Supplementary material of Twice evasions of Omicron variants can explain the temporal patterns in six Asia and Oceania countries

Boqiang Chen[a], Yanji Zhao[a], Zhen Jin[c], Daihai He *[a], and Huaichen Li†[b]

[a]Department of Applied Mathematics, Kong Kong Polytenic University, Hong Kong, China
[b]Department of Respiratory and Critical Care Medicine, Shandong Provincial Hospital Affiliated to Shandong First Medical University, Jinan, China
[c]School of Computer and Information Technology, Shanxi University, Taiyuan, China

S1 Parameters used in the model simulation

We have introduced some parameters of S-S_V-E-I-H-D-R model in the main text. We here introduce the data and some other parameters in the model simulations process.

Table S1: The population, Log likelihood value and Log likelihood value standard derivation

Country	Population	Log likelihood value	Log likelihood value SD
India	1393409033	-963.1556	0.1627
Indonesia	276361788	-731.9173	0.1813
Malaysia	32776195	-553.4498	0.1103
Bangladesh	166303494	-577.8098	0.0946
Nepal	29674920	-447.7515	0.1041
Myanmar	54806014	-419.5027	0.0827

In Table S1, the population is the whole population in each country at the time when we started our study. We assume the population is constant during our study period. The Log likelihood value is the current optimal outcome of our codes. The Log likelihood value standard derivation is the standard derivation of the The Log likelihood value we computed ten times under the optimal condition.

Table S2: The parameters applied in the model simulation

	ϕ	θ	θ_1	α	t_1	τ	BS.0	BE.0	BI.0	BT.0	BD.0	BR.0
India	0.0185	0.4	0.05	0.2978	2021.97695	0.1654	0.99	6	6	1	0	0.01
Indonesia	0.023166667	0.404	0.01	0.2393	2021.97221	0.0425	0.99	14	14	1	0	0.01
Malaysia	0.042333333	0.4	0.05	0.1526	2022.04799	0.1459	0.99	12	12	1	0	0.01
Bangladesh	0.0125	0.4	0.24	0.1	2021.95745	0.1011	0.99	9	9	1	0	0.01
Nepal	0.0195	0.4	0.24	0.1	2021.90909	0.1647	0.99	3	3	0	0	0.01
Myanmar	0.016833333	0.4	0.05	0.1	2021.92475	0.3595	0.99	6	6	1	0	0.01

In Table S2, ϕ is the infection severity case ratio, we choose the different ϕ in each of country. θ is the first immune evasion proportion and θ_1 is the second immune evasion proportion. θ and θ_1 represent how much loss of immunity for the recovered (R) and vaccinated (V) at time t_1 and $t_1 + 120$ days, respectively. We presume the second invasion occurred at $t_1 + 120$ days for simplicity. α is the relative

*Corresponding author: daihai.he@polyu.edu.hk
†Corresponding author: lihuaichen@163.com

ratio of Omicron IFR vs pre-Omicron IFR. t_1 is the Omicron first invasion time in each country. For example, $t_1 = 2021.97695$ in India, this means the Omicron first invasion time is on the day 0.97695×365, 2021. τ is the over dispersion, which appears in the $Z_{t+\Delta t} \sim Negative\_Binominal(mean = D_{t+\Delta t}, variance = D_{t+\Delta t}(1 + \tau D_{t+\Delta t}))$. Δt in this equation is the τ. BS.0, BE.0, BI.0, BT.0, BD.0 and BR.0 are the system state initial values.

In Table S3, we show the cubic spline nodes number and nodes value ($log.\beta_i$, $i = 1, \ldots, 16$) of the transmission rate β_t [1–5].

The data and parameters listed in these three tables as an example to show what kind of detailed information we need to get the results in the main text. Actually, one of the result (Scenario 4, Fig.S4) in the next section is generated using these data and parameters. There would be some minor changes or adjustments to the parameters when we want to set different assumptions and fit different scenarios.

Table S3: The cubic spline nodes number and nodes value of the transmission rate β_t ($log.\beta_i$, $i = 1, \ldots, 16$).

Country	n_β	$log.\beta_1$	$log.\beta_2$	$log.\beta_3$	$log.\beta_4$	$log.\beta_5$	$log.\beta_6$	$log.\beta_7$	$log.\beta_8$
India	16	5.9	5.056	4.8214	4.7973	4.9078	4.7835	5.214	5.3882
Indonesia	16	5.8993	4.7829	4.7769	4.7093	4.764	4.8728	4.85	4.9861
Malaysia	16	5.6779	4.311	4.4027	5.1247	4.7031	4.731	4.6626	4.8984
Bangladesh	16	5.775	4.9891	4.8336	4.6924	4.9821	4.7943	5.1501	5.1045
Nepal	16	4.5535	5.3215	4.781	4.9321	4.7605	4.8068	4.6099	5.4652
Myanmar	16	5.5742	4.3581	2.6564	5.7855	4.6862	4.8636	4.1881	4.9389

Country	$log.\beta_9$	$log.\beta_{10}$	$log.\beta_{11}$	$log.\beta_{12}$	$log.\beta_{13}$	$log.\beta_{14}$	$log.\beta_{15}$	$log.\beta_{16}$
India	5.7451	6.0895	6.2625	6.1876	6.1875	6.8749	6.7429	6.1937
Indonesia	5.4297	6.4258	6.7963	6.2139	6.2138	6.1877	6.7386	6.2015
Malaysia	4.9958	5.65	6.4417	6.1876	6.1877	6.1882	6.8805	6.2543
Bangladesh	5.5265	6.5185	6.8807	6.4069	6.4075	6.8657	6.2533	6.54
Nepal	5.4071	6.2198	6.2433	6.1876	6.1876	6.188	6.1924	6.8255
Myanmar	5.5056	5.6104	6.7413	6.1877	6.1876	6.1878	6.2338	6.5149

S2 The results under different scenarios

To test the sensitivity and consistency of our model,we set the different assumptions and scenarios to fit the model. We list several of them as following:

- Scenario 1: Consider "a single" invasion scenario of Omicron variants, to fit the transmission rate β_t (in the unit of $R_0(t)$) with 17 cubic spline nodes, $\psi = 1/2$;
- Scenario 2: Consider "a single" invasion scenario of Omicron variants, to fit the transmission rate β_t (in the unit of $R_0(t)$) with 17 cubic spline nodes, $\psi = 1/3$;
- Scenario 3: Consider multiple (e.g. "twice") invasions scenario by initial Omicron BA1 (or BA2 or both) variant and follow-up Omicron (BA4 or BA5) variant,to fit the transmission rate β_t (in the unit of $R_0(t)$) with 17 cubic spline nodes, $\psi = 1/2$;
- Scenario 4: Consider multiple (e.g. "twice") invasions scenario by initial Omicron BA1 (or BA2 or both) variant and follow-up Omicron (BA4 or BA5) variant,to fit the transmission rate β_t (in the unit of $R_0(t)$) with 16 cubic spline nodes, $\psi = 1/3$.

S2.1 Scenario 1

In this subsection, we consider "a single" invasion scenario of Omicron variants, to fit the transmission rate β_t (in the unit of $R_0(t)$) with 17 cubic spline nodes, $\psi = 1/2$. The model simulation result is shown in Figure S1.

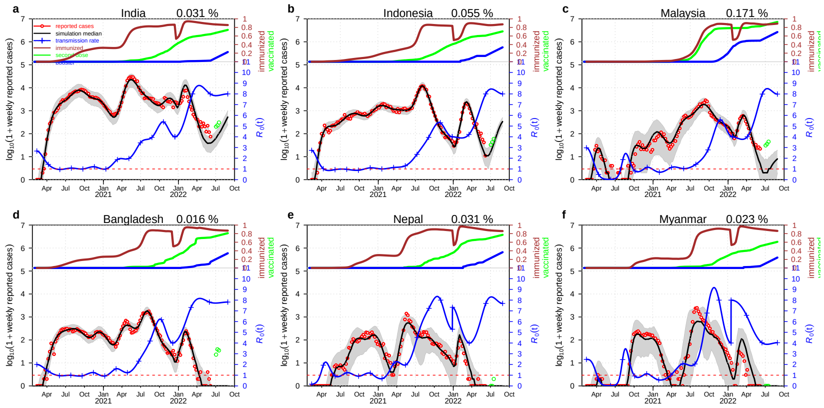

Figure S2: Model simulated death vs reported death with the assumption of only once Omicron invasion and the rate of loss of immunity protection $\phi = 1/3$ in India(a), Indonesia(b), Malaysia(c), Bangladesh(d), Nepal(e) and Myanmar(f). The brown curve, green curve and blue cure in the top of each panel show the currently immunized per capita, second dose per capita and the booster per capita, respectively. The immune evasion caused by once Omicron variant invasion is showed as the sudden drop of the brown curve. While the red circles, black curve and blue cure with plus in the bottom of each panel show the reported cases, the simulation median and the transmission rate (in the unit of $R_0(t) = \beta(t)/\gamma$), respectively. The grey region denotes the 95% CI of 1000 model simulations. The green circles are the reported cases for testing. The percent on the top of each panel is the estimated maximum log likelihood pre-Omicron IFR.

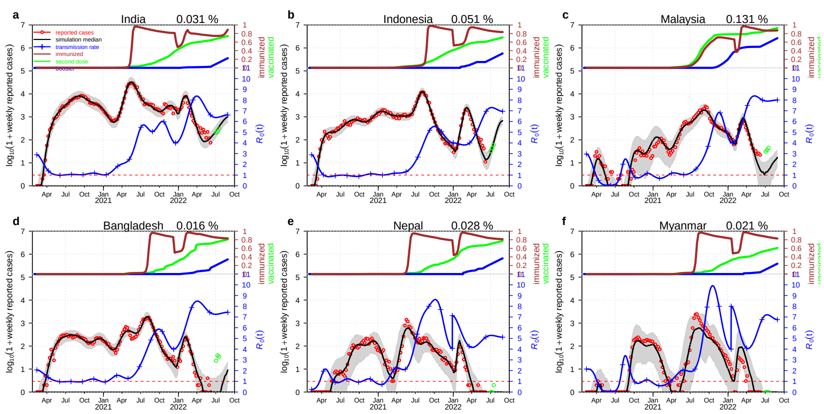

Figure S1: Model simulated death vs reported death with the assumption of only once Omicron invasion and the rate of loss of immunity protection $\phi = 1/2$ in India(a), Indonesia(b), Malaysia(c), Bangladesh(d), Nepal(e) and Myanmar(f). The brown curve, green curve and blue cure in the top of each panel show the currently immunized per capita, second dose per capita and the booster per capita, respectively. The immune evasion caused by once Omicron variant invasion is showed as the sudden drop of the brown curve. While the red circles, black curve and blue cure with plus in the bottom of each panel show the reported cases, the simulation median and the transmission rate (in the unit of $R_0(t) = \beta(t)/\gamma$), respectively. The grey region denotes the 95% CI of 1000 model simulations. The green circles are the reported cases for testing. The percent on the top of each panel is the estimated maximum log likelihood pre-Omicron IFR.

S2.2 Scenario 2

In this subsection, we consider "a single" invasion scenario of Omicron variants, to fit the transmission rate β_t (in the unit of $R_0(t)$) with 17 cubic spline nodes, $\psi = 1/3$. The model simulation result is shown in Figure S2.

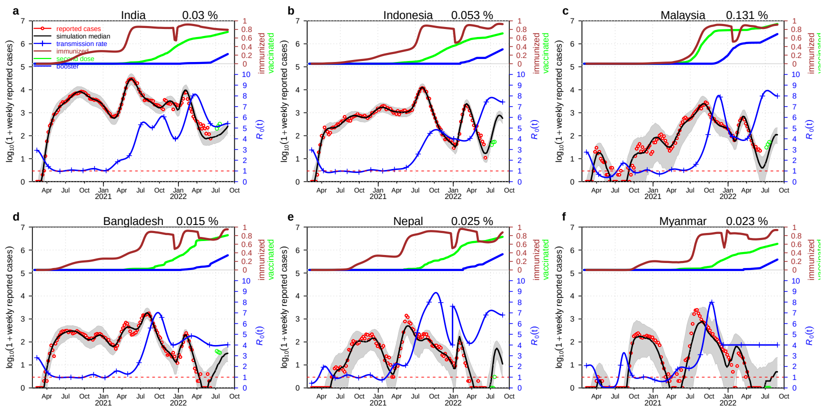

Figure S3: Model simulated death vs reported death with the assumption of twice Omicron invasions and the rate of loss of immunity protection $\phi = 1/2$ in India(a), Indonesia(b), Malaysia(c), Bangladesh(d), Nepal(e) and Myanmar(f). The brown curve, green curve and blue cure in the top of each panel show the currently immunized per capita, second dose per capita and the booster per capita, respectively. The immune evasion caused by once Omicron variant invasion is showed as the sudden drop of the brown curve. While the red circles, black curve and blue cure with plus in the bottom of each panel show the reported cases, the simulation median and the transmission rate (in the unit of $R_0(t) = \beta(t)/\gamma$), respectively. The grey region denotes the 95% CI of 1000 model simulations. The green circles are the reported cases for testing. The percent on the top of each panel is the estimated maximum log likelihood pre-Omicron IFR.

S2.3 Scenario 3

In this subsection, we consider multiple (e.g. "twice") invasions scenario by initial Omicron BA1 (or BA2 or both) variant and follow-up Omicron (BA4 or BA5) variant,to fit the transmission rate β_t (in the unit of $R_0(t)$) with 17 cubic spline nodes, $\psi = 1/2$. The model simulation result is shown in Figure S3.

S2.4 Scenario 4

In this subsection, we consider multiple (e.g. "twice") invasions scenario by initial Omicron BA1 (or BA2 or both) variant and follow-up Omicron (BA4 or BA5) variant,to fit the transmission rate β_t (in the unit of $R_0(t)$) with 16 cubic spline nodes, $\psi = 1/3$. The model simulation result is shown in Figure S4.

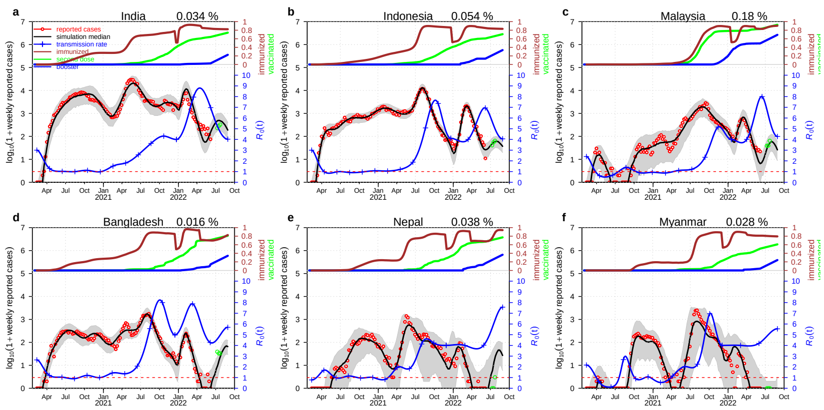

Figure S4: Model simulated death vs reported death with the assumption of twice Omicron invasions and the rate of loss of immunity protection $\phi = 1/3$ in India(a), Indonesia(b), Malaysia(c), Bangladesh(d), Nepal(e) and Myanmar(f). The brown curve, green curve and blue cure in the top of each panel show the currently immunized per capita, second dose per capita and the booster per capita, respectively. The immune evasion caused by once Omicron variant invasion is showed as the sudden drop of the brown curve. While the red circles, black curve and blue cure with plus in the bottom of each panel show the reported cases, the simulation median and the transmission rate (in the unit of $R_0(t) = \beta(t)/\gamma$), respectively. The grey region denotes the 95% CI of 1000 model simulations. The green circles are the reported cases for testing. The percent on the top of each panel is the estimated maximum log likelihood pre-Omicron IFR.

References

[1] Richard H Bartels, John C Beatty, and Brian A Barsky. *An introduction to splines for use in computer graphics and geometric modeling*. Morgan Kaufmann, 1995.

[2] William T Vetterling et al. *Numerical recipes example book (c++): The art of scientific computing*. Cambridge University Press, 2002.

[3] Daihai He et al. "New estimates of the Zika virus epidemic attack rate in Northeastern Brazil from 2015 to 2016: A modelling analysis based on Guillain-Barré Syndrome (GBS) surveillance data". In: *PLoS neglected tropical diseases* 14.4 (2020), e0007502.

[4] Lewi Stone et al. "Extraordinary curtailment of massive typhus epidemic in the Warsaw Ghetto". In: *Science advances* 6.30 (2020), eabc0927.

[5] Shi Zhao et al. "Modelling the large-scale yellow fever outbreak in Luanda, Angola, and the impact of vaccination". In: *PLoS neglected tropical diseases* 12.1 (2018), e0006158.