to 92%]	89% [87 to 92%]	89% [87 to 92%]
San Francisco-Oakland-Berkeley, CA	95% [93 to 97%]	95% [92 to 97%]	95% [92 to 97%]
Phoenix-Mesa-Chandler, AZ	88% [85 to 91%]	88% [84 to 91%]	88% [84 to 91%]
Tampa-St. Petersburg-Clearwater, FL	89% [86 to 92%]	89% [85 to 93%]	89% [85 to 93%]
Riverside-San Bernardino-Ontario, CA	89% [85 to 92%]	89% [85 to 92%]	89% [85 to 92%]
Detroit-Warren-Dearborn, MI	90% [87 to 93%]	90% [86 to 93%]	90% [86 to 93%]
Baltimore-Columbia-Towson, MD	95% [93 to 97%]	95% [93 to 97%]	95% [93 to 97%]
Las Vegas-Henderson-Paradise, NV	83% [80 to 86%]	83% [80 to 86%]	83% [80 to 86%]
Boston-Cambridge-Newton, MA-NH	94% [91 to 96%]	93% [90 to 96%]	93% [90 to 96%]
San Diego-Chula Vista-Carlsbad, CA	92% [89 to 95%]	92% [88 to 94%]	92% [88 to 94%]
Charlotte-Concord-Gastonia, NC-SC	90% [86 to 92%]	89% [86 to 92%]	89% [86 to 92%]
San Antonio-New Braunfels, TX	85% [81 to 88%]	84% [81 to 88%]	84% [81 to 88%]
Jacksonville, FL	90% [87 to 93%]	90% [86 to 92%]	90% [86 to 92%]
New Orleans-Metairie, LA	88% [85 to 91%]	88% [84 to 91%]	88% [84 to 91%]
Memphis, TN-MS-AR	90% [88 to 92%]	90% [87 to 92%]	90% [87 to 92%]
Seattle-Tacoma-Bellevue, WA	93% [91 to 95%]	92% [90 to 94%]	92% [90 to 94%]
Austin-Round Rock-Georgetown, TX	87% [84 to 90%]	87% [84 to 90%]	87% [84 to 90%]
Indianapolis-Carmel-Anderson, IN	86% [82 to 89%]	85% [82 to 89%]	85% [82 to 89%]
Cincinnati, OH-KY-IN	83% [77 to 87%]	82% [77 to 87%]	82% [77 to 87%]
Columbus, OH	88% [84 to 91%]	87% [84 to 91%]	87% [84 to 91%]
Baton Rouge, LA	87% [83 to 90%]	86% [83 to 90%]	86% [83 to 90%]
Sacramento-Roseville-Folsom, CA	90% [87 to 93%]	90% [87 to 92%]	90% [87 to 92%]
Cleveland-Elyria, OH	89% [86 to 92%]	89% [86 to 92%]	89% [86 to 92%]
Total	92% [91 to 92%]	92% [91 to 92%]	92% [91 to 92%]

Table S13: Projected Knowledge of Status in 2021 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2021	Prolonged Barriers to Care, 2021	Rapid Resumption of Care, 2021
New York-Newark-Jersey City, NY-NJ-PA	96% [95 to 97%]	95% [93 to 96%]	95% [94 to 97%]
Miami-Fort Lauderdale-Pompano Beach, FL	91% [88 to 95%]	91% [87 to 95%]	91% [88 to 95%]
Los Angeles-Long Beach-Anaheim, CA	92% [90 to 93%]	91% [88 to 93%]	91% [89 to 93%]
Atlanta-Sandy Springs-Alpharetta, GA	92% [89 to 95%]	91% [87 to 94%]	92% [88 to 95%]
Houston-The Woodlands-Sugar Land, TX	88% [86 to 91%]	88% [85 to 90%]	88% [86 to 91%]
Dallas-Fort Worth-Arlington, TX	90% [88 to 92%]	89% [86 to 92%]	90% [87 to 92%]
Chicago-Naperville-Elgin, IL-IN-WI	93% [91 to 95%]	93% [90 to 95%]	93% [91 to 95%]
Washington-Arlington-Alexandria, DC-VA-MD-WV	96% [95 to 97%]	96% [94 to 97%]	96% [95 to 97%]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	95% [93 to 97%]	94% [92 to 96%]	95% [93 to 97%]
Orlando-Kissimmee-Sanford, FL	91% [88 to 93%]	90% [86 to 92%]	90% [87 to 93%]
San Francisco-Oakland-Berkeley, CA	95% [93 to 97%]	95% [92 to 97%]	95% [92 to 97%]
Phoenix-Mesa-Chandler, AZ	89% [85 to 92%]	88% [84 to 91%]	89% [85 to 92%]
Tampa-St. Petersburg-Clearwater, FL	90% [86 to 93%]	89% [85 to 93%]	90% [86 to 93%]
Riverside-San Bernardino-Ontario, CA	90% [85 to 93%]	89% [84 to 92%]	89% [85 to 93%]
Detroit-Warren-Dearborn, MI	90% [88 to 93%]	89% [85 to 93%]	90% [87 to 93%]
Baltimore-Columbia-Towson, MD	96% [94 to 97%]	95% [93 to 97%]	96% [93 to 97%]
Las Vegas-Henderson-Paradise, NV	84% [81 to 87%]	84% [80 to 87%]	84% [81 to 88%]
Boston-Cambridge-Newton, MA-NH	94% [91 to 96%]	93% [89 to 95%]	93% [90 to 96%]
San Diego-Chula Vista-Carlsbad, CA	93% [89 to 95%]	92% [88 to 95%]	92% [89 to 95%]
Charlotte-Concord-Gastonia, NC-SC	90% [87 to 93%]	89% [86 to 92%]	90% [86 to 93%]
San Antonio-New Braunfels, TX	86% [82 to 89%]	85% [80 to 88%]	85% [81 to 89%]
Jacksonville, FL	90% [87 to 93%]	90% [86 to 93%]	90% [87 to 93%]
New Orleans-Metairie, LA	88% [85 to 92%]	88% [84 to 91%]	88% [85 to 91%]
Memphis, TN-MS-AR	91% [88 to 93%]	90% [87 to 93%]	91% [88 to 93%]
Seattle-Tacoma-Bellevue, WA	93% [91 to 95%]	92% [88 to 95%]	93% [90 to 95%]
Austin-Round Rock-Georgetown, TX	88% [85 to 91%]	87% [84 to 90%]	88% [85 to 91%]
Indianapolis-Carmel-Anderson, IN	86% [82 to 89%]	85% [81 to 89%]	86% [82 to 89%]
Cincinnati, OH-KY-IN	83% [77 to 88%]	82% [75 to 87%]	83% [76 to 87%]
Columbus, OH	88% [84 to 92%]	87% [83 to 91%]	88% [84 to 91%]
Baton Rouge, LA	87% [84 to 91%]	87% [83 to 90%]	87% [83 to 91%]
Sacramento-Roseville-Folsom, CA	90% [87 to 93%]	89% [86 to 93%]	90% [87 to 93%]
Cleveland-Elyria, OH	90% [87 to 93%]	89% [86 to 92%]	90% [86 to 93%]
Total	92% [92 to 93%]	91% [90 to 93%]	92% [91 to 93%]

Table S14: Projected Knowledge of Status in 2025 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2025	Prolonged Barriers to Care, 2025	Rapid Resumption of Care, 2025
New York-Newark-Jersey City, NY-NJ-PA	96% [95 to 97%]	96% [95 to 97%]	96% [95 to 97%]
Miami-Fort Lauderdale-Pompano Beach, FL	93% [90 to 97%]	93% [89 to 96%]	93% [90 to 97%]
Los Angeles-Long Beach-Anaheim, CA	93% [90 to 94%]	92% [90 to 94%]	93% [90 to 95%]
Atlanta-Sandy Springs-Alpharetta, GA	93% [90 to 96%]	93% [89 to 95%]	93% [90 to 96%]
Houston-The Woodlands-Sugar Land, TX	90% [87 to 93%]	89% [86 to 92%]	90% [87 to 93%]
Dallas-Fort Worth-Arlington, TX	92% [89 to 94%]	92% [89 to 94%]	92% [89 to 94%]
Chicago-Naperville-Elgin, IL-IN-WI	94% [91 to 96%]	94% [91 to 96%]	94% [91 to 96%]
Washington-Arlington-Alexandria, DC-VA-MD-WV	97% [96 to 98%]	97% [96 to 98%]	97% [96 to 98%]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	96% [94 to 98%]	96% [94 to 98%]	96% [94 to 98%]
Orlando-Kissimmee-Sanford, FL	93% [90 to 95%]	92% [89 to 95%]	93% [89 to 95%]
San Francisco-Oakland-Berkeley, CA	96% [93 to 98%]	96% [93 to 98%]	96% [94 to 98%]
Phoenix-Mesa-Chandler, AZ	91% [87 to 94%]	91% [87 to 94%]	91% [87 to 94%]
Tampa-St. Petersburg-Clearwater, FL	92% [87 to 95%]	92% [87 to 95%]	92% [87 to 95%]
Riverside-San Bernardino-Ontario, CA	91% [85 to 95%]	91% [85 to 95%]	91% [85 to 95%]
Detroit-Warren-Dearborn, MI	92% [88 to 95%]	91% [87 to 95%]	92% [88 to 95%]
Baltimore-Columbia-Towson, MD	97% [95 to 98%]	97% [95 to 98%]	97% [95 to 98%]
Las Vegas-Henderson-Paradise, NV	87% [84 to 91%]	87% [83 to 91%]	87% [84 to 91%]
Boston-Cambridge-Newton, MA-NH	95% [91 to 97%]	95% [91 to 97%]	95% [91 to 97%]
San Diego-Chula Vista-Carlsbad, CA	94% [91 to 97%]	94% [91 to 96%]	94% [91 to 96%]
Charlotte-Concord-Gastonia, NC-SC	91% [87 to 94%]	91% [87 to 94%]	91% [87 to 94%]
San Antonio-New Braunfels, TX	88% [83 to 91%]	87% [83 to 91%]	87% [83 to 91%]
Jacksonville, FL	92% [87 to 95%]	92% [87 to 95%]	92% [87 to 95%]
New Orleans-Metairie, LA	90% [87 to 94%]	90% [86 to 93%]	90% [86 to 94%]
Memphis, TN-MS-AR	93% [90 to 96%]	93% [89 to 95%]	93% [90 to 96%]
Seattle-Tacoma-Bellevue, WA	95% [91 to 97%]	94% [90 to 97%]	95% [91 to 97%]
Austin-Round Rock-Georgetown, TX	90% [87 to 93%]	90% [86 to 93%]	90% [87 to 93%]
Indianapolis-Carmel-Anderson, IN	88% [83 to 91%]	87% [83 to 91%]	88% [83 to 91%]
Cincinnati, OH-KY-IN	85% [78 to 90%]	84% [77 to 90%]	84% [77 to 90%]
Columbus, OH	90% [85 to 93%]	89% [85 to 93%]	90% [85 to 93%]
Baton Rouge, LA	89% [85 to 93%]	89% [85 to 93%]	89% [85 to 93%]
Sacramento-Roseville-Folsom, CA	91% [87 to 94%]	91% [87 to 94%]	91% [87 to 94%]
Cleveland-Elyria, OH	92% [89 to 95%]	92% [88 to 94%]	92% [88 to 95%]
Total	93% [92 to 95%]	93% [92 to 95%]	93% [92 to 95%]

4.5 Projected Viral Suppression in 2020, 2021, and 2025

Table S15: Projected Viral Suppression in 2020 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2020	Prolonged Barriers to Care, 2020	Rapid Resumption of Care, 2020
New York-Newark-Jersey City, NY-NJ-PA	80% [79 to 81%]	72% [64 to 80%]	72% [64 to 80%]
Miami-Fort Lauderdale-Pompano Beach, FL	65% [62 to 68%]	58% [52 to 66%]	58% [52 to 66%]
Los Angeles-Long Beach-Anaheim, CA	66% [64 to 68%]	60% [53 to 67%]	60% [53 to 67%]
Atlanta-Sandy Springs-Alpharetta, GA	56% [52 to 59%]	50% [44 to 57%]	50% [44 to 57%]
Houston-The Woodlands-Sugar Land, TX	67% [65 to 69%]	60% [53 to 67%]	60% [53 to 67%]
Dallas-Fort Worth-Arlington, TX	70% [68 to 73%]	63% [56 to 71%]	63% [56 to 71%]
Chicago-Naperville-Elgin, IL-IN-WI	52% [50 to 54%]	47% [41 to 52%]	47% [41 to 52%]
Washington-Arlington-Alexandria, DC-VA-MD-WV	76% [73 to 79%]	68% [61 to 77%]	68% [61 to 77%]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	62% [58 to 65%]	55% [48 to 62%]	55% [48 to 62%]
Orlando-Kissimmee-Sanford, FL	68% [64 to 72%]	61% [53 to 70%]	61% [54 to 70%]
San Francisco-Oakland-Berkeley, CA	80% [78 to 82%]	72% [64 to 80%]	72% [64 to 80%]
Phoenix-Mesa-Chandler, AZ	69% [64 to 74%]	62% [54 to 71%]	62% [54 to 71%]
Tampa-St. Petersburg-Clearwater, FL	71% [67 to 75%]	64% [56 to 72%]	64% [56 to 72%]
Riverside-San Bernardino-Ontario, CA	73% [71 to 76%]	66% [58 to 74%]	66% [58 to 74%]
Detroit-Warren-Dearborn, MI	80% [77 to 82%]	72% [63 to 80%]	72% [63 to 80%]
Baltimore-Columbia-Towson, MD	73% [70 to 77%]	66% [58 to 74%]	66% [58 to 74%]
Las Vegas-Henderson-Paradise, NV	55% [51 to 58%]	49% [43 to 56%]	49% [43 to 56%]
Boston-Cambridge-Newton, MA-NH	75% [72 to 79%]	68% [60 to 76%]	68% [60 to 76%]
San Diego-Chula Vista-Carlsbad, CA	77% [74 to 79%]	69% [61 to 77%]	69% [61 to 77%]
Charlotte-Concord-Gastonia, NC-SC	69% [65 to 74%]	62% [54 to 71%]	62% [54 to 71%]
San Antonio-New Braunfels, TX	68% [65 to 71%]	61% [54 to 69%]	61% [54 to 69%]
Jacksonville, FL	70% [66 to 75%]	63% [55 to 72%]	63% [55 to 72%]
New Orleans-Metairie, LA	73% [66 to 78%]	65% [56 to 74%]	65% [56 to 74%]
Memphis, TN-MS-AR	69% [63 to 76%]	62% [54 to 71%]	62% [54 to 72%]
Seattle-Tacoma-Bellevue, WA	87% [86 to 88%]	78% [70 to 87%]	78% [70 to 87%]
Austin-Round Rock-Georgetown, TX	80% [77 to 83%]	72% [64 to 80%]	72% [64 to 80%]
Indianapolis-Carmel-Anderson, IN	71% [67 to 75%]	63% [56 to 72%]	64% [56 to 72%]
Cincinnati, OH-KY-IN	54% [49 to 60%]	48% [41 to 56%]	49% [41 to 57%]
Columbus, OH	70% [65 to 75%]	63% [55 to 72%]	63% [55 to 72%]
Baton Rouge, LA	70% [65 to 75%]	63% [55 to 71%]	63% [55 to 71%]
Sacramento-Roseville-Folsom, CA	75% [72 to 78%]	67% [60 to 75%]	67% [60 to 75%]
Cleveland-Elyria, OH	70% [64 to 76%]	63% [54 to 72%]	63% [54 to 72%]
Total	70% [69 to 71%]	63% [57 to 70%]	63% [57 to 70%]

Table S16: Projected Viral Suppression in 2021 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2021	Prolonged Barriers to Care, 2021	Rapid Resumption of Care, 2021
New York-Newark-Jersey City, NY-NJ-PA	81% [79 to 83%]	73% [65 to 81%]	73% [65 to 81%]
Miami-Fort Lauderdale-Pompano Beach, FL	66% [63 to 70%]	59% [52 to 67%]	60% [52 to 68%]
Los Angeles-Long Beach-Anaheim, CA	67% [64 to 70%]	60% [53 to 68%]	60% [54 to 68%]
Atlanta-Sandy Springs-Alpharetta, GA	57% [52 to 62%]	51% [44 to 58%]	51% [44 to 58%]
Houston-The Woodlands-Sugar Land, TX	68% [65 to 71%]	61% [54 to 68%]	61% [54 to 68%]
Dallas-Fort Worth-Arlington, TX	71% [68 to 75%]	64% [56 to 72%]	64% [56 to 72%]
Chicago-Naperville-Elgin, IL-IN-WI	52% [49 to 55%]	46% [41 to 53%]	47% [41 to 53%]
Washington-Arlington-Alexandria, DC-VA-MD-WV	78% [74 to 81%]	70% [61 to 79%]	70% [61 to 79%]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	63% [58 to 67%]	56% [48 to 64%]	56% [48 to 64%]
Orlando-Kissimmee-Sanford, FL	70% [64 to 75%]	63% [54 to 72%]	63% [55 to 72%]
San Francisco-Oakland-Berkeley, CA	81% [78 to 84%]	73% [65 to 81%]	73% [65 to 81%]
Phoenix-Mesa-Chandler, AZ	71% [64 to 76%]	64% [54 to 74%]	64% [55 to 74%]
Tampa-St. Petersburg-Clearwater, FL	73% [68 to 77%]	65% [57 to 74%]	65% [57 to 74%]
Riverside-San Bernardino-Ontario, CA	75% [71 to 78%]	67% [59 to 75%]	67% [59 to 75%]
Detroit-Warren-Dearborn, MI	81% [77 to 84%]	73% [64 to 82%]	73% [64 to 82%]
Baltimore-Columbia-Towson, MD	75% [71 to 79%]	68% [59 to 77%]	68% [59 to 77%]
Las Vegas-Henderson-Paradise, NV	58% [51 to 63%]	52% [43 to 60%]	52% [43 to 60%]
Boston-Cambridge-Newton, MA-NH	76% [72 to 80%]	68% [60 to 77%]	68% [60 to 77%]
San Diego-Chula Vista-Carlsbad, CA	79% [74 to 82%]	70% [62 to 79%]	71% [62 to 79%]
Charlotte-Concord-Gastonia, NC-SC	71% [66 to 76%]	63% [55 to 73%]	64% [55 to 73%]
San Antonio-New Braunfels, TX	69% [65 to 72%]	62% [54 to 70%]	62% [54 to 70%]
Jacksonville, FL	71% [66 to 77%]	64% [55 to 74%]	64% [56 to 74%]
New Orleans-Metairie, LA	74% [67 to 80%]	67% [56 to 76%]	67% [56 to 76%]
Memphis, TN-MS-AR	71% [63 to 78%]	64% [54 to 74%]	64% [55 to 74%]
Seattle-Tacoma-Bellevue, WA	87% [86 to 88%]	78% [70 to 87%]	79% [70 to 87%]
Austin-Round Rock-Georgetown, TX	81% [77 to 84%]	73% [64 to 81%]	73% [64 to 82%]
Indianapolis-Carmel-Anderson, IN	72% [67 to 77%]	65% [56 to 74%]	65% [56 to 74%]
Cincinnati, OH-KY-IN	56% [49 to 63%]	50% [42 to 60%]	50% [42 to 60%]
Columbus, OH	72% [66 to 77%]	64% [55 to 73%]	64% [55 to 73%]
Baton Rouge, LA	72% [66 to 77%]	64% [55 to 74%]	64% [56 to 74%]
Sacramento-Roseville-Folsom, CA	76% [73 to 80%]	68% [60 to 77%]	68% [60 to 77%]
Cleveland-Elyria, OH	73% [65 to 79%]	65% [55 to 76%]	66% [55 to 76%]
Total	72% [69 to 74%]	64% [57 to 72%]	64% [57 to 72%]

Table S17: Projected Viral Suppression in 2025 by Metropolitan Statistical Area, Absent Pandemic, Prolonged Barriers to Care, and Rapid Resumption of Care Scenarios

Location	Absent Pandemic, 2025	Prolonged Barriers to Care, 2025	Rapid Resumption of Care, 2025
New York-Newark-Jersey City, NY-NJ-PA	83% [80 to 86%]	83% [80 to 86%]	83% [80 to 86%]
Miami-Fort Lauderdale-Pompano Beach, FL	68% [63 to 74%]	68% [63 to 75%]	68% [63 to 75%]
Los Angeles-Long Beach-Anaheim, CA	68% [64 to 74%]	68% [64 to 74%]	68% [64 to 74%]
Atlanta-Sandy Springs-Alpharetta, GA	58% [52 to 66%]	58% [52 to 67%]	58% [53 to 67%]
Houston-The Woodlands-Sugar Land, TX	69% [65 to 76%]	70% [65 to 76%]	70% [65 to 76%]
Dallas-Fort Worth-Arlington, TX	73% [68 to 78%]	73% [68 to 79%]	73% [68 to 79%]
Chicago-Naperville-Elgin, IL-IN-WI	51% [46 to 56%]	51% [46 to 57%]	51% [46 to 57%]
Washington-Arlington-Alexandria, DC-VA-MD-WV	80% [74 to 85%]	80% [74 to 85%]	80% [74 to 85%]
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	64% [57 to 72%]	64% [57 to 72%]	64% [57 to 72%]
Orlando-Kissimmee-Sanford, FL	71% [64 to 79%]	71% [64 to 79%]	71% [64 to 79%]
San Francisco-Oakland-Berkeley, CA	82% [79 to 86%]	82% [79 to 86%]	82% [79 to 86%]
Phoenix-Mesa-Chandler, AZ	73% [64 to 82%]	73% [64 to 82%]	73% [64 to 82%]
Tampa-St. Petersburg-Clearwater, FL	74% [68 to 81%]	74% [68 to 81%]	74% [68 to 81%]
Riverside-San Bernardino-Ontario, CA	76% [71 to 82%]	76% [71 to 82%]	76% [71 to 82%]
Detroit-Warren-Dearborn, MI	83% [78 to 87%]	83% [78 to 87%]	83% [78 to 87%]
Baltimore-Columbia-Towson, MD	77% [71 to 84%]	77% [71 to 84%]	77% [71 to 84%]
Las Vegas-Henderson-Paradise, NV	61% [51 to 73%]	61% [51 to 73%]	61% [51 to 73%]
Boston-Cambridge-Newton, MA-NH	77% [72 to 82%]	77% [72 to 82%]	77% [72 to 82%]
San Diego-Chula Vista-Carlsbad, CA	80% [74 to 86%]	80% [74 to 85%]	80% [74 to 85%]
Charlotte-Concord-Gastonia, NC-SC	72% [66 to 80%]	73% [66 to 80%]	73% [66 to 80%]
San Antonio-New Braunfels, TX	70% [65 to 76%]	70% [65 to 76%]	70% [65 to 76%]
Jacksonville, FL	73% [66 to 80%]	73% [67 to 80%]	73% [67 to 80%]
New Orleans-Metairie, LA	76% [68 to 83%]	76% [68 to 83%]	76% [68 to 83%]
Memphis, TN-MS-AR	73% [64 to 82%]	73% [64 to 82%]	73% [64 to 82%]
Seattle-Tacoma-Bellevue, WA	88% [87 to 89%]	88% [86 to 89%]	88% [86 to 89%]
Austin-Round Rock-Georgetown, TX	82% [78 to 86%]	82% [78 to 86%]	82% [78 to 86%]
Indianapolis-Carmel-Anderson, IN	74% [68 to 81%]	74% [68 to 81%]	74% [68 to 81%]
Cincinnati, OH-KY-IN	58% [49 to 70%]	58% [50 to 70%]	58% [50 to 70%]
Columbus, OH	73% [66 to 81%]	73% [66 to 81%]	73% [66 to 81%]
Baton Rouge, LA	74% [67 to 81%]	74% [66 to 81%]	74% [66 to 81%]
Sacramento-Roseville-Folsom, CA	77% [73 to 83%]	77% [73 to 83%]	77% [73 to 83%]
Cleveland-Elyria, OH	76% [65 to 85%]	76% [65 to 84%]	76% [65 to 84%]
Total	73% [69 to 78%]	73% [70 to 78%]	73% [70 to 78%]

5 Model Structure and Differential Equations

5.1 Terminology

- In general, we partition the population into A age brackets (indexed $a = 1, ..., A$), R races (indexed $r = 1, ..., R$), S sex/sexual behavioral categories (indexed $s = 1, ..., S$), and k states of intravenous drug use (indexed $k = 1, ..., K$).
- For each stratum a, r, s, k of age $\times$ race $\times$ sex/sexual behavior $\times$ IV drug use status, we define seven states with respect to HIV status.
- We let $U_{a,r,s,k}(t)$ denote those within the stratum who are uninfected
- We let $IA_{a,r,s,k}$ and $IC_{a,r,s,k}$ denote those ***i**nfected* with hiv but unaware of their diagnosis with ***a**cute* and ***c**hronic* HIV respectively
- We let $PA_{a,r,s,k}$ and $PC_{a,r,s,k}$ denote those infected with HIV, unaware of their diagnosis, but enrolled in a ***P**rEP* with ***a**cute* and ***c**hronic* HIV respectively
- We let $DA_{a,r,s,k}$ and $DC_{a,r,s,k}$ denote those aware of their ***d**iagnosis* with ***a**cute* and ***c**hronic* HIV respectively
- We assume there are M modes of HIV transmission, indexed $1, ..., m$. In this work, $M = 2$ (sexual and intravenous)

5.1.1 Partitions of Age, Race, Sex/Sexual Behavior, and IV Drug Use

The terminology above allows for an arbitrary number of partitions by age, race, sex/sexual behavior, and IV drug use status. In this work, we use the following partitions:

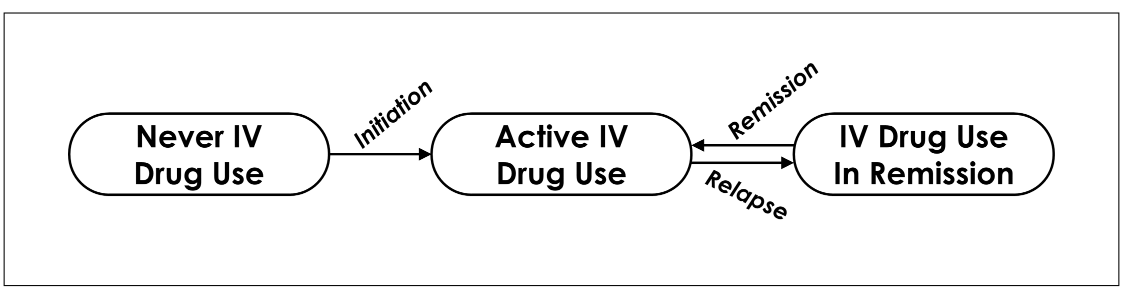
5.1.1.1 Age To align with CDC reporting, we split the adult population into age strata of 13-24yo, 25-34yo, 35-44yo, 45-54yo, and $\geq$55 years old.

5.1.1.2 Race We split the population into three race strata: Black, Hispanic, and Other (non-Black/non-Hispanic), since Black and Hispanic individuals account for a disproportionate number of new HIV infections.

5.1.1.3 Sex/Sexual Behavior We separate the population into three strata vis-a-vis sex and sexual behaviors: female, heterosexual male, and men who have sex with men (MSM). In combination with IV drug use strata (below), this allows us to fully represent all risk categories captured by the CDC (male and female heterosexual contact, MSM, heterosexual IV drug use, and MSM plus IV drug use).

5.1.1.4 Intravenous Drug Use We partition strata of age, sex/sexual behavior, and race into 3 strata with respect to IV drug use: "Never Use", "Active Use", and "IV Drug Use in Remission". As shown in the figure below, there are three transitions possible with respect to IV drug use: *initiation* of use, *remission* from use, and *relapse*:

Figure S8: IV Drug Use Transitions



5.1.2 Time-Varying Parameters

Many of the parameters in our differential equations are time-varying. We present the differential equations here using general formulations for time-varying parameters (e.g., $\theta(t)$ for mortality rate). In section 8 - "Functional Forms for Parameters" - we present the specific functional forms we used to allow parameters to vary over time.

5.2 HIV Transmission

For shorthand, here we will replace a, r, s, k by i and j to index strata of age $\times$ race $\times$ sex/sexual behavior $\times$ IV drug use, where there are $N = A \cdot R \cdot S \cdot K$ total strata $(i, j = 1, ..., N)$

The rate of new infections into stratum i at time t - denoted $\Delta_i(t)$ - is the sum of the rates of new infections by each of the M modes of transmission:

$$\Delta_i(t) = \sum_{m=1}^{M} \Delta_{i,m}(t) \tag{1}$$

where $\Delta_{i,m}(t)$ is the rate of new infections into stratum i by transmission mode m at time t, which is the sum over all strata j of the rate of new infections into stratum i from contact with stratum j via mode m of transmission:

$$\Delta_{i,m}(t) = \sum_{j=1}^{N} \Delta_{i,j,m}(t) \tag{2}$$

where $\Delta_{i,j,m}(t)$ is the rate of new infections in stratum i due to contact with those infected in stratum j via a mode of transmission m at time t. Broadly speaking, this is the product of:

- The *transmissibility* from stratum j at time t, which is a function of the prevalence of unsuppressed PWH in the stratum.
- The proportion of stratum i's partners who come from stratum j (for transmission mode m) at time t, denoted $\Phi_{i,j,m}(t)$
- The rate of transmission from stratum j to stratum i via mode m at time t, denoted $\Gamma_{i,j,m}(t)$
- The *susceptibility* of stratum i to infection at time t (in this work, this is a function of PrEP coverage within the stratum)

$$\Delta_{i,j,m} = transmissibility_{j,m}(t) \times \Phi_{i,j,m}(t) \times \Gamma_{i,j,m}(t) \times susceptibility_{i,m}(t) \tag{3}$$

We describe *transmissibility* and *susceptibility* in further detail:

5.2.1 Transmissibility

The transmissibility of HIV from stratum j via mode of transmission m at time t is a function of the prevalence of unsuppressed HIV in stratum j, allowing for PWH in the acute phase of HIV to transmit more and for those who are diagnosed to reduce transmission behaviors:

$$transmissibility_{j,m}(t) = \frac{\eta \cdot IA_j(t) + IC_j(t) + \eta \cdot PA_j(t) + PC_j(t) + \eta \cdot \upsilon_j(t) \cdot DA_j(t) \cdot [1 - \rho_j(t)] + \upsilon_j(t) \cdot DC_j(t) \cdot [1 - \rho_j(t)]}{U_j(t) + IA_j(t) + IC_j(t) + PA_j(t) + PC_j(t) + DA_j(t) + DC_j(t)} \tag{4}$$

where

- η is the ratio of transmissibility in the acute phase of HIV relative to the chronic phase
- $\rho_j(t)$ is the proportion of diagnosed PWH in stratum j who are virally suppressed at time t
- $\upsilon_j(t)$ is the degree (relative rate) to which PWH who are aware of their diagnosis reduce their transmission behaviors, on average, relative to PWH who are unaware of their diagnosis

5.2.2 Susceptibility

$$susceptibility_{i,m}(t) = [1 - \pi_i(t)] + \pi_i(t) \times \kappa_i \tag{5}$$

- $\pi_i(t)$ is the proportion uninfected individuals at risk for HIV in stratum i at time t who are enrolled in a PrEP program
- κ_i is the relative risk of HIV infection for those on PrEP (relative to no PrEP) in stratum i

5.3 Uninfected $(U_{a,r,s,k}(t))$

The inflows into each stratum a, r, s, k of uninfected are those entering the model at the youngest age bracket or aging into age stratum a and those moving into IV drug use state k. The outflows are those who become infected with HIV, as well as those who die, age out of age stratum a, or move out of IV drug use state k.

$$\begin{aligned}
\frac{\partial U_{a,r,s,k}(t)}{\partial t} &= \mathbb{1}_{a=1} \times \lambda_r \times P_r(t) + \mathbb{1}_{a>1} \times \alpha^U_{a-1,r,s,k}(t) \times U_{a-1,r,s,k}(t) \\
&+ \mathbb{1}_{k=active_use} \times [\zeta_{a,r,s}(t) \times U_{a,r,s,never_use}(t) + \xi_{a,r,s}(t) \times U_{a,r,s,prior_use}(t)] \\
&\quad + \mathbb{1}_{k=prior_use} \times \psi_{a,r,s}(t) \times U_{a,r,s,active_use}(t) \\
&- \Delta_{a,r,s,k}(t) \\
&- \theta^G_{a,r,s,k} \times U_{a,r,s,k}(t) - \mathbb{1}_{k=active_use} \times \theta^{IDU} \times U_{a,r,s,k}(t) \\
&- \alpha^U_{a,r,s,k}(t) \times U_{a,r,s,k}(t) \\
&- U_{a,r,s,k}(t) \times \left[\mathbb{1}_{k=never_use} \times \zeta_{a,r,s}(t) + \mathbb{1}_{k=active_use} \times \psi_{a,r,s}(t) + \mathbb{1}_{k=prior_use} \times \xi_{a,r,s}(t)\right]
\end{aligned}$$

where

- $\mathbb{1}_{a=1}$ evaluates to 1 if a is the first age bracket and 0 otherwise, and $\mathbb{1}_{a>1}$ evaluates to 0 if a is the first age bracket and 1 otherwise
- $\lambda_(t)$ denotes the birth rate for race r at time t
- $P_r(t)$ is the total size of all strata where race = r at time t. i.e.

$$P_r(t) = \sum_{a,s,k} U_{a,r,s,k}(t) + IA_{a,r,s,k}(t) + IC_{a,r,s,k}(t) + PA_{a,r,s,k}(t) + PC_{a,r,s,k}(t) + DA_{a,r,s,k}(t) + DC_{a,r,s,k}(t)$$

- $\alpha^U_{a-1,r,s,k}$ denotes the aging rate at time t of uninfected individuals in the age stratum before a - the average rate at which uninfected individuals move from age stratum $a-1$ to a
- $\mathbb{1}_{k=active\_use}$ evaluates to 1 if k denotes a compartment of active IV drug use and 0 otherwise, and $\mathbb{1}_{k=prior\_use}$ evaluates to 1 if k denotes a compartment of prior IV drug use
- $\zeta_{a,r,s}(t)$ denotes the rate of first-time initiation of IV drug use at time t in stratum a, r, s
- $\xi_{a,r,s}(t)$ denotes the rate of relapse into IV drug use among prior users of IV drugs at time t in stratum a, r, s
- $\psi_{a,r,s}(t)$ denotes the rate of remission of IV drug use among active users at time t in stratum a, r, s
- $U_{a,r,s,never\_use}$, $U_{a,r,s,prior\_use}$, $U_{a,r,s,active\_use}$ denote the compartments with the same age, race, and sex/sexual behavior as a, r, s, k but whose IV drug use stratum is "never use", "prior use", or "active use" respectively
- $\Delta_{a,r,s,k}(t)$ denotes the number of new HIV infections in stratum a, r, s, k at time t. This is detailed in Section 5.2 on page 36
- $\theta^G_{a,r,s,k}$ denotes the general mortality rate of individuals in stratum a, r, s, k
- θ^{IDU} denotes the excess mortality rate due to active IV drug use
- $\alpha^U_{a,r,s,k}(t)$ denotes the aging rate at time t for uninfected individuals in stratum a, r, s, k

5.4 Undiagnosed, Acute HIV $(IA_{a,r,s,k}(t))$

The inflows into each stratum a, r, s, k of acute, undiagnosed HIV are the new infections among those who were not on PrEP, those aging into age stratum a, and those moving into IV drug use state k. The outflows are those who get diagnosed or progress to chronic HIV, as well as those who die (from HIV or other causes), age out of age stratum a, or move out of IV drug use state k.

$$
\begin{aligned}
\frac{\partial IA_{a,r,s,k}(t)}{\partial t} &= \Delta_{a,r,s,k}(t) \times [1 - \mu_{a,r,s,k}(t)] \\
&+ \mathbb{1}_{a>1} \times \alpha^H_{a-1,r,s,k}(t) \times IA_{a-1,r,s,k}(t) \\
&+ \mathbb{1}_{k=active\_use} \times [\zeta_{a,r,s}(t) \times IA_{a,r,s,never\_use}(t) + \xi_{a,r,s}(t) \times IA_{a,r,s,prior\_use}(t)] \\
&\quad + \mathbb{1}_{k=prior\_use} \times \psi_{a,r,s}(t) \times IA_{a,r,s,active\_use}(t) \\
&- \beta_{a,r,s,k}(t) \times IA_{a,r,s,k}(t) \\
&- \tau \times IA_{a,r,s,k}(t) \\
&- \theta^{HIV}(t) \times IA_{a,r,s,k}(t) - \theta^G_{a,r,s,k} \times IA_{a,r,s,k}(t) - \mathbb{1}_{k=active\_use} \times \theta^{IDU} \times IA_{a,r,s,k}(t) \\
&- \alpha^H_{a,r,s,k}(t) \times IA_{a,r,s,k}(t) \\
&- IA_{a,r,s,k}(t) \times \left[\mathbb{1}_{k=never\_use} \times \zeta_{a,r,s}(t) + \mathbb{1}_{k=active\_use} \times \psi_{a,r,s}(t) + \mathbb{1}_{k=prior\_use} \times \xi_{a,r,s}(t)\right]
\end{aligned}
$$

where

- $\mu_{a,r,s,k}(t)$ denotes the proportion of new infections in stratum a, r, s, k at time t that were among individuals on PrEP.

  $$\mu_{a,r,s,k}(t) = \frac{\pi_{a,r,s,k}(t) \times \kappa_{a,r,s,k}}{[1 - \pi_{a,r,s,k}(t)] + \pi_{a,r,s,k}(t) \times \kappa_{a,r,s,k}}$$

  where $\pi_{a,r,s,k}(t)$ is the proportion uninfected individuals at risk for HIV in stratum a, r, s, k at time t who are enrolled in a PrEP program, and $\kappa_{a,r,s,k}$ is the relative risk of HIV infection for PrEP use in stratum a, r, s, k
- $\alpha^H_{a-1,r,s,k}(t)$ denotes the aging rate of HIV-positive individuals in the age stratum prior to a
- $\beta_{a,r,s,k}(t)$ is the rate of diagnosis of HIV for those in stratum a, r, s, k at time t
- τ is the rate of progression from acute to chronic HIV
- $\theta^{HIV}(t)$ is the (time-varying) rate of excess mortality from unsuppressed HIV
- $\alpha^H_{a,r,s,k}(t)$ is the aging rate at time t for PWH in stratum a, r, s, k

5.5 Undiagnosed, Acute HIV, Enrolled in a PrEP Program $\left(PA_{a,r,s,k}(t)\right)$

The inflows into each stratum a, r, s, k of acute, undiagnosed HIV among those enrolled in a PrEP program are the proportion of new infections among those who were on PrEP, those aging into age stratum a, and those moving into IV drug use state k. The outflows are those who get diagnosed or progress to chronic HIV, as well as those who die (from HIV or other causes), age out of age stratum a, or move out of IV drug use state k.

$$
\begin{aligned}
\frac{\partial PA_{a,r,s,k}(t)}{\partial t} &= \Delta_{a,r,s,k}(t) \times \mu_{a,r,s,k}(t) \\
&+ \mathbb{1}_{a>1} \times \alpha^H_{a-1,r,s,k}(t) \times PA_{a-1,r,s,k}(t) \\
&+ \mathbb{1}_{k=active\_use} \times [\zeta_{a,r,s}(t) \times PA_{a,r,s,never\_use}(t) + \xi_{a,r,s}(t) \times PA_{a,r,s,prior\_use}(t)] \\
&\quad + \mathbb{1}_{k=prior\_use} \times \psi_{a,r,s}(t) \times PA_{a,r,s,active\_use}(t) \\
&- \beta^{PrEP} \times PA_{a,r,s,k}(t) \\
&- \tau \times PA_{a,r,s,k}(t) \\
&- \theta^{HIV}(t) \times PA_{a,r,s,k}(t) - \theta^G_{a,r,s,k} \times PA_{a,r,s,k}(t) - \mathbb{1}_{k=active\_use} \times \theta^{IDU} \times PA_{a,r,s,k}(t) \\
&- \alpha^H_{a,r,s,k}(t) \times PA_{a,r,s,k}(t) \\
&- PA_{a,r,s,k}(t) \times \left[\mathbb{1}_{k=never\_use} \times \zeta_{a,r,s}(t) + \mathbb{1}_{k=active\_use} \times \psi_{a,r,s}(t) + \mathbb{1}_{k=prior\_use} \times \xi_{a,r,s}(t)\right]
\end{aligned}
$$

where

- β^{PrEP} is the rate of diagnosis of HIV among those enrolled in a PrEP program

5.6 Diagnosed, Acute HIV $\left(DA_{a,r,s,k}(t)\right)$

The inflows into each stratum a, r, s, k of acute, diagnosed HIV are new HIV diagnoses among those with undiagnosed, acute HIV (those enrolled in a PrEP program and not), those aging into age stratum a, and those moving into IV drug use state k. The outflows are those who progress to chronic HIV, as well as those who die (from unsuppressed HIV or other causes), age out of age stratum a, or move out of IV drug use state k.

$$
\begin{aligned}
\frac{\partial DA_{a,r,s,k}(t)}{\partial t} &= \beta_{a,r,s,k}(t) \times IA_{a,r,s,k}(t) + \beta^{PrEP} \times PA_{a,r,s,k}(t) \\
&+ \mathbb{1}_{a>1} \times \alpha^H_{a-1,r,s,k}(t) \times DA_{a-1,r,s,k}(t) \\
&+ \mathbb{1}_{k=active\_use} \times [\zeta_{a,r,s}(t) \times DA_{a,r,s,never\_use}(t) + \xi_{a,r,s}(t) \times DA_{a,r,s,prior\_use}(t)] \\
&\quad + \mathbb{1}_{k=prior\_use} \times \psi_{a,r,s}(t) \times DA_{a,r,s,active\_use}(t) \\
&- \beta_{a,r,s,k}(t) \times DA_{a,r,s,k}(t) \\
&- \tau \times DA_{a,r,s,k}(t) \\
&- \theta^{HIV}(t) \times DA_{a,r,s,k}(t) \times [1 - \rho_{a,r,s,k}(t)] - \theta^G_{a,r,s,k} \times DA_{a,r,s,k}(t) - \mathbb{1}_{k=active\_use} \times \theta^{IDU} \times DA_{a,r,s,k}(t) \\
&- \alpha^H_{a,r,s,k}(t) \times DA_{a,r,s,k}(t) \\
&- DA_{a,r,s,k}(t) \times \left[\mathbb{1}_{k=never\_use} \times \zeta_{a,r,s}(t) + \mathbb{1}_{k=active\_use} \times \psi_{a,r,s}(t) + \mathbb{1}_{k=prior\_use} \times \xi_{a,r,s}(t)\right]
\end{aligned}
$$

where

- $\rho_{a,r,s,k}(t)$ is the proportion of those with diagnosed HIV in stratum a, r, s, k who are virally suppressed at time t.

5.7 Undiagnosed, Chronic HIV $\left(IC_{a,r,s,k}(t)\right)$

The inflows into each stratum a, r, s, k of chronic, undiagnosed HIV are those who progress from acute to chronic HIV, those aging into age stratum a, and those moving into IV drug use state k. The outflows are those who get diagnosed, as well as those who die (from HIV or other causes), age out of age stratum a, or move out of IV drug use state k.

$$
\begin{aligned}
\frac{\partial IC_{a,r,s,k}(t)}{\partial t} &= \tau \times IA_{a,r,s,k}(t) \\
&+ \mathbb{1}_{a>1} \times \alpha^H_{a-1,r,s,k}(t) \times IC_{a-1,r,s,k}(t) \\
&+ \mathbb{1}_{k=active\_use} \times [\zeta_{a,r,s}(t) \times IC_{a,r,s,never\_use}(t) + \xi_{a,r,s}(t) \times IC_{a,r,s,prior\_use}(t)] \\
&\quad + \mathbb{1}_{k=prior\_use} \times \psi_{a,r,s}(t) \times IC_{a,r,s,active\_use}(t) \\
&- \beta_{a,r,s,k}(t) \times IC_{a,r,s,k}(t) \\
&- \theta^{HIV}(t) \times IC_{a,r,s,k}(t) - \theta^G_{a,r,s,k} \times IC_{a,r,s,k}(t) - \mathbb{1}_{k=active\_use} \times \theta^{IDU} \times IC_{a,r,s,k}(t) \\
&- \alpha^H_{a,r,s,k}(t) \times IC_{a,r,s,k}(t) \\
&- IC_{a,r,s,k}(t) \times \left[\mathbb{1}_{k=never\_use} \times \zeta_{a,r,s}(t) + \mathbb{1}_{k=active\_use} \times \psi_{a,r,s}(t) + \mathbb{1}_{k=prior\_use} \times \xi_{a,r,s}(t)\right]
\end{aligned}
$$

5.8 Undiagnosed, Chronic HIV, Enrolled in a PrEP Program $\left(PC_{a,r,s,k}(t)\right)$

The inflows into each stratum a, r, s, k of chronic, undiagnosed HIV among those enrolled in a PrEP program are those who progress from acute to chronic HIV, those aging into age stratum a, and those moving into IV drug use state k. The outflows are those who get diagnosed, as well as those who die (from HIV or other causes), age out of age stratum a, or move out of IV drug use state k.

$$
\begin{aligned}
\frac{\partial PC_{a,r,s,k}(t)}{\partial t} &= \tau \times PA_{a,r,s,k}(t) \\
&+ \mathbb{1}_{a>1} \times \alpha^H_{a-1,r,s,k}(t) \times PC_{a-1,r,s,k}(t) \\
&+ \mathbb{1}_{k=active\_use} \times [\zeta_{a,r,s}(t) \times PC_{a,r,s,never\_use}(t) + \xi_{a,r,s}(t) \times PC_{a,r,s,prior\_use}(t)] \\
&\quad + \mathbb{1}_{k=prior\_use} \times \psi_{a,r,s}(t) \times PC_{a,r,s,active\_use}(t) \\
&- \beta^{PrEP} \times PC_{a,r,s,k}(t) \\
&- \theta^{HIV}(t) \times PC_{a,r,s,k}(t) - \theta^G_{a,r,s,k} \times PC_{a,r,s,k}(t) - \mathbb{1}_{k=active\_use} \times \theta^{IDU} \times PC_{a,r,s,k}(t) \\
&- \alpha^H_{a,r,s,k}(t) \times PC_{a,r,s,k}(t) \\
&- PC_{a,r,s,k}(t) \times \left[\mathbb{1}_{k=never\_use} \times \zeta_{a,r,s}(t) + \mathbb{1}_{k=active\_use} \times \psi_{a,r,s}(t) + \mathbb{1}_{k=prior\_use} \times \xi_{a,r,s}(t)\right]
\end{aligned}
$$

5.9 Diagnosed, Chronic HIV $\left(DC_{a,r,s,k}(t)\right)$

The inflows into each stratum a, r, s, k of chronic, diagnosed HIV are new HIV diagnoses among those with undiagnosed, chronic HIV (those enrolled in a PrEP program and not), those who progress from acute to chronic HIV, those aging into age stratum a, and those moving into IV drug use state k. The outflows are those who die (from unsuppressed HIV or other causes), age out of age stratum a, or move out of IV drug use state k.

$$
\begin{aligned}
\frac{\partial DC_{a,r,s,k}(t)}{\partial t} &= \beta_{a,r,s,k}(t) \times IC_{a,r,s,k}(t) + \beta^{PrEP} \times PC_{a,r,s,k}(t) \\
&+ \tau \times DA_{a,r,s,k}(t) \\
&+ \mathbb{1}_{a>1} \times \alpha^{H}_{a-1,r,s,k}(t) \times DC_{a-1,r,s,k}(t) \\
&+ \mathbb{1}_{k=active\_use} \times [\zeta_{a,r,s}(t) \times DC_{a,r,s,never\_use}(t) + \xi_{a,r,s}(t) \times DC_{a,r,s,prior\_use}(t)] \\
&\quad + \mathbb{1}_{k=prior\_use} \times \psi_{a,r,s}(t) \times DC_{a,r,s,active\_use}(t) \\
&- \beta_{a,r,s,k}(t) \times DC_{a,r,s,k}(t) \\
&- \theta^{HIV}(t) \times DC_{a,r,s,k}(t) \times [1 - \rho_{a,r,s,k}(t)] - \theta^{G}_{a,r,s,k} \times DC_{a,r,s,k}(t) - \mathbb{1}_{k=active\_use} \times \theta^{IDU} \times DC_{a,r,s,k}(t) \\
&- \alpha^{H}_{a,r,s,k}(t) \times DC_{a,r,s,k}(t) \\
&- DC_{a,r,s,k}(t) \times \left[\mathbb{1}_{k=never\_use} \times \zeta_{a,r,s}(t) + \mathbb{1}_{k=active\_use} \times \psi_{a,r,s}(t) + \mathbb{1}_{k=prior\_use} \times \xi_{a,r,s}(t)\right]
\end{aligned}
$$

6 Running And Calibrating the Model

6.1 Initializing and Running the Model

We initialize the model with population sizes from 2007, and seed three HIV cases, one to each race, in the stratum of MSM aged 35-44yo.

We let the model start running at 1970 with this initial state, and run forward to 2007. From 1970 to 2007, we keep the sizes of each stratum of age × race × sex/sexual behavior constant; the prevalence of HIV and IV drug use states can vary within these strata. (Fixing strata sizes allowed us to avoid having to replicate birth patterns prior to the 2010-2030 time period).

We continue running the model from 2007 to 2030, without the requirement that strata sizes remain constant.

6.2 Calibration Method

To fit our 131 sampled parameters in each MSA, we use Adaptive Metropolis Sampling, a Markov-chain Monte-Carlo technique first described by Haario et. al.[?] We use a variation of algorithm 5 ("componentwise" sampling) in Andrieu et. al,[?] in which we sample blocks of 1 to 6 parameters at a time in a "blockwise" fashion.

For each iteration of the MCMC, we:

1. Sample the new parameters for the block
2. Run a simulation using the parameters (the new values for parameters in the block, and prior values for parameters not in the block)
3. Compute the likelihood (and prior for the parameters) and accept or reject

6.2.1 Finding Initial Parameter Values

For each location, we developed a set of starting parameter values by manually calibrating transmission rates and age susceptibilities so that the marginal reported diagnoses and prevalence by age, by race, and by risk factor visually approximated the calibration targets. All other parameter values were left at their "best guess" values (the median for parameters following a Log-normal prior).

Using these starting values, we ran an exploratory, single-chain Adaptive Metropolis Sampling Process for 20,000 iterations with a target acceptance rate of 0.10. We discarded the first 10,000 parameter sets and thinned the remainder to every 20th set, yielding 500 parameter sets. For each parameter value, we calculated a mean and standard deviation on the log scale across the 500 values, as well as correlations with all other parameters. We used the resulting Log-Multivariate-Normal distribution to sample initial parameters for the MCMC runs described below.

6.2.2 Likelihood and Priors

In our deterministic, compartmental model, there is a one-to-one correlation between parameters and simulations. The likelihood function can only be computed on a simulation once it has run. Our log-likelihood is actually the sum of ten independent sub-likelihoods, detailed in Section 7.

The prior distributions for parameters are mostly Log-Normal distributions (a few are Logit-Normal or Uniform), as detailed in Table S1.

6.2.3 MCMC Sampling

For each location, we ran four chains, sampling starting parameter values for each chain from the Log-Multivariate-Normal distribution described above in section 6.2.1. For each chain, we ran 50,000 burn-in iterations followed by 50,000 sampling iterations. We thinned to every 200th iteration, leaving us with a set of 1,000 simulations. We used a target acceptance rate of 0.234.

We assessed for convergence using the split-$\hat{r}$ described in Gelman,[?] as well as visual inspection of trace plots for important or poorly mixing parameters.

7 The Likelihood

Our likelihood decomposes into 10 independent likelihoods for each of the 10 calibration targets: new diagnoses, prevalence, HIV mortality, proportion of PWH aware of their diagnosis, proportion of PWH virally suppressed, number of at-risk individuals receiving prescriptions for emtricitabine/tenofovir, probability of receiving an HIV test, prevalence of injection drug use, historical AIDS mortality (prior to 2002), and historical reported diagnoses (1998-2002).

7.1 Calibrating Model Rates to Observed Data: Binomial Likelihood

In general, for each of our outcome targets, we will use some variation of a binomial likelihood that maps the probability of an outcome in stratum i in a simulation to the number of events in reported data.

$$y_{i,t} \sim Binomial(n_t, p_{i,t}) \tag{6}$$

where

- $y_{i,t}$ is the reported outcome in subgroup i at time t
- n_t is the total population size at time t
- $p_{i,t}$ is the simulated outcomes in subgroup i at time t divided by the simulated total population size at time t

Note that we scale our outcome probabilities - even for a subgroup - relative to the total population. For example, if we were calibrating to the number of reported diagnoses in MSM in 2015, $p_{i,t}$ would be the simulated number of new infections among MSM in 2015 divided by the *total* simulated population in 2015. Similarly, the n_t used in our likelihood represents the *total* population, even when calibrating a subgroup.

Formulating the likelihood in this way allows us to avoid conditioning on subgroup numbers that are not known or known imperfectly. For example, the true number of MSM is not recorded by the US census. While estimates are available, they are imprecise and not stratified by race.

In actuality, we use the Normal approximation to the binomial, which is computationally more efficient and allows us to formulate multivariate likelihoods easily:

$$y_{i,t} \sim Normal\Big(n_t \cdot p_{i,t}, n_t \cdot p_{i,t} \cdot (1 - p_{i,t})\Big) \tag{7}$$

7.2 Mapping Outcomes in Stratified Compartments to Reported Marginal Observations

Our model produces estimates of each outcome in 135 strata per year of age (5 brackets), race (Black, Hispanic, Other), sex/sexual behavior (MSM, heterosexual male, female), and IV drug use (never use, active use, prior use). Calibration targets are rarely reported as fully stratified. To calibrate to marginal data, we use a multivariate likelihood which uses matrix multiplication to aggregate strata into marginal subgroups.

To illustrate, we use a simplified example in which a model partitions the population four strata of age (young vs. old) and sex (male vs. female), but calibrates to marginal outcomes at time t: $y_{young,t}$, $y_{old,t}$, $y_{male,t}$, $y_{female,t}$.

We presume that:

$$\begin{aligned}
y_{young,t} &= y_{young,male,t} + y_{young,female,t} \\
y_{old,t} &= y_{old,male,t} + y_{old,female,t} \\
y_{male,t} &= y_{young,male,t} + y_{old,male,t} \\
y_{female,t} &= y_{young,female,t} + y_{old,female,t}
\end{aligned}$$

$y_{young,male,t}$, $y_{young,female,t}$, $y_{old,male,t}$, $y_{old,female,t}$ are not actually reported. However, we formulate the likelihood we would use if they were, using an independent, binomial likelihood for each of the four stratified outcomes:

$$\begin{aligned}
y_{young,male,t} &\sim Binomial(n_t, p_{young,male,t}) \\
y_{young,female,t} &\sim Binomial(n_t, p_{young,female,t}) \\
y_{old,male,t} &\sim Binomial(n_t, p_{old,male,t}) \\
y_{old,female,t} &\sim Binomial(n_t, p_{old,female,t})
\end{aligned}$$

For computational efficiency and to facilitate multivariate formulation, we use the normal approximation to the binomial:

$$\begin{aligned}
y_{young,male,t} &\sim Normal\big(n_t \times p_{young,male,t}, n_t \times p_{young,male,t} \times (1 - p_{young,male,t})\big) \\
y_{young,female,t} &\sim Normal\big(n_t \times p_{young,female,t}, n_t \times p_{young,female,t} \times (1 - p_{young,female,t})\big) \\
y_{old,male,t} &\sim Normal\big(n_t \times p_{old,male,t}, n_t \times p_{old,male,t} \times (1 - p_{old,male,t})\big) \\
y_{old,female,t} &\sim Normal\big(n_t \times p_{old,female,t}, n_t \times p_{old,female,t} \times (1 - p_{old,female,t})\big)
\end{aligned}$$

We write this as a multivariate normal distribution with a mean vector corresponding to the four individual means and a diagonal variance-covariance matrix whose diagonal elements are the four individual variances:

$$\boldsymbol{y_t'} = \begin{bmatrix} y_{young,male,t} \\ y_{young,female,t} \\ y_{old,male,t} \\ y_{old,female,t} \end{bmatrix} \sim Multivariate\text{-}Normal(\boldsymbol{\mu_t}, \boldsymbol{\Sigma_t}) \tag{8}$$

Next, we formulate a matrix, $\boldsymbol{M}$, that maps from the unobserved, stratified outcomes to the marginal outcomes which we do observe:

$$\boldsymbol{y_t} = \begin{bmatrix} y_{young,t} \\ y_{old,t} \\ y_{male,t} \\ y_{female,t} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} y_{young,male,t} \\ y_{young,female,t} \\ y_{old,male,t} \\ y_{old,female,t} \end{bmatrix} = \boldsymbol{M_t} \begin{bmatrix} y_{young,male,t} \\ y_{young,female,t} \\ y_{old,male,t} \\ y_{old,female,t} \end{bmatrix} = \boldsymbol{M_t y_t'} \tag{9}$$

Using this matrix, we can map the likelihood over the unobserved, stratified outcomes to a likelihood over the observed, marginal outcomes:

$$\boldsymbol{y_t} \sim Multivariate\text{-}Normal\big(\boldsymbol{M_t \mu_t}, \boldsymbol{M \Sigma_t M_t^T}\big) \tag{10}$$

This formulation preserves the correlations induced by calibrating to marginal outcomes. For example, if a simulation over-estimated the young, male stratum, we would expect the overestimation of both the total young and overestimation of the total male to be related.

We can extend this approach to formulate a matrix $\boldsymbol{M}$ that maps our 135 strata to any set of marginal outcomes. We can map to two-level marginals (e.g., new diagnoses reported by sex and age bracket).

We can also extend this approach across multiple years by assuming that the errors in any one year are independent of other years:

$$\boldsymbol{y} = \begin{bmatrix} \boldsymbol{y_{t1}} \\ \boldsymbol{y_{t2}} \\ \vdots \\ \boldsymbol{y_{tT}} \end{bmatrix} \sim Multivariate\text{-}Normal\big(\boldsymbol{M\mu}, \boldsymbol{M\Sigma M}^T\big) \tag{11}$$

where

- T is the number of years we include

- $\boldsymbol{\mu} = \begin{bmatrix} \boldsymbol{\mu_{t1}} \\ \boldsymbol{\mu_{t2}} \\ \vdots \\ \boldsymbol{\mu_{tT}} \end{bmatrix}$

- $\boldsymbol{M} = \begin{bmatrix} \boldsymbol{M_{t1}} & \boldsymbol{0} & \dots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{M_{t2}} & \dots & \boldsymbol{0} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{0} & \boldsymbol{0} & \dots & \boldsymbol{M_{tT}} \end{bmatrix}$

- $\boldsymbol{\Sigma} = \begin{bmatrix} \boldsymbol{\Sigma_{t1}} & \boldsymbol{0} & \dots & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{\Sigma_{t2}} & \dots & \boldsymbol{0} \\ \vdots & \vdots & \ddots & \vdots \\ \boldsymbol{0} & \boldsymbol{0} & \dots & \boldsymbol{\Sigma_{tT}} \end{bmatrix}$

7.3 Incorporating Measurement Error

The formulation described in Section 7.2 above captures error that stems from the degree to which model simulations depart from reported outcomes. However, we also consider that reported outcomes are imperfect measures of a "true" outcome, and adjust our likelihoods accordingly. For this formulation, we introduce $y^*_{i,t}$ - the true (unobserved) outcome for subgroup i at time t, and use it to decomponse the relationship between $y_{i,t}$ - the reported outcome - and simulated outcomes.

For every subgroup i and time t, we write:

$$y_{i,t} = y^*_{i,t} + Bias_{i,t} + \epsilon_{i,t} \tag{12}$$

- $y_{i,t}$ is the reported (measured) outcome for subgroup i at time t to which we calibrate
- $y^*_{i,t}$ is the true (unobserved) outcome
- $Bias_{i,t}$ represents the bias. We set this term to zero for most reported outcomes. However, some outcomes are expected to differ systematically from the truth. For example, with respect to HIV mortality, it is known that a small proportion of deaths in PWH are not reported to the National Death Index.[?,?]
- $\epsilon_{i,t}$ The measurement error for outcome $y_{i,t}$

We can vectorize Equation 12

$$\boldsymbol{y} = \boldsymbol{y^*} + \boldsymbol{Bias} + \boldsymbol{\epsilon} \tag{13}$$

We let

$$\boldsymbol{Bias} \sim Multivariate\text{-}Normal\Big(\boldsymbol{B}, \boldsymbol{\Sigma_B}\Big) \tag{14}$$

$$\boldsymbol{\epsilon} \sim Multivariate\text{-}Normal\Big(\boldsymbol{0}, \boldsymbol{\Sigma_\epsilon}\Big) \tag{15}$$

And we replace $\boldsymbol{y}$ in Equation 11 with $\boldsymbol{y^*}$:

$$\boldsymbol{y^*} \sim Multivariate\text{-}Normal\big(\boldsymbol{M\mu}, \boldsymbol{M\Sigma M}^T\big) \tag{16}$$

We can combine Equations 14, 15, and 16 to yield a likelihood that incorporates different sources of error: the degree to which the model deviate from the truth, measurement error of reported outcomes, and bias.

$$\boldsymbol{y} \sim Multivariate\text{-}Normal\Big(\boldsymbol{M\mu} + \boldsymbol{B}, \boldsymbol{M\Sigma M}^T + \boldsymbol{\Sigma_B} + \boldsymbol{\Sigma_\epsilon}\Big) \tag{17}$$

7.3.1 Correlated Measurement Errors

We also allow for measurement errors and bias to be correlated over time. For example, if estimated prevalent HIV cases among MSM are overestimated in 2015, they are likely to be overestimated in 2016 and 2017 when using the same methods.[?] To represent these correlations, we decompose $\boldsymbol{\Sigma_\epsilon}$ and $\boldsymbol{\Sigma_B}$ into a vector of standard deviations, $\boldsymbol{\sigma}$ and a correlation matrix, $\boldsymbol{\Lambda}$:

$$\boldsymbol{\Sigma_\epsilon} = \boldsymbol{\sigma_\epsilon \Lambda_\epsilon \sigma_\epsilon^T} \tag{18}$$
$$\boldsymbol{\Sigma_B} = \boldsymbol{\sigma_B \Lambda_B \sigma_B^T} \tag{19}$$

In most cases, we give $\boldsymbol{\Lambda_\epsilon}$ and $\boldsymbol{\Lambda_B}$ a compound symmetry (AKA exchangeable) structure:

$$\Lambda_{ij} = \begin{cases} 1 & \text{if } i = j \\ \rho & \text{if } i \neq j \end{cases} \tag{20}$$

In general we formulate the standard deviations, σ using a coefficient of variance: $\sigma_{i,t} = y_{i,t} \times cv_{i,t}$. We estimate the coefficients of variance and correlation parameters based off of reported data where possible.

7.4 Reported Diagnoses 2008-2018

7.4.1 Calibration Targets

We calibrate to reported diagnoses from 2008-2018 as reported by the CDC in HIV Atlas[?] and Metropolitan Statistical Area Reports.[?,?,?,?,?,?,?] We fit to total as well as stratified data when available (the years 2010,2011, and 2013-2017):

- Total diagnoses for all years 2008-2018
- Stratified by age × sex for 2010, 2011, and 2013-2017
- Stratified by race × sex for 2010, 2011, and 2013-2017
- Stratified by risk factor × sex for 2010, 2011, and 2013-2017
- Stratified by race × risk factor for 2010, 2011, and 2013-2017

When the sum of stratified diagnoses from MSA reports did not equal the reported total diagnoses from HIV Atlas, we scaled the stratified diagnoses such that they summed to the total, but maintained the relative proportions of the MSA report.

7.4.2 Measurement Error

Because HIV Atlas estimates differed from those in the MSA reports, we were able to estimate the standard deviations of measurement errors by treating the HIV Atlas estimates as truth and the MSA reports as a measured quantity. We formulated the standard deviation as a coefficient of variance multiplied by the estimate, and derived a frequentist maximum likelihood estimate of 0.065 for the coefficient of variance.

Because there was a change in the method of reporting from 2014 to 2015, we assumed that 2008-2014 errors were strongly correlated with a correlation of 0.65, as were 2015-2018 errors, but that errors from the years 2008-2014 had a weaker correlation of 0.25 with errors from 2015-2018.

7.4.3 Likelihood Formulation

Using the error terms above, we formulated a multivariate normal likelihood based off of a binomial (Section 7.1) with a mapping to account for correlations between overlapping strata (Section 7.2) and correlated measurement errors (Section 7.3.1) using the error terms described above.

7.4.4 Variance Inflation

To improve parameter mixing in the MCMC, we inflate the variances for this likelihood by a factor of 4.

7.5 Estimated Prevalence 2008-2018

7.5.1 Calibration Targets

We calibrate to the estimated prevalence (of those aware of their diagnosis) from 2008-2018 as reported by the CDC in HIV Atlas[?] and Metropolitan Statistical Area Reports.[?,?,?,?,?,?,?] We fit to total as well as stratified data when available (the years 2009, 2010, and 2012-2016):

- Total diagnoses for all years 2008-2018
- Stratified by age × sex for 2009, 2010, and 2012-2016
- Stratified by race × sex for 2009, 2010, and 2012-2016
- Stratified by risk factor × sex for 2009, 2010, and 2012-2016
- Stratified by race × risk factor for 2009, 2010, and 2012-2016

When the sum of stratified prevalence from MSA reports did not equal the reported total prevalence from HIV Atlas, we scaled the stratified prevalences such that they summed to the total, but maintained the relative proportions of the MSA report.

7.5.2 Measurement Error

As with reported diagnoses, we were able to estimate the standard deviations of measurement errors by treating the HIV Atlas estimates as truth and the MSA reports as a measured quantity. We formulated the standard deviation as a coefficient of variance multiplied by the estimate, and derived a frequentist maximum likelihood estimate of 0.09 for the coefficient of variance.

Because there was a change in the method of reporting from 2014 to 2015, we assumed that 2008-2013 errors were strongly correlated with a correlation of 0.65, as were 2014-2018 errors, but that errors from the years 2008-2013 had a weaker correlation of 0.25 with errors from 2014-2018.

7.5.3 Likelihood Formulation

As with reported diagnoses, we formulated a multivariate normal likelihood based off of a binomial (Section 7.1) with a mapping to account for correlations between overlapping strata (Section 7.2) and correlated measurement errors (Section 7.3.1) using the error terms described above.

7.5.4 Variance Inflation

To improve parameter mixing in the MCMC and to prevent the likelihood for prevalence from dominating the likelihood for reported diagnoses (prevalence has a much larger p than reported diagnoses, so a much smaller binomial variance), we inflate the variances for this likelihood by a factor that is equal to the square-root of the average total prevalence from 2010-2018 divided by the square-root of the average number of reported diagnoses from 2010-2018.

7.6 Mortality in PWH 2009-2016

7.6.1 Calibration Targets

We calibrate to the mortality among PWH aware of their diagnosis in 2009, 2010, and 2012-2016 as reported by the CDC in Metropolitan Statistical Area Reports.[?,?,?,?,?,?,?] We fit to total mortality as well as mortality stratified by sex.

7.6.2 Measurement Error

We took the standard deviation to be a product of the coefficient of variance and the mortality estimate. We used the same coefficient of variance calculated for prevalence (0.09), as well as correlation coefficients (0.65 for 2009-2013 errors with 2009-2013 errors, 0.65 for 2014-2016 errors with 2014-2016 errors, and 0.25 for 2009-2013 errors with 2014-2016 errors).

7.6.3 Bias

Because a small proportion of deaths in PWH are not captured by the National Death Index,[?,?] we presumed that mortality was biased down by 2.6% with a standard deviation of 1.3%.[?,?]

7.6.4 Likelihood Formulation

We formulate a multivariate normal likelihood analagous to the likelihood for reported diagnoses and mortality, with the addition of the bias term as outlined in Section 7.3.

7.6.5 Variance Inflation

To improve parameter mixing in the MCMC, we inflate the variances for this likelihood by a factor of 2.

7.7 Awareness of Diagnosis Among PWH 2010-2018

7.7.1 Calibration Targets

We calibrate to the proportion of PWH who are aware of their disease. For five MSAs (Houston-The Woodlands-Sugar Land, TX; Los Angeles-Long Beach-Anaheim, CA; Memphis, TN-MS-AR; New York-Newark-Jersey City, NY-NJ-PA; Seattle-Tacoma-Bellevue, WA) estimates of the proportion aware for at least 3 years from 2010-2018 were publicly available from local public health websites. For the remaining 27 MSAs, we used the state-level estimates of proportion aware of their diagnoses available through HIV Atlas.[?] For MSAs that spanned multiple states, we calibrated to the weighted average of the proportion aware, where weights were the population within in the MSA that falls into each state from 2010-2018.

7.7.2 Formulation of Binomial Likelihood Component

For each year t, we postulated that:

$$y_t \sim Binomial(\frac{y_t}{\pi_t}, p_t) \tag{21}$$

where:

- y_t is the prevalence of PWH aware of their diagnosis in year t as reported by the CDC
- π_t represents our calibration target, the proportion of PWH aware of their diagnosis in year t as reported by the CDC or local health department
- $\frac{y_t}{\pi_t}$ is the estimated number of all PWH (both those aware and unaware of their diagnosis) in year t
- p_t is the simulated proportion of PWH aware of their diagnosis in year t

In order to generalize to a multivariate likelihood, we used the normal approximation to the binomial:

$$y_t \sim Normal\Big(\frac{y_t}{\pi_t} \cdot p_t, \frac{x_t}{\pi_t} \cdot p_t \cdot (1 - p_t)\Big) \tag{22}$$

7.7.3 Measurement Error

We included a measurement error as described in section 7.3.1. We assumed that the reported proportion of PWH aware of their diagnosis had a standard deviation of 0.005 when based on county- or MSA-level data data, and a standard deviation of 0.015 when based on state-level data.

We furthermore presumed that measurement errors were correlated across time, using a compound symmetry correlation structure with $\rho = 0.5$

7.7.4 Likelihood Formulation

We incorporated the Binomial component and measurement error into a multivariate normal likelihood as described in 7.2.

7.7.5 Variance Inflation

To improve parameter mixing in the MCMC, we inflate the variances for this likelihood by a factor of 8.

7.8 Viral Suppression Among PWH 2010-2018

The likelihood for suppression had two independent components: a multivariate-normal component targeting the reported proportion of PWH who were suppressed, and a Bernoulli component to weight whether suppression was increasing or decreasing.

7.8.1 Calibration Targets

We calibrated to the proportion of PWH who were suppressed, as reported on local health department websites, for all years between 2010 and 2018 where data were available. If multiple jurisdictions within an MSA reported proportions, we took the weighted average. If no data was available at the county- or MSA-level we used state-level proportions. A total proportion suppressed was available for all 32 MSAs; we also included estimates stratified by age, by race, by sex, and by HIV-acquisition risk factor if they were available.

7.8.2 Binomial Likelihood Component

We formulated a multivariate-normal approximation to a Binomial likelihood, similar to the one detailed in Section 7.1 with the exceptions that (1) the response was the CDC-reported prevalence of HIV multiplied by the reported proportion suppressed and (2) that the n was the simulated prevalence of diagnosed HIV instead of the total population. We used the matrix mapping described in Section 7.2 to account for correlations in overlapping stratifications.

7.8.3 Measurement Error

We included a measurement error as described in section 7.3.1. We assumed that the reported proportion of PWH aware of their diagnosis had a standard deviation of 0.01 when based on county- or MSA-level data data, and a standard deviation of 0.03 when based on state-level data.

We furthermore presumed that measurement errors were correlated across time, using a compound symmetry correlation structure with $\rho = 0.5$

7.8.4 Multivariate Normal Likelihood Formulation

We incorporated the Binomial component and measurement error into a multivariate normal likelihood as described in 7.2.

7.8.5 Bernoulli Likelihood for Increasing vs. Decreasing Suppression

In general, suppression is increasing or stable over time in most locations across most subgroups. In order to discourage solutions where one race or age subgroup had decreasing suppression over time but total suppression followed overall trends (which was possible in locations where stratified data on suppression were unavailable), we also included a Bernoulli likelihood. This likelihood specified that the probability that, for each stratum of age, race, sex, and IV drug use, the probability that simulated suppression had a decreasing slope on the logit scale was 0.05 (which we estimated from the average number of reported suppressed proportions that decreased from one year to the next in all locations and all stratifications for which we had data). ie:

$$\prod_{a,r,s,k} 0.05^{\text{suppression in stratum } a,r,s,k \text{ is decreasing}} \times 0.95^{\text{suppression in stratum } a,r,s,k \text{ is not decreasing}} \tag{23}$$

7.9 Pharmacy Fills of Prescriptions for PrEP 2012-2018

7.9.1 Calibration Targets

We calibrated to the number of prescriptions for Emtricitabine/Tenofovir for use as PrEP from 2012 to 2018, as reported by AIDSVu.[?] We used both total numbers as well as numbers stratified by age and by sex (although, due to data suppression rules, stratified estimates were sometimes missing).

7.9.2 Differences between Model Representation and Reported Data

The concept of PrEP in our model differs from the data reported by AIDSVu in a number of ways, and our likelihood has to make adjustments for these discrepancies.

Our model simulations produce a proportion of at-risk individuals who are currently enrolled in a PrEP program (since most prescriptions for PrEP are written on a 3-month basis, we take this to correspond to a prescription in the past 3 months).

The AIDSVu data report the number of individuals who filled at least one prescription for emtricitabine/tenofovir in the past year, and who were not using it (as judged by a validated algorithm[?]) for treatment of HIV infection or viral hepatitis. Pharmacy records come from a commercial dataset that captures 83% of prescriptions nationally.[?]

This introduces several discrepancies:

1. Not all individuals who have a prescription for PrEP will be captured in the dataset
2. Some individuals who take emtricitabine/tenofovir for indications other than PrEP (HIV treatment, viral hepatitis) will be incorrectly classified as taking it for PrEP

3. Not all individuals who filled a PrEP prescription in the past year will have filled in the past 3 months (ie, have an "active" prescription)

7.9.3 Adjusting the Calibration Target to Account for Discrepancies

We mapped our model output to the calibration target - the number of pharmacy fills for emtricitabine/tenofovir - using four adjustment factors, as follows:

$$y_i' = y_i \times \frac{\pi \cdot \phi \cdot \rho}{\theta} \tag{24}$$

where:

- $y_{i,t}$ Represents the reported number of pharmacy fills in the past year for a stratum i at time t t
- $y_{i,t}'$ Represents our adjusted response - the number of individuals on PrEP at time t
- π denotes the proportion of emtricitabine/tenofovir prescriptions classified as for PrEP that are truly for PrEP and not some other indication (the positive predictive value of the algorithm)
- ρ denotes the ratio of the number of people with a pharmacy fill in the past three months to the number of people with a pharmacy fill in the past year
- θ denotes the proportion of pharmacy fills that are captured in the dataset

As each of the four adjustment factors is itself uncertain, we represented each with a Lognormal distribution:

$$\begin{aligned} Ln(\pi) &\sim Normal(\pi_0', \sigma_\pi'^2) \\ Ln(\rho) &\sim Normal(\rho_0', \sigma_\rho'^2) \\ Ln(\theta) &\sim Normal(\theta_0', \sigma_\theta'^2) \end{aligned}$$

We derived estimates of the mean and variance for each of the factors from the literature (Table S18 below). We converted these to the mean and distribution of a Lognormal distribution using the approximation that the log-sd is approximately equation to the coefficient of variance:

$$\begin{aligned} \pi_0' &= Ln(\pi_0) \\ \sigma_\pi' &= \frac{\sigma_\pi}{\pi_0} \end{aligned}$$

where π_0 is the mean and σ_π is the standard deviation for π (NOT on the log scale), with analagous calculations for ρ and θ.

This formulation allowed us to articulate a Lognormal distribution for $y_{i,t}'$ - the number of people on PrEP at time t - that is a function of our reported calibration target - $y_{i,t}$ - and the adjustment factors:

$$\begin{aligned} Ln(y_{i,t}') &= Ln(y_{i,t}) + Ln(\pi) + Ln(\phi) + Ln(\rho) - Ln(\theta) \qquad (25) \\ &\sim Normal\Big(Ln(y_{i,t}) + \pi_0' + \rho_0' - \theta_0', \sigma_\pi'^2 + \sigma_\rho'^2 + \sigma_\theta'^2\Big) \qquad (26) \end{aligned}$$

We used approximations to give $y_{i,t}'$ a Normal distribution that will allow us to more easily fold it into a multivariate likelihood, with mean and variance:

$$\begin{aligned} E\big[y_{i,t}'\big] &= y_{i,t} \times \frac{\pi \cdot \rho}{\theta} \\ Var\big[y_{i,t}'\big] &= \big(\sigma_\pi'^2 + \sigma_\rho'^2 + \sigma_\theta'^2\big) \times E\big[y_{i,t}'\big] \end{aligned}$$

We imposed a correlation in the effects of these factors across time, by defining the vector $\boldsymbol{y_i'}$ of all $y'i,t$ to have a compound symmetry matrix with correlation coefficient of 0.5.

Table S18: Means and Standard Deviations of PrEP Likelihood Adjustment Factors

Adjustment Factor	Mean	Standard Deviation	Reference
Proportion of prescriptions correctly classified as PrEP (π)	0.901	0.035	MacCannell 2015[?]
Ratio of PrEP within 3mo to PrEP within 1yr (ρ)	0.523	0.038	Siegler 2018,[?] AIDSVu[?]
Proportion of pharmacy fills captured in dataset (θ)	0.83	0.05	Sullivan 2018[?]

7.9.4 Measurement Error

On top of the adjustments mapping pharmacy fills to enrollment in a PrEP program, we allowed for the reported pharmacy fills to have a measurement error standard deviation equal to $\sqrt{y_{i,t}}$. This is based on the assumption that the observed number of pharmacy fills follows a binomial distribution, and when p is small, the variance of a binomial distribution $n \cdot p \cdot (1-p) \approx n \cdot p$.

7.9.5 Adjusting the probability of taking PrEP to Account for who is 'At-Risk' for HIV

We postulated that the number of people on PrEP, $y'_{i,t}$, followed a binomial distribution. We took the whole population to be the n of the binomial, which required that the p be the probability of being at risk for HIV AND being on PrEP.

Our model simulations output a probability of being on PrEP for those at risk for acquiring HIV. We multiplied this probability by the probability of being at risk for acquiring HIV to get the overall p for the binomial distribution.

We estimated the proportion at risk for acquiring HIV by calculating the proportion of MSM, PWID, and heterosexuals who meet CDC criteria for PrEP[?] for each stratum of age and race from NHBS surveillance reports (Tables S19, S20, S21).[?,?,?] For MSM and heterosexuals, we multiplied this by the proportion in each age bracket who are sexually active (Table S22).

We used the normal approximation to the binomial to formulate these as a multivariate normal, as described in Section 7.2. Because the proportion indicated for PrEP in a location is likely correlated from year to year, we imposed an autoregressive correlation structure on the distribution with a $\rho = 0.9$.

Table S19: Estimated Proportion of Sexually Active MSM with Indication for PrEP*

	Black	Hispanic	Other
13-24 years	0.363	0.416	0.476
25-34 years	0.429	0.492	0.562
35-44 years	0.420	0.482	0.551
45-54 years	0.370	0.424	0.485
55+ years	0.305	0.350	0.401

*Estimated as the proportion reporting condomless sex with a casual partner from the 2017 NHBS Report[?]

Table S20: Estimated Proportion of PWID with Indication for PrEP*

	Black	Hispanic	Other
13-24 years	0.606	0.703	0.831
25-34 years	0.593	0.689	0.814
35-44 years	0.566	0.656	0.776
45-54 years	0.502	0.582	0.688
55+ years	0.419	0.486	0.575

*Estimated as the proportion reporting needle-sharing from the 2018 NHBS Report[?]

Table S21: Estimated Proportion of Heterosexuals with Indication for PrEP*

	Black	Hispanic	Other
13-24 years	0.1305	0.0611	0.0595
25-34 years	0.1225	0.0574	0.0558
35-44 years	0.0641	0.0300	0.0292
45-54 years	0.0538	0.0252	0.0245
55+ years	0.0435	0.0204	0.0198

*Estimated as the proportion reporting a recent STI in the 2016 NHBS Report[?]

Table S22: Estimated Proportion of Individuals Who Are Sexually Active, by Age and Race

	Female	Male
13-24 years	0.659	0.626
25-34 years	0.975	0.953
35-44 years	0.986	0.977
45-54 years	0.987	0.982
55+ years	0.390	0.656

Proportions for 13-54 year olds derived from Mosher 2005,[?] for 55+ from Lindau 2007[?]

7.9.6 Likelihood Formulation

We combined these three elements - a multivariate normal deriving from the adjustment factors, a multivariate normal encapsulating the measurement errors, and a multivariate normal approximation of the binomial by adding the mean vectors and covariance matrices.

7.9.7 Variance Inflation

To improve parameter mixing in the MCMC, we inflated the variances for this likelihood by a factor of 2.

7.10 Receipt of HIV Test 2013-2017

7.10.1 Calibration Targets

We calibrated testing rates to several targets:

1. The total proportion of individuals reporting ever taking an HIV test in the MSA in 2013, 2014, 2016, and 2017, as reported by the Behavioral Risk Factor Surveillance System (BRFSS)[?]
2. The relative likelihood (odds ratio) by race/ethnicity of reporting ever receiving a test at the state level for Black vs. Non-Black/Non-Hispanic and Hispanic vs. Non-Black/Non-Hispanic as reported by BRFSS.
3. The relative likelihood (odds ratio) by sex of reporting ever receiving a test at the state level (female vs. male) as reported by BRFSS.
4. The relative likelihood (odds ratio) by age of reporting ever receiving a test at the state level for 13-24 vs 35-44 years, 25-34 vs 35-44 years, 45-54 vs 35-44 years, and 55+ vs 35-44 years as reported by BRFSS.

We presumed each of these targets to follow an independent likelihood, which we combined

7.10.2 Likelihood Component for Total Proportion Ever Tested

The portion of the likelihood which calibrated to the total proportion of individuals reporting ever taking an HIV test incorporated three sources of uncertainty:

1. The uncertainty in relating our simulated parameter - the rate of testing in subgroups - to a proportion ever tested
2. A binomial component which captures the uncertainty in mapping from model simulations to observed calibration targets
3. Measurement error in the observed calibration targets

We describe these three components in the next three paragraphs.

7.10.3 Mapping Model Testing Rates to Proportion Ever Tested

Our model simulations produce rates of testing for each compartment, which we needed to map to the probability of ever receiving an HIV test.

We first translated the testing rate for stratum i at time t, $r_{i,t}$, to the probability of receiving a test in the past year, $p_{i,t}$, under the assumption that testing follows a Poisson process:

$$p_{i,t} = 1 - e^{-r_{i,t}} \tag{27}$$

We related the probability of receiving a test in the past year to the probability of ever receiving a test under the following model:

$$Ln(1 - p_{i,t}^{ever}) =\sim Normal\big(\beta \cdot Ln(1 - p_{i,t}), \sigma^2\big) \tag{28}$$

which postulates that the log-probability of never receiving a test is proportional to the log probability of not receiving at test in the past year. We fit this model using data from NHBS surveys from 2011-2018,[?,?,?,?,?,?,?,?] which reported both the proportion ever receiving a test and the proportion receiving a test in the past year in 23 US metropolitan statistical areas, yielding $\beta = 2.49$, $\sigma = 0.046$.

Combining equations 27 and 28 yields:

$$Ln\big(1 - p_{i,t}^{ever}\big) \sim Normal\big(\beta \cdot r_{i,t}, \sigma'^2\big) \tag{29}$$

By the properties of the log-normal distribution, we have

$$E\big[1 - p_{i,t}^{ever}\big] = \mu_{i,t} = e^{\beta r_{i,t} \cdot \frac{\sigma'^2}{2}} \tag{30}$$

$$Var\big(1 - p_{i,t}^{ever}\big) = \sigma_{i,t}^2 = \big(e^{\sigma'^2} - 1\big) \cdot e^{2\beta r_{i,t} + \sigma'^2} \tag{31}$$

For feasibility integrating with other components in the likelihood, we approximated this Log-normal for $1 - p_i^{ever}$ distribution by a Normal distribution:

$$1 - p_{i,t}^{ever} \sim Normal\big(\mu_{i,t}, \sigma_{i,t}^2\big) \tag{32}$$

$$p_{i,t}^{ever} \sim Normal\big(1 - \mu_{i,t}, \sigma_{i,t}^2\big) \tag{33}$$

7.10.4 Binomial Likelihood Component for Total Proportion Ever Tested

We defined $\hat{p}_{i,t}$ to be the 'true' proportion of individuals in stratum i ever tested for HIV at time t, and formulated a binomial likelihood in terms of $p_{i,t}^{ever}$:

$$n_{i,t} \cdot \hat{p}_{i,t} | p_{i,t}^{ever} \sim Binomial\big(n_{i,t}, p_{i,t}^{ever}\big) \tag{34}$$

Where $n_{i,t}$ is the simulated size of stratum i at time t.

Using a normal approximation to the binomial gives us:

$$n_{i,t} \cdot \hat{p}_{i,t} \sim Normal\big(n_{i,t} \cdot p_{i,t}^{ever}, n_{i,t} \cdot p_{i,t}^{ever} \cdot (1 - p_{i,t}^{ever})\big) \tag{35}$$

To correspond to the observed total proportion ever tested, we summed across strata:

$$n_t \cdot \hat{p}_t = \sum_i n_{i,t} \cdot \hat{p}_{i,t} \sim Normal\Big(\sum_i n_{i,t} \cdot p_{i,t}^{ever}, \sum_i n_{i,t} \cdot p_{i,t}^{ever} \cdot (1 - p_{i,t}^{ever})\Big) \tag{36}$$

$$\hat{p}_t \sim Normal\left(\frac{\sum_i n_{i,t} \cdot p_{i,t}^{ever}}{n_t}, \frac{\sum_i n_{i,t} \cdot p_{i,t}^{ever} \cdot (1 - p_{i,t}^{ever})}{n_t^2}\right) \tag{37}$$

$$\tag{38}$$

where $n_t = \sum_i n_{i,t}$

7.10.5 Measurement Error for Total Proportion Ever Tested

We calibrated to the reported proportion ever tested for HIV at a given time t for each MSA, which we denote p_t^{obs}.

We postulated that this is a noisy measurement of the true proportion ever tested, $\hat{p}_t$:

$$p_t^{obs} | \hat{p}_t \sim Normal(\hat{p}_t, \tau^2) \tag{39}$$

Where τ^2 comes from the Wald interval for the sample data, ie:

$$\tau^2 = n_t^{obs} \cdot p_t^{obs} \cdot (1 - p_t^{obs}) \tag{40}$$

We vectorized the observed probabilities, and allowed the measurement errors to be correlated across the resulting multivariate normal distribution:

$$\boldsymbol{p^{obs}} \sim Multivariate\text{-}Normal\big(\boldsymbol{\hat{p}}, \boldsymbol{\tau \Gamma \tau}^T\big) \tag{41}$$

Where $\boldsymbol{\Gamma}$ is a compound symmetry (exchangeable) correlation matrix with $\rho = 0.5$

7.10.6 Likelihood Components for Odds Ratios of Ever-Testing by Sex, Age, and Race

We included three likelihood components for the odds ratios of ever receiving a test by sex, age, and race at the state level. These include two sources of uncertainty: measurement error for the reported proportion ever tested, and a binomial error mapping the simulated outputs to observed data.

7.10.7 Binomial Component for Odds Ratios

In general, we wanted to compare the proportion ever receiving an HIV test in two subgroups (which we denote 1 and 2) at time t.

We defined $\bar{p}_{1,t}$ to be the estimated proportion ever tested in subgroup 1 and $\bar{p}_{2,t}$ to be the estimated proportion ever tested in subgroup 2 at time t, and assigned them a binomial distribution:

$$\bar{p}_{1,t} \cdot n_{1,t} \sim Binomial(n_{1,t}, \bar{\mu}_{1,t}) \tag{42}$$
$$\bar{p}_{2,t} \cdot n_{2,t} \sim Binomial(n_{2,t}, \bar{\mu}_{2,t}) \tag{43}$$
$$\tag{44}$$

Where we formulated $\bar{\mu}_{1,t}$ and $\bar{\mu}_{2,t}$ using the quantity $\mu_{i,t}$ defined in Section 7.10.3, equation 30,

$$\bar{\mu}_{1,t} = 1 - \frac{\sum_i \mu_{i,t} \cdot n_{i,t} \cdot \mathbb{1}_{i \in \text{subgroup 1}}}{\sum_i n_i \cdot \mathbb{1}_{i \in \text{subgroup 1}}} \tag{45}$$
$$\bar{\mu}_{2,t} = 1 - \frac{\sum_i \mu_{i,t} \cdot n_{i,t} \cdot \mathbb{1}_{i \in \text{subgroup 2}}}{\sum_i n_i \cdot \mathbb{1}_{i \in \text{subgroup 2}}} \tag{46}$$

Using the normal approximation to tbe binomial gives us:

$$\bar{p}_{1,t} \cdot n_{1,t} \sim Normal\Big(n_{1,t} \cdot \bar{\mu}_{1,t}, n_{1,t} \cdot \bar{\mu}_{1,t} \cdot (1 - \bar{\mu}_{1,t})\Big) \tag{47}$$
$$\bar{p}_{1,t} \sim Normal\left(\bar{\mu}_{1,t}, \frac{\bar{\mu}_{1,t} \cdot (1 - \bar{\mu}_{1,t})}{n_{1,t}}\right) \tag{48}$$
$$\bar{p}_{2,t} \sim Normal\left(\bar{\mu}_{2,t}, \frac{\bar{\mu}_{2,t} \cdot (1 - \bar{\mu}_{2,t})}{n_{2,t}}\right) \tag{49}$$
$$\tag{50}$$

We used the delta method to derive a distribution for the log odds ratio:

$$Ln\big(\bar{OR}_{12,t}\big) = Ln\left(\frac{\bar{p}_{1,t}}{1 - \bar{p}_{1,t}} \cdot \frac{1 - \bar{p}_{2,t}}{\bar{p}_{2,t}}\right) \sim Normal\left(Ln\left(\frac{\bar{\mu}_{1,t}}{1 - \bar{\mu}_{1,t}} \cdot \frac{1 - \bar{\mu}_{2,t}}{\bar{\mu}_{2,t}}\right), \gamma_{12,t}^2\right) \tag{51}$$

where

$$\gamma_{12,t}^2 = \frac{\bar{\mu}_{1,t} \cdot (1 - \bar{\mu}_{1,t})}{n_{1,t}} \times \left(\frac{1}{\bar{\mu}_{1,t}} - \frac{1}{1 - \bar{\mu}_{1,t}}\right)^2 + \frac{\bar{\mu}_{2,t} \cdot (1 - \bar{\mu}_{2,t})}{n_{2,t}} \times \left(\frac{1}{\bar{\mu}_{2,t}} - \frac{1}{1 - \bar{\mu}_{2,t}}\right)^2 \tag{52}$$

7.10.8 Measurement Error for Odds Ratios

We defined our response, $OR_{12,t}$, as the odds ratio of the reported proportions ever tested in subgroups 1 and 2 at time t (denoted $p_{1,t}^{obs}$ and $p_{2,t}^{obs}$):

We gave the log odds ratio derived from $\bar{p}_{1,t}$ and $\bar{p}_{2,t}$ a normal distribution centered at $\bar{OR}_{12,t}$ as defined above:

$$Ln\big(OR_{12,t}\big) \sim Normal\big(\bar{OR}_{12,t}, \sigma_{12,t}^2\big) \tag{53}$$

$\sigma_{12,t}$ is the standard deviation of the log odds ratio calculated from the sample:

$$\sigma_{12,t} = \sqrt{\frac{1}{p_{1,t}^{obs} \cdot n_{1,t}^{obs}} + \frac{1}{(1 - p_{1,t}^{obs}) \cdot n_{1,t}^{obs}} + \frac{1}{p_{2,t}^{obs} \cdot n_{2,t}^{obs}} + \frac{1}{(1 - p_{2,t}^{obs}) \cdot n_{1,t}^{obs}}} \tag{54}$$

We allowed measurement errors to be correlated over time by vectorizing, and using a multivariate-normal distribution:

$$\boldsymbol{Ln\big(OR_{12}\big)} \sim Multivariate\text{-}Normal\big(\boldsymbol{\bar{OR}_{12}}, \boldsymbol{\sigma_{12,t}\Gamma\sigma_{12,t}^T}\big) \tag{55}$$

where Γ is a compound symmetry correlation matrix with $\rho = 0.5$.

7.10.9 Variance Inflation

To improve parameter mixing in the MCMC, we inflate the variances for this likelihood by a factor of 64.

7.11 Injection Drug Use 2014-2016

7.11.1 Calibration Targets

We calibrated simulated IV drug use to four targets each for active use and prior use, drawn from the NSDUH 2014-2016:[?]

1. The total prevalence of active IV drug use, calculated as the NSDUH substate estimate for heroin use in the past year multiplied by the national ratio of use of any injection drug within 30 days to use of heroin within the past year
2. The total prevalence of prior IV drug use, calculated as the NSDUH substate estimate for heroin use in the past year multiplied by the national ratio of use of any injection drug more than 30 days prior to use of heroin within the past year
3. The odds ratio of the prevalence of drug use within 30 days for Black vs. non-Black/non-Hispanic and non-Black/non-Hispanic, based on national NSDUH surveys
4. The odds ratio of the prevalence of drug use more than 30 days prior for Black vs. non-Black/non-Hispanic and non-Black/non-Hispanic, based on national NSDUH surveys
5. The odds ratio of the prevalence of drug use within 30 days for female vs. heterosexual male and MSM vs. heterosexual male, based on national NSDUH surveys
6. The odds ratio of the prevalence of drug use more than 30 days prior for female vs. heterosexual male and MSM vs. heterosexual male, based on national NSDUH surveys
7. The odds ratio of the prevalence of drug use within 30 days for 13-24yo vs. 35-44yo, 25-34yo vs 35-44yo, 45-54yo vs 35-44yo, and 55+yo vs. 35-44yo, based on national NSDUH surveys
8. The odds ratio of the prevalence of drug use more than 30 days prior for 13-24yo vs. 35-44yo, 25-34yo vs 35-44yo, 45-54yo vs 35-44yo, and 55+yo vs. 35-44yo, based on national NSDUH surveys

These values were summed across 2014-2016. We treated the likelihoods for each of these targets as independent.

7.11.2 Log-Normal Likelihood

For the first two targets (prevalence of active and prior IV drug use), we used a Lognormal likelihood centered at the simulated prevalence, with a standard deviation of $\frac{Ln(2)}{2}$ (which gives a 95% interval from half to twice the median estimate).

$$Ln\big(p^{obs}\big) \sim Normal\big(p^{sim}, \sigma^2\big) \tag{56}$$

For the remaining targets (odds ratios by race, sex/sexual behavior, and age), we used a Lognormal distribution centered at the odds ratio from simulations, also with a standard deviation of $\frac{Ln(2)}{2}$:

$$Ln\big(OR^{obs}\big) \sim Normal\big(OR^{sim}, \sigma^2\big) \tag{57}$$

7.12 Cumulative AIDS Mortality prior to 2002

To help with estimation of parameters in the early part of the simulation, we included a calibration target of the total mortality due to AIDS from 1981 to 2000, stratified by race, sex, and HIV-acquisition risk factor.

We treated each of the 24 strata (three races, two sexes, four risk factors) as independent. Our likelihood took into account that not all deaths were captured during this time period.[?]

We let:

- y_i denote our response, the observed cumulative number of AIDS death in stratum i of race, sex, and risk factor from 1981 to 2000
- p_i denote the simulated rate of deaths
- n_i denote the sum of the total population over 13 years old (by US census data) from 1981 to 2000 in the location we are calibrating to

- ϕ denote the proportion of AIDS deaths that were captured by reporting systems. We use $\phi = 0.85 \times 0.9 = 0.765$; the technical appendix to the 2001-2002 CDC HIV/AIDS report[?] estimates that 85% of AIDS cases and 90% of deaths in people with reported AIDs were captured.

- $sigma_i^2$ denote the measurement error around y_i. We used $\sigma_i = y_i \times 0.09$ as for reported prevalence (Section 7.5.2).

As with other elements of the likelihood, we decomposed into a term that captures the difference between model simulations and truth (y_i') and measurement error (ϵ_i):

$$y_i = y_i' + \epsilon_i \tag{58}$$
$$y_i' \sim Binomial(n_i, p_i\phi) \tag{59}$$
$$\epsilon_i \sim Normal(0, \sigma_i^2) \tag{60}$$

Using the Normal approximation to the Binomial allowed us to combine this into one Normal distribution:

$$y_i \sim Normal\big(n_i \cdot p_i\phi, n_i \cdot p_i\phi \cdot (1 - p_i\phi_i) + \sigma_i^2\big) \tag{61}$$

7.12.1 Variance Inflation

To improve parameter mixing in the MCMC, we inflate the variances for this likelihood by a factor of 2.

7.13 Reported AIDS Diagnoses from 1999-2002

In addition to the cumulative AIDS mortality, we also helped estimation of parameters early in the simulation by including as a calibration target the total number of AIDS diagnoses in each year from 1999 to 2002. This particularly helped estimate the early trends that produce the prevalence during 2010-2020.

7.13.1 AIDS Diagnoses vs. HIV Diagnoses

Our model does not explicitly capture AIDS - only all HIV infections. We worked around this by postulating that the number of AIDS diagnoses in a year was a multiple of the number of HIV diagnoses in that year:

$$y_t' = \gamma_t \times \phi_t \tag{62}$$

where

- y_t' is the 'true' number of AIDS diagnoses in year t
- γ_t is the number of HIV diagnoses in year t
- ϕ_t is the ratio of AIDS to HIV diagnoses in year t

Because ϕ_t, the ratio of AIDS to HIV diagnoses entails uncertainty, we represented it with a Lognormal distribution:

$$Ln(\phi_t) \sim Normal\big(Ln(\bar{\phi}_t), \tau^2\big) \tag{63}$$

We estimated the values of $\bar{\phi}_t$ from the 2001-2002 CDC HIV/AIDS report,[?] which reported both number of AIDS diagnoses and HIV diagnoses for 30 areas with confidential name based reporting from the previous five years. Specifically, $\bar{\phi}_{1999} = 1.45$, $\bar{\phi}_{2000} = 1.56$, $\bar{\phi}_{2001} = 1.51$, and $\bar{\phi}_{2002} = 1.39$. We chose $\tau = \frac{log(1.1)}{2}$, which gives a 95% interval of 0.9 to 1.1 times $\bar{\phi}_t$.

7.13.2 Measurement Error

We also allowed the reported number of AIDS cases in year t, y_t, to have a measurement error on the log scale:

$$Ln(y_t) \sim Normal(Ln(y_t'), \lambda^2) \tag{64}$$

We chose $\lambda = 0.09$ (essentially a coefficient of variance of 0.09) to align with the measurement error for prevalence given in Seciton 7.5.2.

Combining equations 62, 63, and 64 gives us:

$$Ln(y_t) \sim Normal\big(Ln(\gamma_t) + Ln(\bar{\phi}_t), \tau^2 + \lambda^2\big) \tag{65}$$

By the properties of the Lognormal distribution, we have:

$$E[y_t] = \mu_t = \gamma_t \phi_t \cdot e^{\frac{\tau^2+\lambda^2}{2}} \tag{66}$$
$$Var(y_t) = \sigma_t^2 = \left(e^{\tau^2+\lambda^2} - 1\right) \cdot \left(\gamma_t \phi_t\right)^2 \cdot e^{\tau^2+\lambda^2} \tag{67}$$
$$\tag{68}$$

To more easily integrate this aspect of the likelihood with a binomial component below, we approximated the distribution in 65 with a Normal distribution:

$$y_t \sim Normal(\mu_t, \sigma_t^2) \tag{69}$$

Since measurement errors in the ratio of AIDS to HIV diagnoses, ϕ_i are likely correlated within a location from year to year, we vectorized this to a multivariate normal distribution:

$$\boldsymbol{y} \sim Multivariate\text{-}Normal\left(\boldsymbol{\mu}, \boldsymbol{\sigma}\boldsymbol{\Lambda}\boldsymbol{\sigma}^T\right) \tag{70}$$

where $\boldsymbol{\Lambda}$ is a compound symmetry (exchangeable) correlation matrix with $\rho = 0.5$

7.13.3 Formulation of Binomial Likelihood Component

Lastly, we mapped the model-simulated rate of HIV diagnoses, p_t to the number of HIV diagnoses, γ_t with a binomial distribution:

$$\gamma_t \sim Binomial(n_t, p_t) \tag{71}$$

where n_t is the total population (per US Census Bureau) of 13+ year olds in year t in the location we are calibrating to. We used the normal approximation to the binomial to give us:

$$\gamma_t \sim Normal\left(n_t \cdot p_t, n_t \cdot p_t \cdot (1 - p_t)\right) \tag{72}$$

Combining with equation 70 gives us our likelihood

8 Functional Forms for Parameters

Some of the parameters in the differential equations given in Section 5 are simple scalar quantities, but many are either time-varying or composed of two or more other parameters. We describe the functional forms of these more complex parameters here.

8.1 Some General Structural Forms

Most of our time-varying parameters follow one of three forms:

- **Linear Interpolation** between two or more knots
- **A Logistic Model** with an intercept and linear slope on the log odds scale (Section 8.1.1)
- **Interpolated using a logistic curve** between two or more knots (Section 8.1.2)

8.1.1 Logistic Model for Time-Varying Probabilities

For time varying parameters which are probabilities, we formulated a logistic model which had an intercept and a slope (relative to time), as well as coefficients for each age bracket, race, and combinations of sex/sexual behavior with drug use, plus their interactions with time. We also allowed for there to be a maximum achievable probability absent intervention:

$$
\begin{aligned}
logit\Big(\frac{p_{a,r,s,k}(t)}{p_{max}}\Big) &= \beta_0 + \beta_1 \times t \\
&+ \beta_{0,a1} \times \mathbb{1}_{a=1} + \beta_{1,a1} \times \mathbb{1}_{a=1} \times t \\
&+ \beta_{0,a2} \times \mathbb{1}_{a=2} + \beta_{1,a2} \times \mathbb{1}_{a=2} \times t \\
&+ \beta_{0,a3} \times \mathbb{1}_{a=3} + \beta_{1,a3} \times \mathbb{1}_{a=3} \times t \\
&+ \beta_{0,a4} \times \mathbb{1}_{a=4} + \beta_{1,a4} \times \mathbb{1}_{a=4} \times t \\
&+ \beta_{0,a5} \times \mathbb{1}_{a=5} + \beta_{1,a5} \times \mathbb{1}_{a=5} \times t \\
&+ \beta_{0,r1} \times \mathbb{1}_{r=Black} + \beta_{1,r1} \times \mathbb{1}_{r=Black} \times t \\
&+ \beta_{0,r2} \times \mathbb{1}_{r=Hispanic} + \beta_{1,r2} \times \mathbb{1}_{r=Hispanic} \times t \\
&+ \beta_{0,r3} \times \mathbb{1}_{r=Other} + \beta_{1,r3} \times \mathbb{1}_{r=Other} \times t \\
&+ \beta_{0,sk1} \times \mathbb{1}_{s=MSM,k=never\_use} + \beta_{1,sk1} \times \mathbb{1}_{s=MSM,k=never\_use} \times t \\
&+ \beta_{0,sk2} \times \mathbb{1}_{s=MSM,k\neq never\_use} + \beta_{1,sk2} \times \mathbb{1}_{s=MSM,k\neq never\_use} \times t \\
&+ \beta_{0,sk3} \times \mathbb{1}_{s=heterosexual\_male,k=never\_use} + \beta_{1,sk3} \times \mathbb{1}_{s=heterosexual\_male,k=never\_use} \times t \\
&+ \beta_{0,sk4} \times \mathbb{1}_{s=heterosexual\_male,k\neq never\_use} + \beta_{1,sk4} \times \mathbb{1}_{s=heterosexual\_male,k\neq never\_use} \times t \\
&+ \beta_{0,sk5} \times \mathbb{1}_{s=female,k=never\_use} + \beta_{1,sk5} \times \mathbb{1}_{s=female,k=never\_use} \times t \\
&+ \beta_{0,sk6} \times \mathbb{1}_{s=female,k\neq never\_use} + \beta_{1,sk6} \times \mathbb{1}_{s=female,k\neq never\_use} \times t
\end{aligned}
$$

8.1.2 Logistic Splines for Time-Varying Rates

Many of our time-varying parameters which are not proportions were formulated as splines with two or three knots. For most of these, we interpolated such that values between the knots follow a logistic curve.

8.1.2.1 Two-Point Spline For the case where our time-varying parameter hasdtwo knots y_0 and y_1 at times t_0 and t_1, and where we wanedt p_0 to be the proportion of the total span (difference between asymptotes) of the curve that would be traversed before t_0, and p_1 to be the proportion of the total span of the curve that would be traversed after t_1, we used the following function:

$$y(t) = f_l(t, y_0, y_1, t_0, t_1, p_0, p_1) = A + \frac{(K - A)}{1 + Q \cdot e^{-B\cdot(t-t_0)}} \tag{73}$$

where:

$$A = y_0 - p_0 \times \frac{y_1 - y_0}{1 - p_0 - p_1} \tag{74}$$

$$K = y_1 + p_0 \times \frac{y_1 - y_0}{1 - p_0 - p_1} \tag{75}$$

$$Q = \frac{K - y_0}{y_0 - A} \tag{76}$$

$$B = \frac{log(y_1 - A) - log(K - y_1)}{t_1 - t_0} \tag{77}$$

$$\tag{78}$$

8.1.2.2 Three-Point Splines For the cases where our time-varying parameter had three knots y_0, y_1, and y_2 at times t_0, t_1, and t_2, we split the spline into two logistic curves (before and after t_1). We defined p_0 to be the proportion of the total span (difference between asymptotes) of the curve from t_0 to t_1 that would be traversed before t_0, and p_2 to be the proportion of the total span of the curve from $t_1 tot_2$ that would be traversed after t_2. We took one of two approaches, depending on whether or not the curves changed direction at t_1.

8.1.2.3 Three-Point Spline that changes direction For a spline with three knots where the change from y_0 to y_1 was in the opposite direction to the change from $y_1 toy_2$, we fit one two-point spline for before y_1 and one for after:

$$y(t) = \begin{cases} f_l(t, y_0, y_1, t_0, t_1, p_0, 0.025) & t < t_1 \\ f_l(t, y_1, y_2, t_1, t_2, 0.025, p_2) & t \geq t_1 \end{cases} \tag{79}$$

8.1.2.4 Three-Point Spline that is monotonically increasing or decreasing For a spline with three knots where the change from y_0 to y_1 was in the same direction as the change from $y_1 to y_2$, we fit one two-point spline for before t_1 and one for after, such that the slopes of the two splines are the same at $t1$.

8.2 Rate of Transmission Between Strata $(\Gamma_{i,j,m}(t))$

For shorthand, we use i to denote the stratum where age = a, race = r sex/sexual behavior = s and IV drug use state = k and j to denote stratum a', r', s', k'.

The rate of transmission from stratum j to stratum i via mode m at time t, denoted $\Gamma_{i,j,m}(t)$, follows a smooth function from initiation in 1970 through the run period (2030 for this work). Prior to the year 2000, this is a linear spline; after 2000 it follows a logistic spline (Section 8.1.2).

8.2.1 Transmission Rate After 2000

Following the year 2000, we use a logistic spline (Section 8.1.2), with knots at 2000, 2010, and 2020. These knots are decomposed into a global transmission rate, multipliers for the mode of transmission (MSM, IDU, or heterosexual) interacted with race/ethnicity, multipliers for age, and multipliers for female sex (for heterosexual transmission) or MSM-IDU (for IV transmission).

The knots for 2000 ($C_{2000,i,j,m}$) are given by:

$$C_{2000,i,j,m} = \begin{cases} \gamma \cdot \omega_{r,2000}^{(IDU)} \cdot \omega_a^{(A)} & \text{if } m = IV \text{and } s \neq MSM \\ \gamma \cdot \omega_{r,2000}^{(IDU)} \cdot \omega_a^{(A)} \cdot \omega_{2000}^{(MSM\text{-}IDU)} & \text{if } m = IV \text{and } s = MSM \\ \gamma \cdot \omega_{r,2000}^{(MSM)} \cdot \omega_a^{(A)} & \text{if } m = sexual \text{ and } s \neq female \text{ and } s' \neq female \\ 0 & \text{if } m = sexual \text{ and } s = female \text{ and } s' = female \\ \gamma \cdot \omega_{r,2000}^{(het)} \cdot \omega_a^{(A)} & \text{if } m = sexual \text{ and } s \neq female \text{ and } s' = female \\ \gamma \cdot \omega_{r,2000}^{(het)} \cdot \omega_a^{(A)} \cdot \omega^{(female)} & \text{if } m = sexual \text{ and } s = female \text{ and } s' \neq female \end{cases} \tag{80}$$

where

- γ is the global transmission rate (irrespective of time)
- $\omega_{r,2000}^{(IDU)}$ is a transmission multiplier for IV transmission in 2000, specific to the race of the at-risk partner (r)
- $\omega_a^{(A)}$ is a transmission multiplier for age (irrespective of time) specific to the age of the at-risk partner (a)
- $\omega_{2000}^{(MSM\text{-}IDU)}$ is a relative risk for IV transmission in 2000 for PWID who are MSM, as compared to female or heterosexual male PWID
- $\omega_{r,2000}^{(MSM)}$ is a transmission multiplier for male-to-male sexual transmission in 2000, specific to the race of the at-risk partner (r)
- $\omega_{r,2000}^{(het)}$ is a transmission multiplier for heterosexual transmission in 2000, specific to the race of the at-risk partner (r)
- $\omega^{(female)}$ is the relative risk (irrespective of time) for male-to-female sexual transmission, as compared to female-to-male

The knots for 2010 ($C_{2010,i,j,m}$) are analagous, with the exception that the age-specific transmission multipliers are different for MSM. This allows for greater flexibility in reproducing age trends for MSM, where transmission among younger individuals is particularly dynamic.

$$C_{2010,i,j,m} = \begin{cases} \gamma \cdot \omega_{r,2010}^{(IDU)} \cdot \omega_a^{(A)} & \text{if } m = IV \text{and } s \neq MSM \\ \gamma \cdot \omega_{r,2010}^{(IDU)} \cdot \omega_a^{(A)} \cdot \omega_{2010}^{(MSM\text{-}IDU)} & \text{if } m = IV \text{and } s = MSM \\ \gamma \cdot \omega_{r,2010}^{(MSM)} \cdot \omega_{a,2010}^{(A,MSM)} & \text{if } m = sexual \text{ and } s \neq female \text{ and } s' \neq female \\ 0 & \text{if } m = sexual \text{ and } s = female \text{ and } s' = female \\ \gamma \cdot \omega_{r,2010}^{(het)} \cdot \omega_a^{(A)} & \text{if } m = sexual \text{ and } s \neq female \text{ and } s' = female \\ \gamma \cdot \omega_{r,2010}^{(het)} \cdot \omega_a^{(A)} \cdot \omega^{(female)} & \text{if } m = sexual \text{ and } s = female \text{ and } s' \neq female \end{cases} \tag{81}$$

where $\omega_{a,2010}^{(A,MSM)}$ is an age-specific transmission multiplier that applies only to MSM for sexual transmission at the 2010 knot

The 2020 knots ($C_{2020,i,j,m}$) are analagous to the 2010 knots:

$$C_{2020,i,j,m} = \begin{cases} \gamma \cdot \omega^{(IDU)}_{r,2020} \cdot \omega^{(A)}_{a} & \text{if } m = IV \text{and } s \neq MSM \\ \gamma \cdot \omega^{(IDU)}_{r,2020} \cdot \omega^{(A)}_{a} \cdot \omega^{(MSM\text{-}IDU)}_{2020} & \text{if } m = IV \text{and } s = MSM \\ \gamma \cdot \omega^{(MSM)}_{r,2020} \cdot \omega^{(A,MSM)}_{a,2020} & \text{if } m = sexual \text{ and } s \neq female \text{ and } s' \neq female \\ 0 & \text{if } m = sexual \text{ and } s = female \text{ and } s' = female \\ \gamma \cdot \omega^{(het)}_{r,2020} \cdot \omega^{(A)}_{a} & \text{if } m = sexual \text{ and } s \neq female \text{ and } s' = female \\ \gamma \cdot \omega^{(het)}_{r,2020} \cdot \omega^{(A)}_{a} \cdot \omega^{(female)} & \text{if } m = sexual \text{ and } s = female \text{ and } s' \neq female \end{cases} \tag{82}$$

8.2.2 Transmission Rate Before 2000

Prior to 2000, the transmission rate follows a linear spline with two levels - a "base rate" and a "peak rate". In order to reproduce historical trends where cases among MSM rose first, followed later by cases among heterosexuals and PWID, rates for male-to-male sexual transmission start at the peak rate from 1970 to 1980, decrease from 1980 to the base rate at 1990, and remain flat until 2000. Rates for heterosexual and IV transmission begin at the base rate in 1970, increase to the peak rate by 1980 and continue there until 1990, and decrease back to the base rate by 2000.

The knot for the base rate is taken to be the same as the 2000 knot defined above:

$$C_{base,i,j,m} = C_{2000,i,j,m}) \tag{83}$$

The knot for the peak rate is calculated as the base rate times a multiplier specific to the mode of transmission (MSM, IDU, or heterosexual). In addition, IV transmission among PWID who are MSM factors in a relative risk ($\omega^{(MSM\text{-}IDU)}_{peak}$) that differs from the 2000 relative risk:

$$C_{peak,i,j,m} = \begin{cases} C_{base_i,j,m} \cdot \Omega^{(IDU)} & \text{if } m = IV \text{and } s \neq MSM \\ C_{base_i,j,m} \cdot \Omega^{(IDU)} \cdot \frac{\omega^{(MSM\text{-}IDU)}_{peak}}{\omega^{(MSM\text{-}IDU)}_{2000}} & \text{if } m = IV \text{and } s = MSM \\ C_{base_i,j,m} \cdot \Omega^{(MSM)} & \text{if } m = sexual \text{ and } s \neq female \text{ and } s' \neq female \\ C_{base_i,j,m} \cdot \Omega^{(het)} & \text{otherwise} \end{cases} \tag{84}$$

where $\Omega^{(IDU)}$, $\Omega^{(MSM)}$, and $\Omega^{(het)}$ are the peak transmission multipliers for IV, MSM, and heterosexual transmission respectively.

8.3 Proportion of Partners from Strata ($\Phi_{i,j,m}$)

For each pair of strata i and j, and mode of transmission m, we define $\Phi_{i,j,m}$ to be the proportion of partners for those in stratum i who come from stratum j, such that $\sum_{j=1}^{N} \Phi_{i,j,m} = 1$

We decompose $\Phi_{i,j,m}$ into marginal probabilities of pairing by age, race, sex/sexual behavior, and drug use status:

$$\Phi_{i,j,m} = \phi^{(A)}_{a,a',m} \times \phi^{(R)}_{r,r',m} \times \phi^{(S)}_{s,s',m} \times \phi^{(K)}_{k,k',m} \tag{85}$$

where

- $\phi^{(A)}_{a,a',m}$ is the proportion of partners (for mode of transmission m) of those in age bracket a who come from age bracket a'. $\sum_{a^*=1}^{R} \phi^{(A)}_{a,a^*,m} = 1$
- $\phi^{(R)}_{r,r',m}$ is the proportion of partners (for mode of transmission m) of those of race r who come from race r'. $\sum_{r^*=1}^{R} \phi^{(R)}_{r,r^*,m} = 1$
- $\phi^{(S)}_{s,s',m}$ is the proportion of partners (for mode of transmission m) of those in sex/sexual behavior category s who come from sex/sexual behavior category s'. $\sum_{s^*=1}^{S} \phi^{(S)}_{s,s^*,m} = 1$
- $\phi^{(K)}_{k,k',m}$ is the proportion of partners (for mode of transmission m) of those in IV drug use state k who come from state k'. $\sum_{k^*=1}^{K} \phi^{(K)}_{k,k^*,m} = 1$

Because different locations have different population proportions of age, race, sex/sexual behavior, and IV drug use, we derive $\phi^{(A)}$, $\phi^{(R)}$, $\phi^{(S)}$, and $\phi^{(K)}$ from observed-to-expected ratios. For age pairings, we define the observed-to-expected ratio, $\chi^{(A)}_{a,a',m}$, for every pair of age brackets a and a', which represents the proportion of partners for those in age bracket a who come from age bracket a', relative to the proportion of the general population that is in age bracket a'. We derive $\phi^{(A)}_{a,a',m}$ from $\chi^{(A)}_{a,a',m}$ as follows:

$$\phi^{(A)}_{a,a',m} = \frac{\chi^{(A)}_{a,a',m} \times \frac{P_{a'}}{P}}{\sum_{a^*=1}^{A} \chi^{(A)}_{a,a^*,m} \times \frac{P_{a^*}}{P}} \tag{86}$$

where P_a is the population of individuals in age bracket a and P is the total population size (we used 2012 census estimates for population sizes). We define observed-to-expected ratios for race $\left(\chi^{(R)}_{r,r',m}\right)$, sex/sexual behavior $\left(\chi^{(S)}_{s,s',m}\right)$, and IV drug use $\left(\chi^{(K)}_{k,k',m}\right)$, and calculate the pairing proportions $(\phi^{(R)}_{r,r',m}$, $\phi^{(S)}_{s,s',m}$, and $\phi^{(K)}_{k,k',m})$ in an analagous manner.

Note that when m denotes IV transmission, the observed-to-expected ratios (and therefore pairing probabilities) are zero when either s or s' are not active use strata.

8.4 Proportion of PWH Suppressed $\left(\rho_{a,r,s,k}(t)\right)$

After 2010, the proportion suppressed in stratum a, r, s, k follows a logistic model as described in Section 8.1.1, with a maximum achievable proportion of 0.9 absent intervention. Suppression is presumed to be zero in all strata prior to 1996 (the advent of ART), and scales linearly from 1996 to the 2010-level.

8.5 Rate of HIV Diagnosis $\left(\beta_{a,r,s,k}(t)\right)$

We modeled the time-varying proportion of undiagnosed PWH who receive an HIV test within a given year using a logistic model as described in Section 8.1.1, with a maximum achievable proportion of 0.9 absent intervention. Assuming that this proportion, which we denote $p_{a,r,s,k}(t)$ is the result of a Poisson process with rate $\beta_{a,r,s,k}(t)$, can back-calculate the rate of diagnosis as:

$$\beta_{a,r,s,k}(t) = -Ln\left[1 - p_{a,r,s,k}(t)\right] \tag{87}$$

8.6 Proportion on PrEP $\left(\pi_{a,r,s,k}\right)$

We assume that the maximum proportion, p_{max} of those in each stratum a, r, s, k who are at risk for HIV and can become enrolled in a PrEP program on current trends (ie, absent intervention) is 50%.

Our model sets the proportion of those in each stratum a, r, s, k at risk for HIV infection who are on PrEP to zero in 2011. The proportion rises linearly to an intercept, which we denote $b_{a,r,s,k}$ in 2014. After 2014, the proportion increases linearly with slope $m_{a,r,s,k}$ until reaching 25%. From 25% to 50%, the proportion on PrEP follows the second half of a logistic curve, with a logistic slope and intercept chosen such that the slope of the logistic curve equals $m_{a,r,s,k}$ at the value of 25%:

$$\pi_{a,r,s,k} = \begin{cases} m_{a,r,s,k} \cdot (t - 2014) + b_{a,r,s,k} & \text{if } m_{a,r,s,k} \cdot (t - 2014) + b_{a,r,s,k} \ < 0.5 \cdot p_{max} \\ p_{max} \cdot \left[1 + e^{-(m'_{a,r,s,k} \cdot t + b'_{a,r,s,k})}\right]^{-1} & \text{otherwise} \end{cases} \tag{88}$$

where $m'_{a,r,s,k}$ and $b'_{a,r,s,k}$ are the slope and intercept on the logistic scale, and are calculated from $m_{a,r,s,k}$ and $b_{a,r,s,k}$:

$$m'_{a,r,s,k} = \frac{m_{a,r,s,k}}{0.5 \cdot (1 - 0.5) \cdot p_{max}} \tag{89}$$

$$t^* = 2014 + \frac{0.5 \cdot p_{max} - b_{a,r,s,k}}{m_{a,r,s,k}} \tag{90}$$

$$b'_{a,r,s,k} = -m'_{a,r,s,k} \cdot (t^* - 2014) \tag{91}$$

where t^* represents the year at which the proportion on PrEP reaches 25%.

8.7 IV Drug Use Initiation, Remission, and Relapse Rates $\left(\zeta_{a,r,s}(t), \xi_{a,r,s}(t), \text{ and } \psi_{a,r,s}(t)\right)$

For each stratum a, r, s of age, race, and sex/sexual behavior, the rate of IV drug use initiation follows a logistic spline (Section 8.1.2) with knots at 2000 and 2020. The rates of remission and relapse do not vary with time.

We estimated "best-guess" rates for initiation, remission, and relapse from NSDUH 2014-2016 national data[?] as detailed below. In MCMC sampling, we sampled multipliers for each race for 2000 and 2020 for how much our initiation rates in each race differed from our best guess. We also sampled one multiplier for remission and one multiplier for relapse for how these parameters (across all strata) differed from our best guess.

8.7.1 IV Drug Use Initiation Rates

For each age bracket, we took the proportion of individuals at that age who have ever injected any drug and whose first use of heroin was when they were one year younger, and calculated the constant rate that yielded that proportion ($r = -log(1-p)$). For age groupings that spanned multiple years, we assumed ages are distributed uniformly. For each stratum of age x race x sex/sexual behavior we multiplied this rate by the national ratio of prevalent IV drug use in the stratum divided by IV drug use in the age group

8.7.2 IV Drug Use Remission Rates

For each stratum, we took the ratio of (used in past 30d) / (used in past year), and calculated the (constant) rate that yields that proportion at one year, ignoring mortality, new users, etc.

8.7.3 IV Drug Use Relapse Rates

We assumed that the proportion of active users is in steady state, ignoring contributions from mortality and new users as trivial, and solved: $n_{active\ users} \times r_{remission} = n_{in\ remission} \times r_{relapse}$

8.8 Aging Rates for PWH ($\alpha^{(H)}_{a,r,s,k}$)

Aging rates for those who are HIV-negative are taken to be the inverse of the number of years in the age bracket (eg, for the 25-34 age bracket, the aging rate is $\frac{1}{10}$).

However, we allowed aging rates among some brackets of PWH to deviate from this for two reasons:

1. HIV infections are not distributed uniformly across the 13-24 age bracket; they are concentrated among the older end of the bracket
2. In order to reproduce the age distribution among PWH with a compartmental model, we had to vary aging rates to "push" the large number of people infected at the height of the epidemic in the 1980s and 1990s along the age spectrum. For example, as those individuals reach their 50s, more will be leaving the 45-54 age bracket than entering it, and thus the aging rate will be greater than $\frac{1}{10}$.

To simplify the parameter space, we set aging rates to be the same within each risk group (MSM, PWID, and heterosexuals). The 13-24 aging rate was held fixed through time at a sampled rate. Other age brackets followed a logistic spline (Section 8.1.2) with knots at 2000, 2010, and 2020.

We estimated rates by calculating the proportion of PWH within an age bracket who were in the last year of that age bracket using CDC data.

8.9 HIV Mortality ($\theta^{HIV}(t)$)

Since our model does not represent CD4 strata, we allowed the excess mortality for unsuppressed HIV to vary over time to reproduce the much higher mortality in the early phases of the epidemic. We kept HIV mortality the same for all strata. From 2000 onwards, it followed a logistic spline (Section 8.1.2) with knots at 2000 and 2010. Prior to 2000, it rose linearly from the base (2000) level in 1970 to a sampled peak level in 1980, continued at the peak level until 1996 (the advent of ART), and fell linearly from 1996 to the base level in 2000.

The mortality rate of unsuppressed HIV was multiplied by the proportion unsuppressed in each compartment of PWH to give the mortality rate for that compartment.

8.10 Persistence to Coverage

Given a particular persistence and uptake value, we calculate the estimated coverage value for PrEP. Persistence times uptake will give us the coverage at any given point in time, but we assume persistence to be a function of time following an exponential distribution.

P = Persistence λ = Rate Parameter C = Coverage U = Uptake

$$P = 1 - [1 - e^{-\lambda t}]$$
$$1 - P = e^{-\lambda t}$$
$$ln(1 - p) = -\lambda t$$
$$\lambda = \frac{-ln(P)}{t}$$

We calculate the average persistence over one year as follows:

$$P = \int_0^1 1 - [1 - e^{-\lambda t}] = \int_0^1 e^{-\lambda t} = \frac{1}{\lambda} - \frac{e^{-\lambda}}{\lambda} \tag{92}$$

Given a particular target persistence and uptake value, we can calculate coverage as follows:

$$C = U * P \tag{93}$$

9 References