SUPPLEMENTARY FILE

Assessing Economic Losses with COVID-19 Integrated Models: A Retrospective Analysis

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I. FASSSTER Epidemiological Model

FASSSTER utilized several versions of an epidemiological compartmental model to describe the disease transmission dynamics of COVID-19 in National Capital Region (NCR), Philippines.

a. First Version

The first version of the epidemiological model was utilized within the first year of the COVID-19 pandemic, and is illustrated in Figure 1 below.

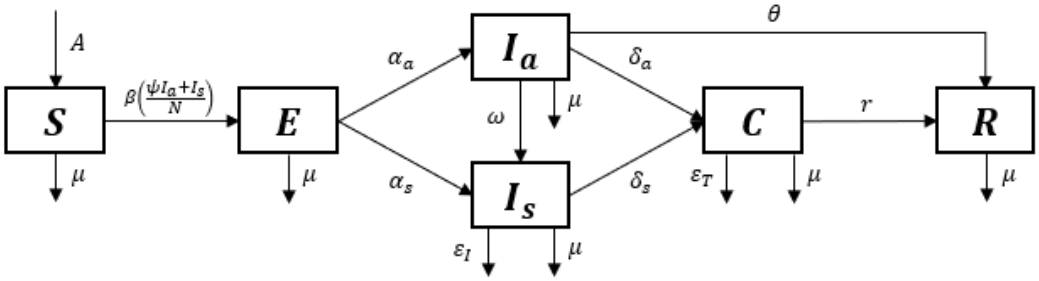

Figure 1: The flow diagram of FASSSTER COVID-19 Model I

It also characterized by the following system of equations:

$$S' = A - \frac{\beta S}{N}(\psi I_a + I_s) - \mu S$$
$$E' = \frac{\beta S}{N}(\psi I_a + I_s) - (\mu + \alpha_a + \alpha_s)E$$
$$I_a' = \alpha_a E - (\mu + \omega + \delta_a + \theta_a)I_a$$
$$I_s' = \alpha_s E + \omega I_a - (\mu + \varepsilon_I + \delta_s)I_s$$
$$C' = \delta_a I_a + \delta_s I_s - (r + \varepsilon_T + \mu)C$$
$$R' = rC + \theta I_a - \mu R$$

Note that $N = S + E + I_a + I_s + C + R$. A detailed discussion of the model and its parameters is presented in de Lara-Tuprio et al. (2022a) and de Lara-Tuprio et al. (2022b).

b. Second Version

This second version was utilized at the onset of the Delta variant local transmission and wide-scale deployment of vaccines in NCR. It is characterized by the following system of differential equations.

Unvaccinated

$$S' = A - \beta S\,\frac{I_e}{N} - \mu S\ - v_1 - j$$
$$E' = \beta S\,\frac{I_e}{N} - (\mu + \alpha_a + \alpha_s)E$$
$$I_a{}' = \alpha_a E - (\mu + \omega + \delta_a + \theta_a)I_a$$
$$I_s{}' = \alpha_s E + \omega I_a\ - (\mu + \varepsilon_I + \delta_s + \theta_s)I_s$$

Partially Vaccinated

$$V_1{}' = v_1 - k_1\beta\frac{I_e}{N}V_1 - \mu V_1 - v_2$$
$$E_1{}' = k_1\,\beta\,\frac{I_e}{N}V_1 - (\mu + \alpha_1^a + \alpha_1^s)E_1$$
$$(I_1^a)' = \alpha_1^a E_1 - (\mu + \omega + \delta_1^a + \theta_a)I_1^a$$
$$(I_1^s)' = \alpha_1^s E_1 + \omega I_1^a - (\mu + \hat{\varepsilon}_I + \delta_1^s + \theta_s)I_1^s$$

Fully Vaccinated

$$V_2{}' = j + v_2 - k_2\beta\frac{I_e}{N}V_2 - \mu V_2$$
$$E_2{}' = k_2\,\beta\,\frac{I_e}{N}V_2 - (\mu + \alpha_2^a + \alpha_2^s)E_2$$
$$(I_2^a)' = \alpha_2^a E_2 - (\mu + \omega + \delta_2^a + \theta_a)I_2^a$$
$$(I_2^s)' = \alpha_2^s E_2 + \omega I_2^a - (\mu + \delta_2^s + \theta_s)I_2^s$$

Confirmed and Recovered

$$C' = (\delta_a I_a + \delta_1^a I_1^a + \delta_2^a I_2^a) + (\delta_s I_s + \delta_1^s I_1^s + \delta_2^s I_2^s) - (r + \varepsilon_T + \mu)C$$
$$R' = rC + \theta_a(I_a + I_1^a + I_2^a) + \theta_s(I_s + I_1^s + I_2^s) - \mu R$$

Note that $I_e = I_a + I_1^a + I_2^a + I_s + I_1^s + I_2^s$. The system of differential equations can also be found in Estuar et al. (2022). A detailed discussion of the model and its parameters is presented in Teng et al. (2024).

c. Third Version

This third version was utilized at the onset of Omicron variant transmission and wide-scale deployment of boosters in NCR. It has a total of 21 compartments, and is represented by the following system of differential equations:

Unvaccinated

$$S' = A - \beta S\,\frac{I_e}{N} - \mu S\ - v_1 - j$$
$$E' = \beta S\,\frac{I_e}{N} - (\mu + \alpha_a + \alpha_s)E$$
$$I_a{}' = \alpha_a E - (\mu + \omega + \delta_a + \theta_a)I_a$$
$$I_s{}' = \alpha_s E + \omega I_a\ - (\mu + \varepsilon_I + \delta_s + \theta_s)I_s$$

Partially Vaccinated

$$V_1{}' = v_1 - k_1\beta\frac{I_e}{N}V_1 - \mu V_1 - v_2$$
$$E_1{}' = k_1\,\beta\,\frac{I_e}{N}V_1 - (\mu + \alpha_1^a + \alpha_1^s)E_1$$
$$(I_1^a)' = \alpha_1^a E_1 - (\mu + \omega + \delta_1^a + \theta_a)I_1^a$$
$$(I_1^s)' = \alpha_1^s E_1 + \omega I_1^a - (\mu + \hat{\varepsilon}_I + \delta_s + \theta_s)I_s$$

Fully Vaccinated

$$V_2{}' = j + v_2 - k_2\beta\frac{I_e}{N}V_2 - \mu V_2 - v_3$$
$$E_2{}' = k_2\,\beta\,\frac{I_e}{N}V_2 - (\mu + \alpha_2^a + \alpha_2^s)E_2$$
$$(I_2^a)' = \alpha_2^a E_2 - (\mu + \omega + \delta_2^a + \theta_a)I_2^a$$
$$(I_2^s)' = \alpha_2^s E_2 + \omega I_2^a - (\mu + \tilde{\varepsilon}_I + \delta_2^s + \theta_s)I_2^s$$

Boosted

$$V_3{}' = v_3 - k_3\beta\frac{I_e}{N}V_3 - \mu V_3$$
$$E_3{}' = k_3\,\beta\,\frac{I_e}{N}V_3 - (\mu + \alpha_3^a + \alpha_3^s)E_3$$
$$(I_3^a)' = \alpha_3^a E_3 - (\mu + \omega + \delta_3^a + \theta_a)I_3^a$$
$$(I_3^s)' = \alpha_3^s E_3 + \omega I_3^a - (\mu + \delta_3^s + \theta_s)I_3^s$$

Confirmed and Recovered

$$C' = \left(\delta_a I_a + \sum_{i=1}^{4}\delta_i^a I_i^a\right) + \left(\delta_s I_s + \sum_{i=1}^{4}\delta_i^s I_i^s\right) - (r + \varepsilon_T + \mu)C$$
$$R' = rC + \theta_a\left(I_a + \sum_{i=1}^{4} I_i^a\right) + \theta_s\left(I_s + \sum_{i=1}^{4} I_i^s\right) - k_4\,\beta\,\frac{I_e}{N}V_4 - \mu R$$

Reinfected

$$E_4' = k_4 \beta \frac{I_e}{N} V_4 - (\mu + \alpha_4^a + \alpha_4^s) E_4$$
$$(I_4^a)' = \alpha_4^a E_4 - (\mu + \omega + \delta_4^a + \theta_a) I_4^a$$
$$(I_4^s)' = \alpha_4^s E_4 + \omega I_4^a - (\mu + \tilde{\varepsilon}_I + \delta_4^s + \theta_s) I_4^s$$

where $I_e = I_a + I_s + \sum_{i=1}^{4} I_i^a + \sum_{i=1}^{4} I_i^s$.

The system of differential equations can also be found in Estuar et al. (2022).

II. Epidemiological Parameters

a. First and Second Version

Parameter estimation details for first and second versions of the epidemiological model can be seen in de Lara-Tuprio et al. (2022a, 2020b) and Teng et al. (2024), respectively.

In applying the second version, for which we considered a baseline and an all mRNA scenario, the following effectiveness values were utilized (presented in Table 1). Note that these values were based on the studies of Sheikh et al. (2021), Li et al. (2021), and Liu et al. (2021).

Table 1: Vaccine effectiveness against Delta symptomatic disease (V_e) and against Delta infection (V_i), from the first dose (1D) and second dose (2D).

	Inactivated (1D)	Viral Vector (1D)	mRNA (1D)	Inactivated (2D)	Viral Vector (2D)	mRNA (2D)
V_e	13.80%	33.00%	33.00%	59.00%	61.00%	83.00%
V_i	10.88%	18.00%	30.00%	51.70%	60.00%	79.00%

b. Third version

For the third version of the epidemiological model, several of its parameters are related to vaccine-related data. To compute such parameters, we need the following:

1. NCR data on vaccinations.

   The vaccination data provided by the National Vaccination Operations Center (NVOC) is the cumulative first dose, second dose, and booster dose administered for each vaccine brand. If such data is available at the end of each month, we can determine the monthly vaccination rates for the first dose, second dose and booster dose.

2. Effectiveness of the vaccine against infection (Vi) and against symptomatic disease (V_e): first dose, second dose and booster dose

   The effectiveness values are taken from United Kingdom Health Security Agency (2022) and Andrews et al. (2022), where they include information on waning vaccine-induced immunity. In these studies, the vaccine effectiveness against symptomatic disease provided by the second dose and boosters is in terms of the number of weeks after the administered dose. But given the model implementation, we adjusted the level of protection provided by the vaccines based on a monthly setting.

   A sample of vaccine effectiveness parameters used for implementing the third version of the

epidemiological model in March 2022 can be seen in Tables 2.1, 2.2, 2.3, and 2.4 below. Note that vaccine effectiveness values V_e and V_i for booster doses are obtained as follows:

- For booster brand x (Pfizer, Moderna, and others), the vaccine effectiveness is affected by the vaccine brand y of the primary series (Pfizer, Moderna, Viral Vector and Inactivated). Let $w_{y,x}$ be the vaccine effectiveness when the primary series is brand y and the booster dose brand is x.
- Moreover, let p_y be the proportion of the cumulative number, up to the end of previous month, of individuals who were vaccinated with primary series of brand y.
- Then the vaccine effectiveness for booster brand x is given by the weighted average $\sum_y p_y w_{y,x}$.

Table 2.1: Vaccine Effectiveness against (Omicron) Symptomatic Disease, Second/Full Dose

(V_e) Weeks	Months	Sinovac	AstraZeneca	Gamaleya	Pfizer	Moderna	Janssen
2-4 weeks	1	37.9	43.0	43.0	64.0	73.0	43.00
5-9 weeks	2	28.2	32.0	32.0	49.0	51.0	32.00
10-14 weeks	3	19.4	28.0	28.0	29.0	35.0	28.00
	4	19.4	28.0	28.0	29.0	35.0	28.00
15-19 weeks	5	11.4	19.0	19.0	17.0	26.0	19.00
20-24 weeks	6	5.3	6.0	6.0	11.0	15.0	6.00
25+ weeks	7+	0.0	0.0	0.0	11.0	10.0	0.00

Table 2.2: Vaccine Effectiveness against (Omicron) Infection, Second/Full Dose

(V_i) Weeks	Months	Sinovac	AstraZeneca	Gamaleya	Pfizer	Moderna	Janssen
2-4 weeks	1	32.1	34.0	34.0	62.6	71.4	34.0
5-9 weeks	2	23.9	25.3	25.3	48.0	49.9	25.3
10-14 weeks	3	16.5	22.2	22.2	28.4	34.3	22.2
	4	16.5	22.2	22.2	28.4	34.3	22.2
15-19 weeks	5	9.7	15.0	15.0	16.6	25.4	15.0
20-24 weeks	6	4.5	4.7	4.7	10.8	14.7	4.7
25+ weeks	7+	0.0	0.0	0.0	10.8	9.8	0.0

Table 2.3: Vaccine Effectiveness against (Omicron) Symptomatic Disease, Booster Dose

(V_e) Weeks	Months	Sinovac	AstraZeneca	Gamaleya	Pfizer	Moderna	Janssen
2-4 weeks	1	47.7	47.7	47.7	59.6	66.6	47.7
5-9 weeks	2	42.6	42.6	42.6	53.3	60.7	42.6
10-14 weeks	3+	38.7	38.7	38.7	48.3	48.3	38.7

Table 2.4: Vaccine Effectiveness against (Omicron) Infection, Booster Dose

(V_i) Weeks	Months	Sinovac	AstraZeneca	Gamaleya	Pfizer	Moderna	Janssen
2-4 weeks	1	42.3	42.3	42.3	52.9	59.0	42.3
5-9 weeks	2	37.8	37.8	37.8	47.2	53.8	37.8
10-14 weeks	3+	34.3	34.3	34.3	42.9	42.9	34.4

For the succeeding discussion on epidemiological parameter estimation used for Model III, we introduce or recall the following notations:

$k_1,\ k_2,\ k_3\ k_4$	These are reduction factors applied to the transmission rate, based on the effectiveness of the first dose (partial), second dose, third dose (booster), and natural immunity, respectively.
c, c_1, c_2, c_3, c_4	These represent the proportion of asymptomatic and infectious individuals coming from E, E_1, E_2, E_3, and E_4, respectively.
$\alpha_a, \alpha_1^a\ \alpha_2^a, \alpha_3^a, \alpha_4^a$	These are transfer rates from the exposed compartments E, E_1, E_2, E_3, E_4 to the corresponding infectious and asymptomatic compartments $I_a, I_1^a, I_2^a, I_3^a\ , I_4^a$ respectively. $\alpha_a = \frac{c}{\tau},\ \alpha_i^a = \frac{c_i}{\tau}$ for $i = 1,2,3,4$
$\alpha_a, \alpha_1^s, \alpha_2^s, \alpha_3^s, \alpha_4^s$	These are transfer rates from the exposed compartments E, E_1, E_2, E_3, E_4 to the corresponding infectious and symptomatic compartments $I_s, I_1^s, I_2^s, I_3^s, I_4^s$ respectively. $\alpha_s = \frac{1-c}{\tau},\ \alpha_i^s = \frac{1-c_i}{\tau}$ for $i = 1,2,3,4$
$\varepsilon_I, \hat{\varepsilon}_I, \tilde{\varepsilon}_I,\ \varepsilon_T$	These are death rates due to COVID-19 disease. $\varepsilon_I, \hat{\varepsilon}_I, \tilde{\varepsilon}_I$ are death rates for undetected symptomatic individuals who are unvaccinated, partially vaccinated, and fully vaccinated (and reinfected), respectively. ε_T is death rate among confirmed individuals
$V_e,\ \hat{V}_e$	Vaccine effectiveness against symptomatic disease for a particular vaccine brand and dosage level (first/partial dose, second/full dose, booster dose) Weighted average of the V_e's across different vaccine brands for a particular dosage level, where each weight is equal to the proportion of the population vaccinated at the given dosage level with the corresponding vaccine brand
$V_i,\ \hat{V}_i$	Vaccine effectiveness against infection defined similarly as $V_e,\ \hat{V}_e$
V_s	Vaccine effectiveness, at a particular dosage level, against symptomatic disease given infection. This quantity satisfies the relation $\hat{V}_e = \hat{V}_i + V_s(1 - \hat{V}_i)$

Dominance of Variant

Two SARS-CoV-2 variants, Delta and Omicron, were present at the start of Model III implementation. To capture this situation in general, we assume that the proportions of COVID-19 cases caused by the Delta and Omicron variants are given by some constants $\pi_{Delta}, \pi_{Omicron}$, respectively, where π_{Delta} +

$\pi_{Omicron} = 1$. Due to lack of genome sequencing data, we assumed the following percentages for new COVID-19 cases that were attributable to the Delta and Omicron variants:

January 2022 - 90% Omicron and 10% Delta
February 2022 onwards - 100% Omicron

Computing k_1, c_1, $\hat{\varepsilon}_I$

We first compute $\hat{V}_e$, $\hat{V}_i$, and V_s for **first/partial dose**, at a particular month t.

The following table introduces notations for the V_e's and V_i's, against the Delta variant, for first/partial dose of the different vaccine brands. On the last row of the table, we introduce the notation for the number of individuals who were still partially vaccinated (i.e. waiting for their second dose) as of the end of the previous month.

Against Delta	Sinovac	AstraZeneca	Gamaleya	Pfizer	Moderna
V_e	$v_{1,S}$	$v_{1,A}$	$v_{1,G}$	$v_{1,P}$	$v_{1,M}$
V_i	$v_{2,S}$	$v_{2,A}$	$v_{2,G}$	$v_{2,P}$	$v_{2,M}$
# of individuals who, at previous month *(t-1)*, were still waiting for their second dose	p_1	p_2	p_3	p_4	p_5

We can then compute $\hat{V}_e$ and $\hat{V}_i$ against the Delta variant:

$$(\text{Delta})\ \hat{V}_e = \frac{v_{1,S}p_1 + v_{1,A}p_2 + v_{1,G}p_3 + v_{1,P}p_4 + v_{1,M}p_5}{p_1 + p_2 + p_3 + p_4 + p_5}; \quad (\text{Delta})\ \hat{V}_i = \frac{v_{2,S}p_1 + v_{2,A}p_2 + v_{2,G}p_3 + v_{2,P}p_4 + v_{2,M}p_5}{p_1 + p_2 + p_3 + p_4 + p_5}.$$

Using a similar table and similar formulas, we can then compute $\hat{V}_e$ and $\hat{V}_i$: $(\text{Omicron})\ \hat{V}_e$ and $(\text{Omicron})\ \hat{V}_i$.

The final values of $\hat{V}_e$, $\hat{V}_i$, and V_s for **first/partial dose** at month t can then be computed as follows:

$$\hat{V}_e = \pi_{Delta} \times (\text{Delta})\ \hat{V}_e + \pi_{Omicron} \times (\text{Omicron})\ \hat{V}_e$$
$$\hat{V}_i = \pi_{Delta} \times (\text{Delta})\ \hat{V}_i + \pi_{Omicron} \times (\text{Omicron})\ \hat{V}_i$$

$$V_s = \frac{\hat{V}_e - \hat{V}_i}{1 - \hat{V}_i}$$

Given that $\hat{V}_e$, $\hat{V}_i$, and V_s have been computed, the values of k_1, c_1 for month t can be computed as follows:

$$k_1 = 1 - \hat{V}_i$$
$$c_1 = 1 - (1 - c)(1 - V_s)$$

The death rate $\hat{\varepsilon}_I$, on the other hand, will utilize the most recent $\hat{V}_e$, and is computed as

$$\hat{\varepsilon}_I = \varepsilon_I(1 - \hat{V}_e)$$

Computing k_2, c_2, $\tilde{\varepsilon}_I$

We first compute $(\text{Delta})\ \hat{V}_e$, $(\text{Delta})\ \hat{V}_i$, $(\text{Omicron})\ \hat{V}_e$, and $(\text{Omicron})\ \hat{V}_i$ for individuals vaccinated with **two doses or a full dose** of a vaccine, at a particular month t. We incorporate waning vaccine-induced immunity so the V_e and V_i values change depending on how much time has passed since the second/full dose of the vaccine was administered. The process of computing each of $(\text{Delta})\ \hat{V}_e$, $(\text{Delta})\ \hat{V}_i$, $(\text{Omicron})\ \hat{V}_e$, and $(\text{Omicron})\ \hat{V}_i$ is the same aside from the V_e and V_i values used.

We introduce the following parameters using the table below:

Weeks (since 2nd/full dose was administered)	Months (since 2nd/full dose was administered)	Sinovac (S)	AstraZeneca (A)	Gamaleya (G)	Pfizer (P)	Moderna (M)	Janssen (J)
2-4 weeks	1	$v_{1,S}$	$v_{1,A}$	$v_{1,G}$	$v_{1,P}$	$v_{1,M}$	$v_{1,J}$
5-9 weeks	2	$v_{2,S}$	$v_{2,A}$	$v_{2,G}$	$v_{2,P}$	$v_{2,M}$	$v_{2,J}$
10-14 weeks	3	$v_{3,S}$	$v_{3,A}$	$v_{3,G}$	$v_{3,P}$	$v_{3,M}$	$v_{3,J}$
	4	$v_{4,S}$	$v_{4,A}$	$v_{4,G}$	$v_{4,P}$	$v_{4,M}$	$v_{4,J}$
15-19 weeks	5	$v_{5,S}$	$v_{5,A}$	$v_{5,G}$	$v_{5,P}$	$v_{5,M}$	$v_{5,J}$
20-24 weeks	6	$v_{6,S}$	$v_{6,A}$	$v_{6,G}$	$v_{6,P}$	$v_{6,M}$	$v_{6,J}$
25+ weeks	7+	$v_{7,S}$	$v_{7,A}$	$v_{7,G}$	$v_{7,P}$	$v_{7,M}$	$v_{7,J}$

In the following discussion, we present how the computation for $(\mathrm{Delta})\ \hat{V}_e$ is done for a given month *t*.

In the table above, set $v_{x,y}$ to be the V_e value, against the Delta variant, for an individual who received, x months ago, his/her 2nd/full dose of vaccine brand y. (The computation for $(\mathrm{Delta})\ \hat{V}_i$, $(\mathrm{Omicron})\ \hat{V}_e$, and $(\mathrm{Omicron})\ \hat{V}_i$ can be done analogously by using the corresponding $v_{x,y}$ values.)

We then proceed using the following table where:

- $n_{i,j}$ is the number of individuals (based on NVOC data) who received a 2nd/full dose of vaccine brand j during month i, where $i = 1,2,\dots,t-1$.
- $n_i = \sum_j n_{i,j}$ is the total number of second/full doses administered for month i.
- Define

$$T_i = \begin{cases} t-i, & \text{if } t-i \le 6, \\ 7, & \text{if } t-i \ge 7. \end{cases}$$

  This counts the number of months between month *t*, and the time when 2nd/full dose was administered, occurring at some prior month i. Considering the data on waning vaccine-induced immunity, all months i for which $T_i = 7$ belong to the category of "7+ months since 2nd/full dose administration."
- $w_i = \frac{\sum_j n_{i,j} v_{T_i,j}}{n_i}$ is the vaccine effectiveness of the 2nd/full dose administered at month i.

	Sinovac (S)	AstraZeneca (A)	Gamaleya (G)	Pfizer (P)	Moderna (M)	Janssen (J)	Total vaccinations for the month	Months since 2nd/full dose administration	Vax. effectiveness (V_e) at month *t*
Month 1	$n_{1,S}$	$n_{1,A}$	$n_{1,G}$	$n_{1,P}$	$n_{1,M}$	$n_{1,J}$	n_1	T_1	w_1
Month 2	$n_{2,S}$	$n_{2,A}$	$n_{2,G}$	$n_{2,P}$	$n_{2,M}$	$n_{2,J}$	n_2	T_2	w_2
Month 3	$n_{3,S}$	$n_{3,A}$	$n_{3,G}$	$n_{3,P}$	$n_{3,M}$	$n_{3,J}$	n_3	T_3	w_3
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Month $t-1$	$n_{t-1,S}$	$n_{t-1,A}$	$n_{t-1,G}$	$n_{t-1,P}$	$n_{t-1,M}$	$n_{t-1,J}$	n_{t-1}	$T_{t-1} = 1$	w_{t-1}

Given the above table, we can then compute $(\text{Delta})\ \hat{V}_e$ for month t as follows: Set $n = \sum_i n_i$.

$$(\text{Delta})\ \hat{V}_e = \sum_i \left[w_i \times \frac{n_i}{n} \right] = \frac{1}{n} \sum_i \sum_j n_{i,j} v_{T_i,j}$$

Once $(\text{Delta})\ \hat{V}_e$, $(\text{Delta})\ \hat{V}_i$,$(\text{Omicron})\ \hat{V}_e$, and $(\text{Omicron})\ \hat{V}_i$ are computed, we then derive $\hat{V}_e$, $\hat{V}_i$, and V_s for **second/full dose** at month t:

$$\hat{V}_e = \pi_{Delta} \times (\text{Delta})\ \hat{V}_e + \pi_{Omicron} \times (\text{Omicron})\ \hat{V}_e$$
$$\hat{V}_i = \pi_{Delta} \times (\text{Delta})\ \hat{V}_i + \pi_{Omicron} \times (\text{Omicron})\ \hat{V}_i$$

$$V_s = \frac{\hat{V}_e - \hat{V}_i}{1 - \hat{V}_i}$$

Given that $\hat{V}_e$, $\hat{V}_i$, and V_s have been computed, the values of k_2, c_2 for month t can be computed as follows:

$$k_2 = 1 - \hat{V}_i$$
$$c_2 = 1 - (1 - c)(1 - V_s)$$

The death rate $\tilde{\varepsilon}_I$, on the other hand, will utilize the most recent $\hat{V}_e$, and is computed as

$$\tilde{\varepsilon}_I = \varepsilon_I(1 - \hat{V}_e)$$

Computing k_3, c_3

We first compute $(\text{Delta})\ \hat{V}_e$, $(\text{Delta})\ \hat{V}_i$, $(\text{Omicron})\ \hat{V}_e$, and $(\text{Omicron})\ \hat{V}_i$ for individuals who have received a **booster dose** of a vaccine, at a particular month t. We incorporate waning vaccine-induced immunity so the V_e and V_i values change depending on how much time has passed since the booster dose of the vaccine was administered. The process of computing each of $(\text{Delta})\ \hat{V}_e$, $(\text{Delta})\ \hat{V}_i$, $(\text{Omicron})\ \hat{V}_e$, and $(\text{Omicron})\ \hat{V}_i$ is the same aside from the V_e and V_i values used.

We introduce the following parameters using the following table:

Weeks (since booster dose was administered)	Months (since booster dose was administered)	Sinovac (S)	AstraZeneca (A)	Gamaleya (G)	Pfizer (P)	Moderna (M)	Janssen (J)
2-4 weeks	1	$v_{1,S}$	$v_{1,A}$	$v_{1,G}$	$v_{1,P}$	$v_{1,M}$	$v_{1,J}$
5-9 weeks	2	$v_{2,S}$	$v_{2,A}$	$v_{2,G}$	$v_{2,P}$	$v_{2,M}$	$v_{2,J}$
10-14 weeks	3	$v_{3,S}$	$v_{3,A}$	$v_{3,G}$	$v_{3,P}$	$v_{3,M}$	$v_{3,J}$

In the following discussion, we present how the computation for (Delta) $\hat{V}_e$ is done for a given month t.

In the table above, set $v_{x,y}$ to be the V_e value, against the Delta variant, for an individual who received, x months ago, his/her booster dose of vaccine brand y. (The computation for $(\text{Delta})\ \hat{V}_i$, $(\text{Omicron})\ \hat{V}_e$, and $(\text{Omicron})\ \hat{V}_i$ can be done analogously by using the corresponding $v_{x,y}$ values.)

We then proceed using the following table where:

- $n_{i,j}$ is the number of individuals (based on NVOC data) who received a booster dose of vaccine brand j during month i, where $i = 1,2,\ldots,t-1$.
- $n_i = \sum_j n_{i,j}$ is the total number of booster doses administered for month i.

- Define

$$T_i = \begin{cases} t-i, & \text{if } t-i \leq 2, \\ 3, & \text{if } t-i \geq 3. \end{cases}$$

  This counts the number of months between month t, and the time when booster doses were administered, occuring at some prior month i. Considering the data on waning booster-induced immunity, all months i for which $T_i \geq 3$ belong to the category of "3+ months since booster dose administration."

- $w_i = \frac{\sum_j n_{i,j} v_{T_i,j}}{n_i}$ is the vaccine effectiveness of the booster dose administered at month i.

	Sinovac (S)	Astrazeneca (A)	Gamaleya (G)	Pfizer (P)	Moderna (M)	Janssen (J)	Total vaccinations for the month	Months since 2nd/full dose administration	Vax. effectiveness (V_e) at month t
Month 1	$n_{1,S}$	$n_{1,A}$	$n_{1,G}$	$n_{1,P}$	$n_{1,M}$	$n_{1,J}$	n_1	T_1	w_1
Month 2	$n_{2,S}$	$n_{2,A}$	$n_{2,G}$	$n_{2,P}$	$n_{2,M}$	$n_{2,J}$	n_2	T_2	w_2
Month 3	$n_{3,S}$	$n_{3,A}$	$n_{3,G}$	$n_{3,P}$	$n_{3,M}$	$n_{3,J}$	n_3	T_3	w_3
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Month $t-1$	$n_{t-1,S}$	$n_{t-1,A}$	$n_{t-1,G}$	$n_{t-1,P}$	$n_{t-1,M}$	$n_{t-1,J}$	n_{t-1}	$T_{t-1} = 1$	w_{t-1}

Given the above table, we can then compute $(\text{Delta})\ \hat{V}_e$ as follows: Set $n = \sum_i n_i$.

$$(\text{Delta})\ \hat{V}_e = \sum_i \left[w_i \times \frac{n_i}{n} \right] = \frac{1}{n} \sum_i \sum_j n_{i,j} v_{T_i,j}$$

Once $(\text{Delta})\ \hat{V}_e$, $(\text{Delta})\ \hat{V}_i$, $(\text{Omicron})\ \hat{V}_e$, and $(\text{Omicron})\ \hat{V}_i$ are computed, we then derive $\hat{V}_e$, $\hat{V}_i$, and V_s for **booster dose** at month t.

$$\hat{V}_e = \pi_{Delta} \times (\text{Delta})\ \hat{V}_e + \pi_{Omicron} \times (\text{Omicron})\ \hat{V}_e$$
$$\hat{V}_i = \pi_{Delta} \times (\text{Delta})\ \hat{V}_i + \pi_{Omicron} \times (\text{Omicron})\ \hat{V}_i$$

$$V_s = \frac{\hat{V}_e - \hat{V}_i}{1 - \hat{V}_i}$$

Given that $\hat{V}_e$, $\hat{V}_i$, and V_s have been computed, the values of k_3, c_3 for the month t can be computed as follows:

$$k_3 = 1 - \hat{V}_i$$
$$c_3 = 1 - (1-c)(1-V_s)$$

Computing k_4, c_4

For month t, the parameter k_4 is assumed to be the product of some multiplier m_t and k_3, while c_4 is assumed to be equal to c_3. The multiplier m_t is given by

$$m_t = \frac{\#\text{ of recoveries as of end of month } (t-4)}{\#\text{ of recoveries as of end of month } (t-1)}.$$

The description and values of the epidemiological parameters utilized in all FASSSTER COVID-19 models are presented in Table 3 and Table 4, respectively.

Remark: A discussion on the epidemiological parameters has been presented in Estuar, et al. (2022).

Table 3: Description of parameters in FASSSTER COVID-19 Models I, II, and III, and their corresponding sources

Variable	Description	Source (applied to Model 1: March 2020 - June 2021) Application I	Source (applied to Model 2: July 2021 - Dec 2021) Application II	Source (applied to Model 3: Jan 2023 onwards) Application III
R_0	Basic Reproduction Number	US Centers for Disease Control (2021)	US Centers for Disease Control (2021)	US Centers for Disease Control (2021)
A	Recruitment rate	macrotrends (2020a); Philippine Statistics Authority (2020)	macrotrends (2020a); Philippine Statistics Authority (2020)	macrotrends (2020a); Philippine Statistics Authority (2020)
μ	Natural death rate	macrotrends (2020b)	macrotrends (2020b)	macrotrends (2020b)
β_0	Baseline transmission rate	Derived from R_0	Derived from R_0	Derived from R_0
λ	Transmission reduction due to mobility restrictions and behavioral changes	Fitted	Fitted	Fitted
k_1, k_2	Transmission reduction due to vaccine effectiveness (partial, full)	n/a	Sheikh, Aziz, et al. (2021); Li, Xiao-Ning.,et al (2021).	United Kingdom Health Security Agency (2022)
k_3, k_4	Transmission reduction due to booster protection, previous infection	n/a	n/a	United Kingdom Health Security Agency (2022)
τ	Incubation period	World Health Organization (2020a)	World Health Organization (2020a)	Zeng, Kangwei, et al. (2023)
c	Proportion of asymptomatic infections	Mizumoto et. al. (2020)	Mizumoto et. al. (2020)	Mizumoto et. al. (2020)
c_1, c_2	asymptomatic proportion (partial and fully vaxxed)	n/a	Sheikh, Aziz, et al. (2021); Li, Xiao-Ning.,et al (2021).	United Kingdom Health Security Agency (2022)
c_3, c_4	asymptomatic proportion (boosted and reinfected)	n/a	n/a	United Kingdom Health Security Agency (2022)
ω	Transition rate from being asymptomatic to symptomatic	Mizumoto et al. (2020); World Health Organization (2020b)	Mizumoto et al. (2020); World Health Organization (2020b)	Mizumoto et al. (2020)); World Health Organization (2020b)
θ_a			World Health Organization (2020a)	United Kingdom Health Security Agency (2023)
θ_s	Symptomatic recovery rate	n\a	World Health Organization (2020a) (1/14)	United Kingdom Health Security Agency (2023)
δ_a	Detection rate for asymptomatic	Department of Health – Epidemiology Bureau (2021a)	Department of Health – Epidemiology Bureau (2021b)	Department of Health – Epidemiology Bureau (2022)

$\delta_1{}^a, \delta_2{}^a$	Detection rate for asymptomatic (partially and fully vaccinated)	n/a	Department of Health – Epidemiology Bureau (2021b)	Department of Health – Epidemiology Bureau (2022)
$\delta_3{}^a, \delta_4{}^a$	Detection rate for asymptomatic (boosted and reinfected)	n/a	n/a	Department of Health – Epidemiology Bureau (2022)
δ_s	Detection rate for symptomatic	Department of Health – Epidemiology Bureau (2021a)	Department of Health – Epidemiology Bureau (2021b)	Department of Health – Epidemiology Bureau (2022)
$\delta_1{}^s, \delta_2{}^s$	Detection rate for symptomatic (partially and fully vaccinated)	n/a	Department of Health – Epidemiology Bureau (2021b)	Department of Health – Epidemiology Bureau (2022)
$\delta_3{}^s, \delta_4{}^s$	Detection rate for symptomatic (boosted and reinfected)	n/a	n/a	Department of Health – Epidemiology Bureau (2022)
r	Recovery rate of confirmed cases	Department of Health – Epidemiology Bureau (2021a)	Department of Health – Epidemiology Bureau (2021b)	Department of Health – Epidemiology Bureau (2022)
ϵ_I	COVID-19 death rate of symptomatic cases	Department of Health – Epidemiology Bureau (2021a)	Department of Health – Epidemiology Bureau (2021b)	Department of Health – Epidemiology Bureau (2022)
ϵ_T	COVID-19 death rate of confirmed cases	Department of Health – Epidemiology Bureau (2021a)	Department of Health – Epidemiology Bureau (2021b)	Department of Health – Epidemiology Bureau (2022)
$\hat{\epsilon}_I$	COVID-19 death rate of symptomatic cases (partially vaccinated)	n/a	Department of Health – Epidemiology Bureau (2021b)	Department of Health – Epidemiology Bureau (2022)
$\tilde{\epsilon}_I$	COVID-19 death rate of symptomatic cases (fully vaccinated and reinfected)	n/a	n/a	Department of Health – Epidemiology Bureau (2022)

Table 4: Parameter values used in the three versions of the FASSSTER Epidemiological Model

Symbol	First Version	Second Version	Third Version
R_0	4	4	4
A	780.47	780.47	780.47
μ	4.0548×10^{-5}	4.0548×10^{-5}	4.0548×10^{-5}
β_0	0.4343	0.4343	0.4343
λ	fitted	fitted	fitted
k_1	n/a	baseline: 0.8116 MRNA: 0.7000	0.7584 - 0.7663

k_2	n/a	baseline: 0.3987 MRNA: 0.2100	0.7573-0.9297
k_3	n/a	n/a	0.4689 - 0.5904
k_4	n/a	n/a	0.3884 - 0.5766
τ	5	5	3
c	0.18	0.18	0.18
c_1	n/a	baseline: 0.2923 MRNA: 0.2151	0.2585 - 0.2653
c_2	n/a	baseline: 0.3987 MRNA: 0.3369	0.1841 - 0.2060
c_3	n/a	n/a	0.2509 - 0.2985
c_4	n/a	n/a	0.2509 - 0.298
ω	0.33	0.33	0.33
θ_a	0.071428571	0.071428571	0.1428571
θ_s	n/a	0.071428571	0.1428571
δ_a	0.1000 - 0.2000	0.25 δ_s	0.25 δ_s
${\delta_1}^a, {\delta_2}^a$	n/a	$0.1{\delta_1}^s,\ 0.1{\delta_2}^s$	$0.1{\delta_1}^s,\ 0.1{\delta_2}^s$
${\delta_3}^a, {\delta_4}^a$	n/a	n/a	$0.1{\delta_3}^s,\ 0.1{\delta_4}^s$
δ_s	0.1000 - 0.2000	0.1000 - 0.3000	0.1000 - 0.3000
${\delta_1}^s, {\delta_2}^s$	n/a	δ_s	δ_s
${\delta_3}^s, {\delta_4}^s$	n/a	n/a	δ_s
r	0.0855	0.09101277	0.1092861
ϵ_I	0.0018	0.00188883	0.001878105
ϵ_T	0.0018	0.00188883	0.001878105
$\hat{\epsilon}_I$	n/a	0.001363472524	0.0005881449109
$\tilde{\epsilon}_I$	n/a	n/a	0.0003373206319

III. Economic Parameters

Computing for economic losses Y^E and Y^{CQ} utilizes several economic parameters as described in Table 5. The values of these parameters used in various applications discussed in Section 4 of the manuscript are presented in Table 6.

Table 5: Description of Economic and Costing Parameters for the Dynamic Cost Estimation.

Symbol	Parameter Name	Source (Int. Model I)	Source (Int. Model II)	Source (Int. Model III)
s_r	Social discount rate	National Economic Development Authority – Investment Coordination Committee (2016)	National Economic Development Authority – Investment Coordination Committee (2016)	National Economic Development Authority – Investment Coordination Committee (2016)
φ	Displacement rate	Estimated Philippine Statistics Authority (2019a, 2019b); Department of Trade and Industry (2020a, 2020b, 2021)	Estimated Philippine Statistics Authority (2019a, 2019b); Department of Trade and Industry (2020a, 2020b, 2021a, 2021b)	Estimated Philippine Statistics Authority (2019a, 2019b); Department of Trade and Industry (2020a, 2020b, 2021a, 2021b)
w	Daily value added	Philippine Statistics Authority (2021, 2019a)	Philippine Statistics Authority (2021, 2019a)	Philippine Statistics Authority (2021, 2019a)
z	Annual gross value added	Philippine Statistics Authority (2021, 2019a)	Philippine Statistics Authority (2021, 2019a)	Philippine Statistics Authority (2021, 2019a)
ι_i	Share in deaths per age group	Calculated Department of Health – Epidemiology Bureau (2020b)	Calculated Department of Health – Epidemiology Bureau (2021)	Calculated Department of Health – Epidemiology Bureau (2021)
T_i	Average remaining productive years per age group	Calculated Department of Health – Epidemiology Bureau (2020b)	Calculated Department of Health – Epidemiology Bureau (2021)	Calculated Department of Health – Epidemiology Bureau (2021)
κ	Employed-to-population ratio	Calculated Philippine Statistics Authority (2020, 2019a, 2019b)	Calculated Philippine Statistics Authority (2020, 2019a, 2019b)	Calculated Philippine Statistics Authority (2020, 2019a, 2019b)

Table 6: Values of Economic and Costing Parameters for the Dynamic Cost Estimation

	Int. Model I, CQ	Int. Model II, CQ		Int. Model II, ALS	Int. Model III, ALS
annual wages (z) in PHP	168,905.75	168,905.75	annual wages (z) in PHP	168,905.75	168,905.75
daily wages (w) in PHP	672.93	672.93	daily wages (w) in PHP	672.93	672.93
Social discount rate (s_r)	10%	10%	Social discount rate (s_r)	10%	10%
Employed-to-population (κ)	0.47470891389567	0.47470891389567	Employed-to-population (κ)	0.47470891389567	0.47470891389567
ι_1 (0-14)	0.010340633	0.01093210587	ι_1 (0-14)	0.01093210587	0.005178365938
ι_2 (15-34)	0.0486618	0.05350978136	ι_2 (15-34)	0.05350978136	0.01596662831
ι_3 (35-49)	0.114355231	0.125575374	ι_3 (35-49)	0.125575374	0.02042577675
ι_4 (50-64)	0.316605839	0.2873993096	ι_4 (50-64)	0.2873993096	0.04602991945
T_1	59	57	T_1	57	58
T_2	37	39	T_2	39	38
T_3	21	24	T_3	24	24
T_4	6	9	T_4	9	9
T_5	5	8	T_5	8	7
ECQ (φ)	0.58636999	0.592528760	AL5 (φ)	0.4803588390	0.4803588390
MECQ (φ)	0.33120796	0.356182336	AL 4 (φ)	0.117252409	0.117252409
GCQ (φ)	0.24158221	0.247507557	AL 3 (φ)	0.08136519045	0.08136519045
MGCQ (φ)	0.07908420	0.078967161	AL 2 (φ)	0.0550082847	0.0550082847
			AL 1 (φ)	0.000000000	0.000000000

IV. Sector Classification

Table 7: General Classification of Sectors under each Category according to the Philippine Department of Trade and Industry at the Onset of the Pandemic.

Category	Sectors
I	Agriculture and auxiliary services, manufacturing of essential goods such as food and medicine, essential retail (of food, non-alcoholic beverages, and health-related goods), healthcare, logistics providers and courier services for essential goods, telecommunications, gasoline stations, media, essential construction, and business process outsourcing sectors
II	Manufacturing of non-essential goods, mining and quarrying, logistics providers and courier services for non-essential goods, hotel and accommodation, real estate and housing services, veterinary services, and security services
III	Bank and non-bank financial services, professional and business support services, publishing and printing, employment activities (i.e., recruitment), trade and repair of motor vehicles and parts, dining/restaurants, mall and commercial centers, non-leisure trade of goods, non-essential construction, and barbers and salon
IV	Gyms and sports facilities, internet cafes, education support services, entertainment, tours and travels, libraries and museums, pet grooming, and other personal care services

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