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Model structure

The STAN model code can be found at the [end of the document](#).

Resident compartment group

$$\frac{dS}{dt} = admissions * (1 - ci - cvax - imm) - IS \beta_{resident-resident} - I_h S \beta_{HCP-resident} - \kappa S - \rho S - \tau S$$

$$\frac{dE}{dt} = IS \beta_{resident-resident} + I_h S \beta_{HCP-resident} + (1 - ve) * \iota V - \eta E - \kappa E - \rho E - \tau E$$

$$\frac{dI}{dt} = \eta E - \gamma I - \rho CI + admissions * ci$$

$$\frac{dV}{dt} = \kappa(S+E) - \iota V - (1-ve) * \iota V - \rho V - \tau V + admissions * cvax$$

$$\frac{dR}{dt} = \gamma I + \iota V - \rho R - \tau R + admissions * imm$$

$$\frac{dD}{dt} = \rho(S+E+V+R) + \rho c I - D$$

$$Admissions = \tau(S+E+V+R) + D$$

Healthcare personnel compartment group

$$\frac{dS_h}{dt} = \sigma R_h - I_h S_h \beta_{HCP-to-HCP} - I_h S_h \beta_{resident-to-HCP} - ci S_h - \kappa_h S_h$$

$$\frac{dE_h}{dt} = I_h S_h \beta_{HCP-to-HCP} + I_h S_h \beta_{resident-to-HCP} + (1-ve_h) * \iota V_h + ci S_h - \eta E_h - \kappa_h E_h$$

$$\frac{dI_h}{dt} = \eta E_h - \gamma I_h$$

$$\frac{dV_h}{dt} = \kappa_h (S_h + E_h) - \iota V_h - (1-ve_h) * \iota V_h$$

$$\frac{dR_h}{dt} = \gamma I_h + \iota V_h - \sigma R_h$$

Sampling distributions

Resident case counts $\sim \text{Binomial}(N, I * \text{Proportion_detected})$

HCP case counts $\sim \text{Binomial}(N_h, I_h * \text{Proportion_detected})$

Vaccinated resident counts $\sim \text{Binomial}(N, V)$

Vaccinated HCP counts $\sim \text{Binomial}(N_h, V_h)$

Resident death counts $\sim \text{Binomial}(N, D)$

Prior distributions

$\beta_{resident-resident} \sim \text{Exponential}(.5)$

$\beta_{resident-to-HCP} \sim \text{Exponential}(.5)$

$\beta_{HCP-to-HCP} \sim \text{Exponential}(.5)$

$\beta_{HCP-resident} \sim \text{Exponential}(.5)$

$\text{Proportion_detected} \sim \text{Beta}(10, 1)$

Model Parameters

Table S1. Parameters for the model shared across categorization schemes

Parameter	Description	Pre-Delta	Delta	Omicron	Reference
ve	Vaccine effectiveness against infection - residents	-	0.6	0.5	[1, 2]
ve_h	Vaccine effectiveness against infection - staff	-	0.8	0.5	[3, 4]
ci	Community infection rate per 1,000	9.3	9.5	14.6	[5]
$cvax$	Community 65+ vaccination rate per 1,000	-	3.4	1.1	[6]
imm	Community 65+ proportion immune	0.0	0.4	0.1	[5]
η	Incubation period (weeks)	0.7	0.7	0.7	[7]
γ	Infectious period (weeks)	1.0	1.0	1.0	[8]
σ	Period of immunity (weeks)	25.0	25.0	25.0	[9, 10]
ι	Time to vaccine effect for 2-dose series (weeks)	-	4.0	4.0	[11]

Table S2. Parameters for the model with facilities categorized by size based on the number of reported beds

Parameter	Description	Less than 300 beds			Largest 1% (Greater than 299 beds)			Reference
		Pre-Delta	Delta	Omicron	Pre-Delta	Delta	Omicron	
κ	Vaccination rate per 1,000 - residents	-	2.6	0.6	-	2.7	0.7	[12]
κ_h	Vaccination rate per 1,000 - staff	-	5.8	4.5	-	7.9	3.8	[12]
ρ	Death rate per 1,000	8.3	5.1	5.4	6.6	4.6	5.1	[12]
ρ_c	COVID death rate per 1,000	2.5	0.3	0.4	1.6	0.2	0.3	[12]
τ	Length of stay (weeks)	6.2	5.6	5.8	14.3	13.3	13.4	Estimated from Unpublished CMS Minimum dataset

Table S3. Parameters for the model with facilities categorized by average resident length of stay

Parameter	Description	<6 weeks			6-10 weeks			>10 weeks			Reference
		Pre-Delta	Delta	Omicron	Pre-Delta	Delta	Omicron	Pre-Delta	Delta	Omicron	
κ	Vaccination rate per 1,000 - residents	-	2.9	0.8	-	2.6	0.5	-	2.1	0.5	[12]
κ_h	Vaccination rate per 1,000 - staff	-	5.9	3.7	-	5.8	4.8	-	5.9	4.9	[12]
ρ	Death rate per 1,000	9.6	6.2	6.6	8.5	5.0	5.2	6.5	3.8	4.2	[12]
ρ_c	COVID death rate per 1,000	2.6	0.3	0.5	2.6	0.3	0.4	2.1	0.2	0.3	[12]
τ	Length of stay (weeks)	3.6	3.5	3.6	7.5	6.4	6.8	17.3	13.0	14.1	Estimated from Unpublished CMS Minimum dataset

Table S4. Parameters for the model with facilities categorized by the surrounding county's social vulnerability index

Parameter	Description	Highest vulnerability			High vulnerability			Low vulnerability			Lowest vulnerability			Reference
		Pre-Delta	Delta	Omicron	Pre-Delta	Delta	Omicron	Pre-Delta	Delta	Omicron	Pre-Delta	Delta	Omicron	
κ	Vaccination rate per 1,000 - residents	-	3.1	0.8	-	2.6	0.6	-	2.3	0.5	-	1.7	0.3	[12]
κ_h	Vaccination rate per 1,000 - staff	-	6.3	4.8	-	6.1	4.3	-	5.6	4.4	-	4.7	3.9	[12]

Parameter	Description	Highest vulnerability			High vulnerability			Low vulnerability			Lowest vulnerability			Reference
		Pre-Delta	Delta	Omicron	Pre-Delta	Delta	Omicron	Pre-Delta	Delta	Omicron	Pre-Delta	Delta	Omicron	
ρ	Death rate per 1,000	7.3	4.1	4.2	8.1	5.1	5.3	9.0	5.8	6.2	10.3	6.5	7.2	[12]
ρ_c	COVID death rate per 1,000	2.5	0.2	0.3	2.4	0.3	0.4	2.5	0.3	0.5	2.7	0.3	0.5	[12]
τ	Length of stay (weeks)	7.1	6.0	6.4	6.4	5.5	5.7	6.0	5.3	5.4	6.2	5.4	5.6	Estimated from Unpublished CMS Minimum dataset

Transmission estimate comparisons

Table S6. The probability of higher transmission comparing the credible intervals between the dominant transmission pathway (grey) for each nursing home type and time period and all other transmission pathways. The darker shade of blue indicates increasing probability of significantly higher transmission in dominant transmission pathway.

			Comparator pathway			
Nursing home Category	Outbreak period	Dominant pathway	Staff-to-staff	Resident-to-Staff	Resident-to-resident	Staff-to-resident
By nursing home size						
Less than 300 beds	Pre-Delta	Staff-to-resident	70	70	25	
	Delta	Resident-to-resident	25	2		10
	Omicron	Staff-to-resident	28	6	4	
Greater than 299 beds	Pre-Delta	Resident-to-resident	91	88		9
	Delta	Resident-to-resident	62	8		37
	Omicron	Resident-to-resident	94	88		21
By average length of stay						
<6 weeks	Pre-Delta	Resident-to-resident	61	53		0

			Comparator pathway			
Nursing home Category	Outbreak period	Dominant pathway	Staff-to-staff	Resident-to-Staff	Resident-to-resident	Staff-to-resident
6-10 weeks	Delta	Resident-to-resident	24	7		4
	Omicron	Staff-to-resident	27	11	6	
	Pre-Delta	Staff-to-resident	65	65	25	
	Delta	Resident-to-resident	20	1		12
	Omicron	Staff-to-resident	40	14	7	
	Pre-Delta	Staff-to-resident	80	80	32	
>10 weeks	Delta	Resident-to-Staff	38		9	31
	Omicron	Resident-to-resident	45	9		1
By county-level measures of social vulnerability						
Highest vulnerability	Pre-Delta	Staff-to-resident	85	87	43	
	Omicron	Staff-to-resident	46	28	14	
High vulnerability	Pre-Delta	Staff-to-resident	79	81	35	
	Delta	Resident-to-resident	24	2		10
	Pre-Delta	Resident-to-resident	77	72		0
Low vulnerability	Delta	Resident-to-resident	25	3		10
	Omicron	Staff-to-resident	33	7	3	
	Pre-Delta	Resident-to-resident	87	82		0
Lowest vulnerability	Delta	Resident-to-resident	24	2		6
	Omicron	Staff-to-resident	19	2	4	

Post estimation assessment methods

Posterior predictive checking. Posterior prediction simulations were produced from the model in order to evaluate the model fit by removing the sampling distributions and setting the transmission and p_{detect}

parameters to their estimated values. The average weekly case counts were used as a test quantity to assess fit numerically, with the ideal scenario of the value falling around the 50th percentile of the posterior prediction. The difference between the 50th percentile from the average weekly case counts was calculated as the Posterior Prediction Deviation (PPD) with a lower value indicating a better fit to the data. A deviation of 25% or less from the 50th percentile was considered a reasonable fit, corresponding to, at most, a deviation of 9 cases per person-week.

Table S7. Posterior predictive check for each category and time period model

Facility Category	Time period	Posterior Prediction Deviation (%)
By facility size		
Less than 300 beds	Pre-Delta	7.8
	Delta	37.3
	Omicron	17.9
Greater than 299 beds	Pre-Delta	18.0
	Delta	28.1
	Omicron	27.4
By average length of stay		
<6 weeks	Pre-Delta	7.5
	Delta	27.2
	Omicron	8.5
6-10 weeks	Pre-Delta	13.8
	Delta	31.4
	Omicron	0.8
>10 weeks	Pre-Delta	12.5
	Delta	37.1
	Omicron	1.7
By county-level measures of social vulnerability		
High vulnerability	Pre-Delta	9.4
	Delta	30.4
	Omicron	2.2

Facility Category	Time period	Posterior Prediction Deviation (%)
Low vulnerability	Pre-Delta	3.2
	Delta	30.0
	Omicron	5.5
Highest vulnerability	Pre-Delta	13.7
	Delta	31.1
	Omicron	2.3
Lowest vulnerability	Pre-Delta	5.1
	Delta	35.4
	Omicron	17.7

Sensitivity analysis. To evaluate the influence of the prior distributions and fixed parameter values on the estimates of the transmission parameters (number of transmission events per week), the models were adjusted to produce estimates under alternative scenarios: flat prior distributions for the transmission and detection parameters, a flat prior distribution for the detection parameter only, and “extreme” values for the time-to-effect for vaccination, the length of immunity, and the vaccine effectiveness. The posterior estimates of the transmission parameters were compared to the original estimates by calculating the number of standard deviations from the original estimates.

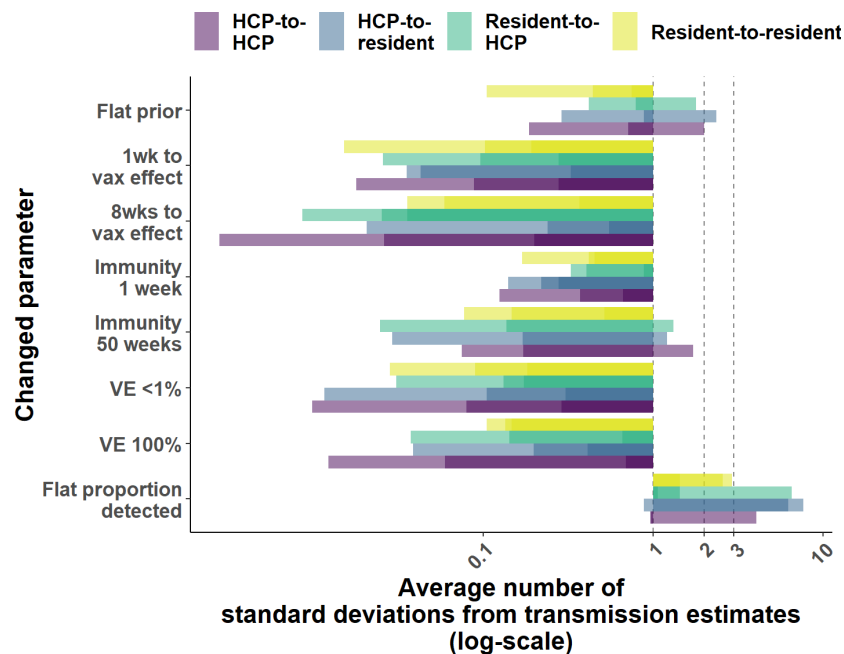


Figure S1. Sensitivity analysis of the fixed parameters and prior distributions assigned in the model. Sensitivity was measured as the average number of standard deviations the transmission estimates were from the estimates produced by the model presented in the paper for facility size. The colors correspond to the estimated transmission pathway and the darker shades represent agreement among the models for each time period. Note: HCP is healthcare provider, i.e., staff.

R packages used in the analysis

- Rstan 2.21.5
- tidyverse 1.3.0
- tidybayes 3.0.2

STAN Model code

```
functions {  
  
  real[] sir(real t, real[] y, real[] theta,  
             real[] x_r, int[] x_i) {  
    //Compartment mapping  
    real S = y[1];  
    real E = y[2];  
    real I = y[3];  
    real V = y[4];  
    real R = y[5];  
    real D = y[6];  
    real Sh = y[7];  
    real Eh = y[8];  
    real Ih = y[9];  
    real Vh = y[10];  
    real Rh = y[11];  
  
    //Fixed value mapping  
    real rhoC = x_r[1]; // death rate among residents - E and I and Ev  
    real rho = x_r[2]; // death rate among residents - S, V, and R  
    real kappa = x_r[3]; // vax rate in residents
```

```

real kappah = x_r[4]; // vax rate in HCW
real sigma = x_r[5]; // 1/period of immunity
real tau = x_r[6]; // 1/length of stay
real eta = x_r[7]; // 1/incubation period
real comminf = x_r[8];
real ve = x_r[9]; //vaccine effectiveness
real veh = x_r[10]; //vaccine effectiveness
real popvax = x_r[11]; //weekly vax'd proportion in 65+ general population
real prtx65pop = x_r[12]; //prop 65+ vaxd in the previous 4-20 weeks
real gamma = x_r[13]; // 1/infectious period
real iota = x_r[14]; // 1/vax effect period

//Estimated parameter mapping
real betar2r = theta[1]; // transmission resident to resident
real betar2h = theta[2]; // transmission resident to HCW
real betah2h = theta[3]; // transmission HCW to HCW
real betah2r = theta[4]; // transmission HCW to resident

//Compartment equations
///Resident model
real dS_dt = (tau*(S+E+V+R) + D)*(1-comminf-popvax-prtx65pop) - betar2r*I*S - betah2r*Ih*S -
kappa*S - rho*S - tau*S; // term (tau*(S+E+V+R) + D) are all new admissions
real dE_dt = betar2r*I*S + betah2r*Ih*S + (1-ve)*iota*V - eta*E - kappa*E - rho*E - tau*E;
real dI_dt = eta*E - gamma*I - rhoC*I + (tau*(S+E+V+R) + D)*comminf;
real dV_dt = kappa*(S+E) - iota*V - (1-ve)*iota*V - rho*V - tau*V + (tau*(S+E+V+R) + D)*popvax;
real dR_dt = gamma*I + iota*V - rho*R - tau*R + (tau*(S+E+V+R) + D)*prtx65pop;
real dD_dt = rho*(S+E+V+R) + rhoC*I - D;

///HCW model
real dSh_dt = sigma*Rh - betah2h*Ih*Sh - betar2h*I*Sh - comminf*Sh - kappah*Sh;
real dEh_dt = betah2h*Ih*Sh + betar2h*I*Sh + (1-veh)*iota*Vh + comminf*Sh - eta*Eh - kappah*Eh;

```

```

    real dlh_dt = eta*Eh - gamma*Ih;
    real dVh_dt = kappah*(Sh+Eh) - iota*Vh - (1-veh)*iota*Vh;
    real dRh_dt = gamma*Ih + iota*Vh - sigma*Rh;

    return {dS_dt, dE_dt, dI_dt, dV_dt, dR_dt, dD_dt, dSh_dt, dEh_dt, dlh_dt, dVh_dt, dRh_dt};
}

}

data {
    int<lower=1> n_days;
    int N[n_days];
    int Nh[n_days];
    real t0;
    real y0[11];
    real ts[n_days];
    int cases[n_days];
    int infhwcw[n_days];
    int vax[n_days];
    int vaxh[n_days];
    int deaths[n_days];
    real rhoC;
    real rho;
    real kappa;
    real kappah;
    real tau;
    real eta;
    real gamma;
    real iota;
    real sigma;

```

```

real ve;

real veh;

real comminf;

real popvax;

real prtx65pop;
}

transformed data {

  real x_r[14] = {rhoC, rho, kappa, kappah, sigma, tau, eta, comminf, ve, veh, popvax, prtx65pop, gamma,
iota};

  int x_i[0];
}

parameters {

  real<lower=0, upper=10> betah2r;

  real<lower=0, upper=10> betar2r;

  real<lower=0, upper=10> betar2h;

  real<lower=0, upper=10> betah2h;

  real<lower=.70, upper=1> p_detected;

}

transformed parameters{

  real y[n_days, 11];

  // initial compartement values

  real theta[4] = {betar2r, betar2h, betah2h, betah2r};

  y = integrate_ode_rk45(sir, y0, t0, ts, theta, x_r, x_i);
}

model {

  //priors

  betar2r ~ exponential(.5);

  betar2h ~ exponential(.5);

```

```

betah2h ~ exponential(.5);
betah2r ~ exponential(.5);
p_detected ~ beta(10, 1);

//sampling distribution
//col(matrix x, int n) - The n-th column of matrix x. Here the number of infected people
cases ~ binomial(N, col(to_matrix(y),3)*p_detected);
infhwcw ~ binomial(Nh, col(to_matrix(y),9)*p_detected);
vax ~ binomial(N, col(to_matrix(y),4));
vaxh ~ binomial(Nh, col(to_matrix(y),10));
deaths ~ binomial(N, col(to_matrix(y),6));
}

generated quantities {
  real pred_cases[n_days];
  real pred_vaxd[n_days];
  real pred_death[n_days];
  real pred_infhwcw[n_days];
  real pred_vaxh[n_days];
  pred_cases = binomial_rng(N, col(to_matrix(y),3)*p_detected);
  pred_vaxd = binomial_rng(N, col(to_matrix(y),4));
  pred_death = binomial_rng(N, col(to_matrix(y),6));
  pred_infhwcw = binomial_rng(N, col(to_matrix(y),9)*p_detected);
  pred_vaxh = binomial_rng(Nh, col(to_matrix(y),10));
}

```

1. Nanduri S, Pilishvili T, Derado G, et al. Effectiveness of Pfizer-BioNTech and Moderna Vaccines in Preventing SARS-CoV-2 Infection Among Nursing Home Residents Before and During

- Widespread Circulation of the SARS-CoV-2 B.1.617.2 (Delta) Variant - National Healthcare Safety Network, March 1-August 1, 2021. *MMWR Morb Mortal Wkly Rep* **2021**; 70(34): 1163-6.
2. Prasad N, Derado G, Nanduri SA, et al. Effectiveness of a COVID-19 Additional Primary or Booster Vaccine Dose in Preventing SARS-CoV-2 Infection Among Nursing Home Residents During Widespread Circulation of the Omicron Variant - United States, February 14-March 27, 2022. *MMWR Morb Mortal Wkly Rep* **2022**; 71(18): 633-7.
 3. Pilishvili T, Gierke R, Fleming-Dutra KE, et al. Effectiveness of mRNA Covid-19 Vaccine among U.S. Health Care Personnel. *The New England journal of medicine* **2021**; 385(25): e90.
 4. Poukka E, Baum U, Palmu AA, et al. Cohort study of Covid-19 vaccine effectiveness among healthcare workers in Finland, December 2020 - October 2021. *Vaccine* **2022**; 40(5): 701-5.
 5. Centers for Disease Control and Prevention. COVID-19 Case Surveillance Public Use Data. In: Centers for Disease Control and Prevention, **2020**.
 6. Centers for Disease Control and Prevention. COVID-19 Vaccination Age and Sex Trends in the United States, National and Jurisdictional. In: Centers for Disease Control and Prevention, **2020**.
 7. Guan J, Wei Y, Zhao Y, Chen F. Modeling the transmission dynamics of COVID-19 epidemic: a systematic review. *J Biomed Res* **2020**; 34(6): 422-30.
 8. He X, Lau EHY, Wu P, et al. Temporal dynamics in viral shedding and transmissibility of COVID-19. *Nature Medicine* **2020**; 26(5): 672-5.
 9. Nordström P, Ballin M, Nordström A. Risk of infection, hospitalisation, and death up to 9 months after a second dose of COVID-19 vaccine: a retrospective, total population cohort study in Sweden. *The Lancet* **2022**; 399(10327): 814-23.
 10. Paz-Bailey G, Sternberg M, Kugeler K, et al. Covid-19 Rates by Time since Vaccination during Delta Variant Predominance. *NEJM Evidence* **2022**; 1(3): EVIDoa2100057.
 11. Polack FP, Thomas SJ, Kitchin N, et al. Safety and Efficacy of the BNT162b2 mRNA Covid-19 Vaccine. *New England Journal of Medicine* **2020**; 383(27): 2603-15.
 12. Centers for Disease Control and Prevention. COVID-19 Nursing Home Data. Available at: <https://data.cms.gov/covid-19/covid-19-nursing-home-data>. Accessed 06/05/2022.