Comment on *"Impact of immune evasion, waning and boosting on dynamics of population mixing between a vaccinated majority and unvaccinated minority"* by Fisman et al. (2024):

Incorrect definition and application of a parameter ψ

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Abstract

We prove that Fisman et al. (2022, 2024) incorrectly define and apply a parameter ψ. They rely

solely on their parameter ψ to erroneously advance that the risk of infection incurred by

vaccinated persons due to contacts with unvaccinated persons is alarmingly "disproportionate".

Their faulty application of ψ would imply that the said risk increases with increasing segregation from the unvaccinated (up to complete segregation, η = 1), increases with increasing vaccination coverage (up to complete coverage, P_v = 1) and increases with increasing vaccine efficacy (up to perfect vaccine efficacy, VE = 1), which is contrary to reason. We show that Fisman et al.'s published errors in applying ψ have a potential to cause harm by encouraging overly aggressive (disproportionate) public health policies and interventions.

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1. Nature of the error made by Fisman et al.

Fisman et al. (2022, 2024) modelled hypothetical COVID-19 epidemics, assuming interacting groups of vaccinated and unvaccinated people, segregated to different degrees η, between 0 and 1, where η = 1 corresponds to total segregation (zero contacts between vaccinated and unvaccinated people).

In their model, Fisman et al. (2022, 2024) have introduced a new parameter (ψ), which (to our knowledge, having examined the literature), has not been used or adopted by other modelling research groups.

Their mathematical definition of ψ can be proven to be incorrect on three grounds, which are disjunctive and individually sufficient:

(1) ψ in its mathematical definition does not represent what Fisman et al. explicitly claim it to represent

(2) ψ — while claimed to represent the physical reality of risk incurred by vaccinated persons due to contacts with unvaccinated persons — diverges to exceedingly large values in approaching model parameter bounds

(3) ψ — while claimed to represent the physical reality of risk incurred by vaccinated persons due to contacts with unvaccinated persons — varies with changing model parameters in directions contrary to reason

We prove these points (1, 2 and 3) below. See Sections 4.1, 4.2 and 4.3, and also Section 5.

Fisman et al. (2022, 2024) explicitly rely on ψ for main conclusions in both their papers. They base these conclusions in their two papers solely on ψ. The conclusions do not follow from ψ values, and are also incorrect. The unfounded conclusions, if propagated, constitute a potential source of harm via thus misinformed public health policy and interventions.

The present refutation of the Fisman et al. (2022, 2024) errors related to their introduced ψ parameter is as succinct as possible, but it is more intricate than many readers might want. This is unavoidable because of the bullshit asymmetry principle, also known as Brandolini's law: *"The amount of energy needed to refute bullshit is an order of magnitude bigger than to produce it."* (Gelman, 2019).

2. How do Fisman et al. define ψ?

In the first paper, Fisman et al. (2022) define ψ as:

> "the fraction of all infections among vaccinated people that derived from contact with unvaccinated people, divided by the fraction of all contacts [involving vaccinated people] that occurred with unvaccinated people".

For convenience, we write this as:

$$\psi = B_v / f_{vu} = (H_{vu} / H_v) / (C_{vu} / C_v) \qquad (1)$$

where

- B_v is the fraction of all infections among vaccinated people that derived from contact with unvaccinated people (over the duration of the considered time period)
- f_{vu} is the fraction of all contacts involving vaccinated people that occurred with unvaccinated people
- H_{vu} is the number of infections among vaccinated people that derived from contact with unvaccinated people (over the duration of the considered time period)
- H_v is the number of all infections among vaccinated people (over the duration of the considered time period)
- C_{vu} is the number of contacts involving vaccinated people that occurred with unvaccinated people (over the duration of the considered time period)
- C_v is the number of all contacts involving vaccinated people (over the duration of the considered time period)

We re-coded the model (e.g., Hickey and Rancourt, 2023a) and established that this is indeed exactly the definition that Fisman et al. (2022) applied in producing their figures.

In the second paper, Fisman et al. (2024) state that they are using the same ψ parameter: "As in our earlier work we estimate a quantity that we denote ψ …". Note that there is again no cited reference, and that such a parameter has not, to our knowledge, previously been introduced in epidemiology, nor has introduction of such a parameter been motivated (e.g., Chapter 8 in Keeling and Rohani, 2008; Bjørnstad et al., 2020).

Fisman et al. (2024) then follow the above phrase with the only explicit definition of ψ stated in the text of the body of their 2024 paper, as:

> "As in our earlier work we estimate a quantity that we denote ψ,
> defined as the incidence of infections among the vaccinated population
> derived from contact with unvaccinated people, divided by the fraction
> of the population that is unvaccinated."

This definition of ψ is clearly and significantly different from the definition expressed in Equation 1 (above), and would be written as:

$$\psi = B_v \,/\, (1 - P_v) \qquad (2)$$

where P_v is the fraction (0 to 1) of the population that is vaccinated.

However, the definition of ψ given in the figure caption of Fisman et al. (2024)'s Fig. 3 is:

> "ψ is the ratio of the fraction infections acquired by vaccinated people
> from unvaccinated people divided by fraction of contacts with
> unvaccinated people." (*sic*)

Typo notwithstanding, this is the same as Equation 1 (above), the same as introduced by Fisman et al. (2022) in the first paper.

We verified Fisman et al. (2024)'s code, provided by them as an Excel calculation (their reference 26), and established that the two papers apply exactly the same definition of ψ: Equation 1 (above), and not the definition given in the text of the body of their 2024 paper (not Equation 2, above).

3. How do Fisman et al. interpret ψ?

Main interpretive statements regarding ψ, in Fisman et al. (2022, 2024) are:

1. "As like-with-like mixing increased (i.e., with reduced contact between vaccinated and unvaccinated subpopulations) … <u>the contribution of risk to vaccinated people caused by</u>

infection acquired from contact with unvaccinated people (as measured by ψ) increased. The larger the value of ψ, the more unvaccinated people contributed to infections in the vaccinated subpopulation." (2022: at pg. E575)

2. "The quantity ψ … remained above 1 throughout, signifying a disproportionate contribution to infection risk to vaccinated people by the unvaccinated population. When we estimated ψ cumulatively, the value at 10 years was approximately 2.14, meaning that infection among vaccinated people was more than twice as likely to have been acquired from unvaccinated people than would have been expected based on contact rates alone." (2024: at pg. 5/13)

3. "(Fig 4). Cumulative ψ rose as like-with-like mixing increased, but was elevated across all scenarios, indicating disproportionate contribution to risk among the vaccinated from the unvaccinated group." (2024: pg. 7/13)

4. "… while the contact-adjusted risk to vaccinated individuals associated with contact with unvaccinated groups is disproportionate." (2024: pg. 10/13, last sentence of the article)

The above statements by Fisman et al., while not being a model of clarity and constancy, allow one to tentatively infer that they believe ψ to measure:

- "the contribution of risk to vaccinated people caused by infection acquired from contact with unvaccinated people"

or

- the likelihood that "infection among vaccinated people was … acquired from unvaccinated people" compared to what "would have been expected based on contact rates alone"

In addition, Fisman et al. appear to imply that one can use ψ to ascertain whether the said risk or likelihood is "disproportionate", and that ψ measures the degree to which the risk or likelihood is "disproportionate". This is addressed in Section 6.

4. Proof that the Fisman et al. definition and interpretation of their ψ are incorrect

4.1. ψ does not represent what Fisman et al. claim it to represent

The statement "the contribution of risk to vaccinated people caused by infection acquired from contact with unvaccinated people (as measured by ψ)" means that ψ is a (valid and useful) measure of "the contribution of risk to vaccinated people caused by infection acquired from contact with unvaccinated people". This is false.

The quantity B_v [the fraction of all infections occurring in vaccinated people caused by contacts with unvaccinated people, $B_v = H_{vu} / (H_{vu} + H_{vv}) = H_{vu} / H_v$] is exactly "the contribution of risk to vaccinated people caused by infection acquired from contact with unvaccinated people". It measures the fraction of infections in the vaccinated, which were caused by contact with the unvaccinated. One cannot have a more direct and transparent measure of the risk in question.

Instead of interpreting and reporting B_v, Fisman et al. (2022, 2024) introduced the concocted parameter ψ, in which B_v is divided by f_{vu} [the fraction of all contacts experienced by vaccinated people, irrespective of whether the contacts were infectious or not, which were with unvaccinated individuals, $f_{vu} = C_{vu} / (C_{vu} + C_{vv}) = C_{vu} / C_v$].

It is far from clear why one would define a new parameter in this way, as $ψ = B_v / f_{vu}$ (Equation 1, above), since B_v itself is already a dimensionless ratio, the desired probability, bounded between 0 and 1, resulting from the full societal structure (η, P_v, etc.) and the contact frequencies. B_v does not need to be normalized or "adjusted".

Fisman et al. appear to be under the false impression that their definition of ψ provides the benefit of a "<u>contact-adjusted</u> risk to vaccinated individuals associated with contact with unvaccinated groups". Contact normalization of risk would involve putting the risk of infection

on a per contact basis. ψ does not achieve this. Likewise, ψ is not a relative risk, as it is not a ratio of risks of the same type.

This proves that ψ in its mathematical definition does not represent what Fisman et al. claim it to represent. Next, we examine how exceedingly large values and unreasonable variations of ψ result from its definition.

4.2.   ψ diverges to exceedingly large values

Examining the *ad hoc* parameter ψ further, it can be written:

$$\psi \;=\; B_v \,/\, f_{vu} \;=\; B_v \,/\, (C_{vu} \,/\, C_v) \;=\; B_v \,(C_v \,/\, C_{vu}) \qquad (3)$$

And — given the definitions of η and P_v — an exact expression for f_{vu} is:

$$f_{vu} \;=\; C_{vu} \,/\, C_v \;=\; (1 - \eta)\,(1 - P_v) \qquad (4)$$

Giving:

$$\psi \;=\; B_v \,/\, (1 - \eta)\,(1 - P_v) \qquad (5)$$

In other words, in defining ψ, Fisman et al. multiply the correct and exact expression for "the contribution of risk to vaccinated people caused by infection acquired from contact with unvaccinated people" (B_v, which is bounded between 0 and 1) by the unrelated quantity $1/f_{vu}$ (or C_v/C_{vu}), which necessarily (by its definition, and in view of Equations 4 and 5) is always greater than 1 and mathematically tends to infinity ($+\infty$) as η → 1 (η = 1 corresponds to complete segregation between the vaccinated and unvaccinated groups, or complete "like-with-like mixing") or as P_v → 1 (P_v = 1 corresponds to the entire population being vaccinated, no unvaccinated individuals). Little wonder that they report much "disproportionality", which they take to follow from ψ > 1 (see Section 6, below).

To formalize this, and to leave no ambiguity:

- as $\eta \to 1$ or as $P_v \to 1$, C_{vu} (the vaccinated-person contacts from unvaccinated persons) must go to zero

- as $\eta \to 1$ or as $P_v \to 1$, the value of C_v is a finite non-zero positive number since it is simply the number of contacts of any type experienced by the vaccinated group (it is zero only if $P_v = 0$)

- therefore, as $\eta \to 1$ or as $P_v \to 1$, $1/f_{vu} = C_v/C_{vu}$ tends to infinity (which equivalently also follows from Equation 4)

This provides a mathematical mechanism whereby ψ can acquire exceedingly large values.

We show by calculations illustrated in the figures below that this does indeed occur. The parameter ψ — by virtue of its incorrect design — exhibits exceedingly large values that cannot reasonably be assigned to the actual risk of interest.

4.3. ψ varies in directions contrary to reason

By virtue of its definition, $1/f_{vu} = C_v/C_{vu} = 1/[(1-\eta)(1-P_v)]$ not only is always greater than 1, and diverges to infinity as $\eta \to 1$ or as $P_v \to 1$, but also always increases with increasing η or with increasing P_v.

The figures below show that ψ also increases with increasing η (**Figure 1**) or with increasing P_v (**Figure 2**), almost always. In addition, ψ often increases with increasing vaccine efficacy VE (**Figure 1**, **Figure 3**).

These behaviours of ψ (shown in the figures below) would imply — adopting Fisman et al.'s incorrect interpretation of the meaning of ψ — that the "infection risk to vaccinated people by the unvaccinated population" or the "contact-adjusted risk to vaccinated individuals associated with contact with unvaccinated groups" ***increases*** (often strongly) as one:

- increases segregation between the vaccinated and unvaccinated groups (η); and/or

- increases the share of the population that is vaccinated (P_v); and/or

- increases vaccine efficacy (VE)

These are absurd consequences resulting from the definition and interpretation of ψ, the opposite of what must occur as η, P_v and VE are increased. The solution to this paradox is that ψ is an *ad hoc* parameter that is ill-defined and that does not mean what Fisman et al. take it to mean.

5. Demonstration of the unrealistic behaviour of ψ

As noted above, B_v is directly the risk of an infected vaccinated person having acquired their infection from an unvaccinated person. The said risk can then be evaluated as a function of the segregation of the two groups (η), vaccine efficacy (*VE*) or population fraction of vaccinated (P_v), and so on. In each case B_v has a straightforward interpretation of interest to policy makers (e.g., Hickey and Rancourt, 2023a, 2023b).

Therefore, it is useful to compare graphs of ψ with graphs of B_v, versus key model parameters, which is done in the following. This quantitatively illustrates the anomalous behaviours of ψ.

In particular, the Fisman et al. (2022) statement that "The larger the value of ψ, the more unvaccinated people contributed to infections in the vaccinated subpopulation" is mathematically incorrect. The opposite is generally true, as shown below.

Figures 1-3 show ψ (left panels) and B_v (right panels) versus η, P_v and *VE*, respectively.

All graphs in Figures 1-3 use the model parameters considered by Fisman et al. (2022): β = 437 yr^{-1} (probability of transmission per contact multiplied by number of contacts per year), γ = 73 yr^{-1}, *NI* = 0.2, and P_v = 0.8 if not otherwise indicated.

Here, *NI* is the proportion of the unvaccinated population that has pre-existing natural immunity at the outset of the epidemic. In the second paper Fisman et al. (2024) do not admit any pre-existing natural immunity, and do not make any mention of "natural immunity".

In Figures 1a and 1b (which have expanded Y-scales compared to Figures 1c and 1d), we note that B_v decreases with increasing η, whereas ψ increases with increasing η (for *VE > NI*). According to Fisman et al., this behaviour of ψ would mean that "the contribution of risk to vaccinated people caused by infection acquired from contact with unvaccinated people" increases with increasing like-with-like mixing (i.e., with increasing segregation between vaccinated and unvaccinated), and is largest for complete segregation (η = 1), even though B_v itself decreases to zero at η = 1 (for all values of *VE,* up to 1, see Figures 1c and 1d and the inset of Figure 1c), which is impossible.

Fisman et al.'s ill-defined "risk from unvaccinated people" (ψ) that monotonically goes to its largest value when the agent of risk is removed (η = 1) is an absurdity, of no valid utility in the real world.
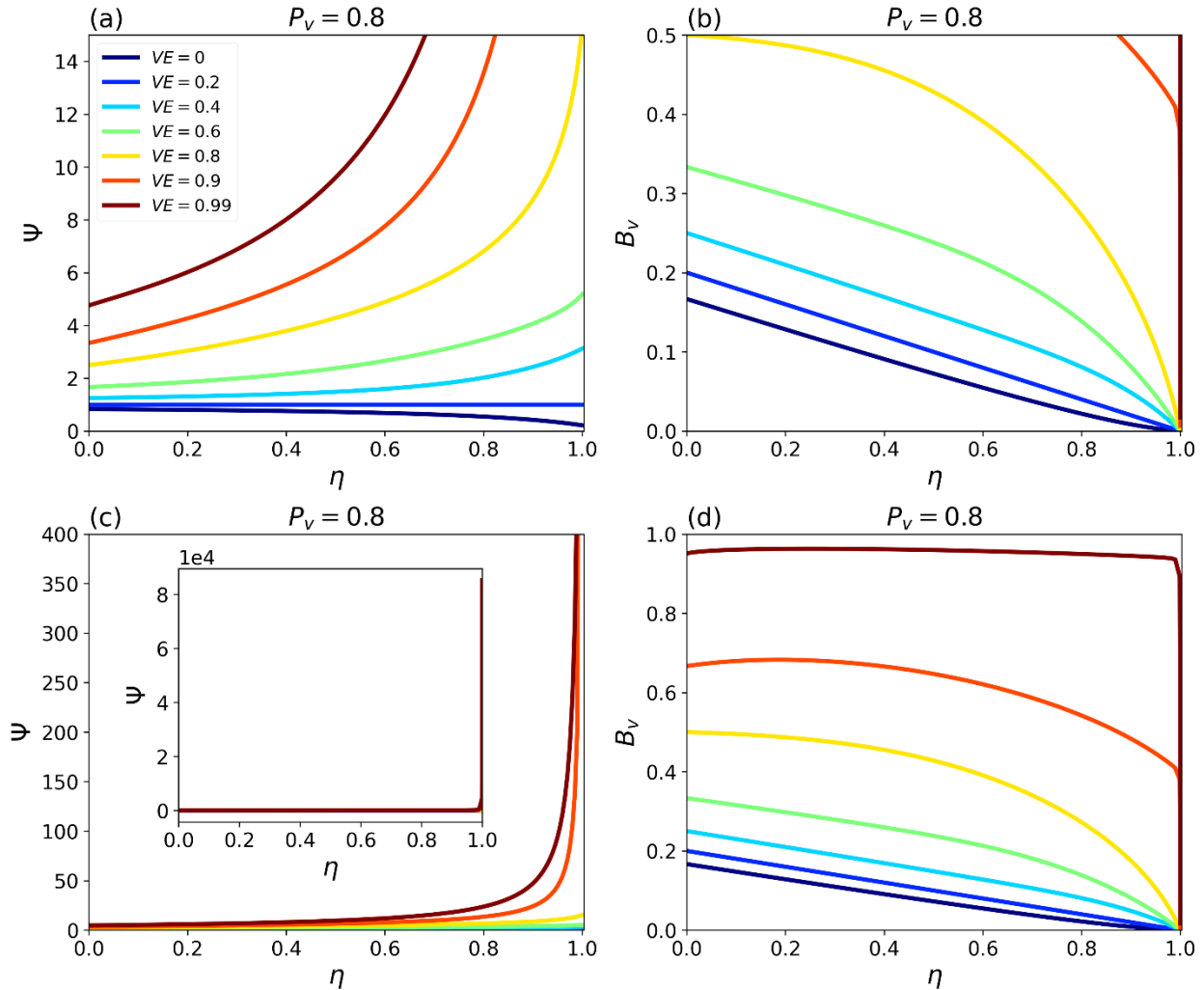
Figure 1: Panels (a) and (c): Fisman et al.'s ψ index vs the degree of segregation η, for different values of the vaccine efficacy *VE*. Panels (b) and (d): the fraction of all infections among vaccinated people that derived from contact with unvaccinated people, B_v, vs η, for different values of *VE*. Panels (a), (b), and (c) have expanded Y-axes, and the inset of panel (c) shows the full span of the Y-axis for the ψ vs η curves.

This meaningless result of largest "risk from unvaccinated people" (ψ) when nothing happens (η = 1), and increasingly so for increasing *VE* (when the vaccinated should be increasingly protected), is maintained and amplified for larger values of *VE*, as shown in Figure 1c. Here, Figure 1 illustrates the behaviours as η → 1 (using η = 0.999, 0.9999, …). Note that, although it is not apparent in the figure, ψ itself (as opposed to its factor $1/f_{vu}$) does not tend to infinity as η → 1. Rather, it converges to a large finite value for each value of VE.

The curves with $VE > NI$ ($VE = 0.4$ through 0.99) in **Figure 1** prove that the Fisman et al. (2022) statement "The larger the value of ψ, the more unvaccinated people contributed to infections in the vaccinated subpopulation" is unambiguously false. We see that the opposite is true: on increasing segregation η, where ψ increases (left panels), B_v decreases (right panels). B_v is defined "as the share of infections among vaccinated people that were due to contacts with infectious unvaccinated people", which is exactly the proportion that "unvaccinated people contributed to infections in the vaccinated subpopulation".

Here (**Figure 1**), as the vaccine is made perfectly effective (near-1 values of VE), "the contribution of risk to vaccinated people caused by infection acquired from contact with unvaccinated people", supposedly and incorrectly represented by ψ, now diverges (ψ diverges) to large values, orders of magnitude outside of any reasonable range compared to its values at the lower values of η (Figure 1c).

On the contrary, for VE near 1, the actual risk B_v does not diverge as one approaches η = 1, and there is virtually no change in B_v versus segregation η, up to nearly complete segregation (Figures 1b and 1d). It is difficult to reconcile the "disproportionate" risk from the unvaccinated (inferred from ψ as interpreted by Fisman et al. (2022, 2024): "their choices affect risk of viral infection among those who are vaccinated in a manner that is disproportionate to the portion of unvaccinated people in the population") with B_v decreasing with increasing η (**Figure 1**), while being virtually independent of η for large VE (**Figure 1**). In plain terms: In the real world, separation from the cause of risk reduces the risk. In the real world, there is no risk to the vaccinated, "disproportionate" or other, from the unvaccinated when $VE = 1$.

Figure 1 proves that the main stated inference of Fisman et al. based on their ψ ("disproportionate" to the degree that ψ is large) is false.

This should be sufficient to convince readers of the misguided approach of introducing and thus interpreting ψ, but there is more.

Figure 2 shows ψ and B_v versus P_v, for many values of η. Here, B_v monotonically decreases to zero as P_v is increased to 1, as expected, and has smaller and smaller values for larger and larger values of η.

In contrast, the "contribution of risk to vaccinated people caused by infection acquired from contact with unvaccinated people", as supposedly and incorrectly represented by ψ, monotonically increases as P_v is increased, and is systematically larger for larger values of η. This would mean that the "contribution of risk to vaccinated people caused by infection acquired from contact with unvaccinated people" increases the more people are vaccinated, and the more the vaccinated are segregated from the unvaccinated, up to the extreme values of total vaccination coverage ($P_v = 1$), and up to total segregation ($\eta = 1$), and both total vaccination coverage and total segregation ($P_v = 1$ and $\eta = 1$), which is contrary to reason.
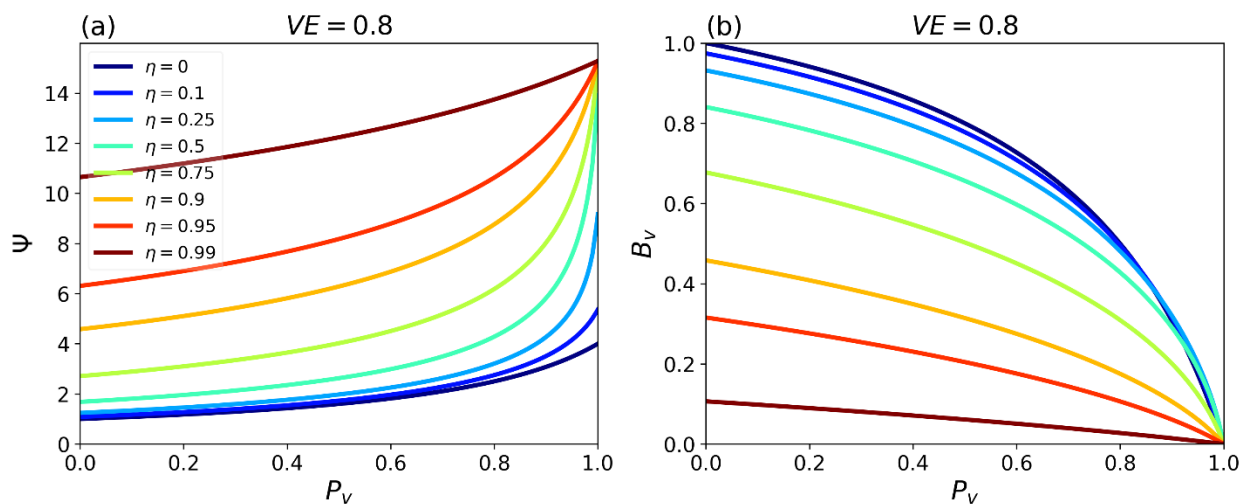
Figure 2: (a) ψ vs the population fraction of vaccinated people P_v for different values of the degree of segregation η. (b) B_v vs P_v for different values of η.

We learn, for example (Figure 2a), that the supposed "contribution of risk to vaccinated people caused by infection acquired from contact with unvaccinated people" or likelihood that "infection among vaccinated people was … acquired from unvaccinated people" compared to what "would have been expected based on contact rates alone" (ψ) is approximately "15" at

total vaccine coverage ($P_v = 1$) and for virtually total segregation ($\eta \to 1$) when $VE = 0.8$, which would be a stunning result if it were not meaningless.

In all the ψ-B_v pairs of curves shown in the two panels of **Figure 2**, for each of the values of η shown, the larger the value of ψ, the smaller the value of B_v (the less unvaccinated people contributed to infections in the vaccinated subpopulation); which again proves that the Fisman et al. (2022) statement "The larger the value of ψ, the more unvaccinated people contributed to infections in the vaccinated subpopulation" is rigorously incorrect.

In every case, we demonstrate that the *ad hoc* parameter ψ is not what Fisman et al. believe it to be.

Finally, **Figure 3** shows ψ and B_v versus vaccine efficacy VE, for many values of segregation η. Here, B_v goes to 1 in the limit as VE approaches 1, trivially because all of the infections of vaccinated individuals must come from unvaccinated individuals as VE approaches 1. Nonetheless, B_v values are systematically smaller for larger and larger segregation η, as expected; and B_v is essentially independent of η when VE is near 1, as also shown above (**Figure 1**).

The opposite is true of ψ (Figure 3a) and its interpretation made by Fisman et al.: the greater the segregation η, the more ψ increases; to astronomical values, as one goes to the larger values of VE. This inversion (compared to the behaviour of B_v) would mean that the more one is segregated, the greater the danger from being infected by the individuals one is segregated from, and all the more so if VE is high. This is difficult to reconcile with reality because it is nonsense, arising from the ill-defined "contact-adjustment" used to construct ψ (i.e., division by f_{vu}, see Equations 1, 3, 4 and 5).
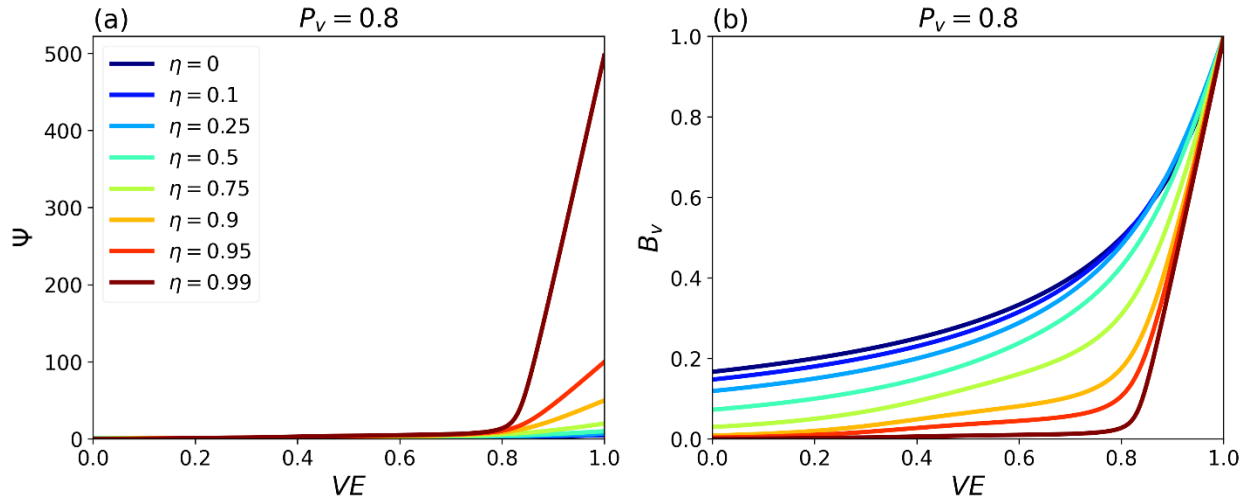
Figure 3: (a) ψ vs the vaccine efficacy *VE*, for different values of the degree of segregation η. (b) B_v vs *VE* for different values of η.

The fundamental problems with and absurdities arising from ψ are not removed in the second paper (Fisman et al., 2024), by adding "diminished vaccine efficacy for preventing infection with the emergence of Omicron SARS-CoV-2 variants, waning immunity, the impact of prior immune experience on infectivity, 'hybrid' effects of infection in previously vaccinated individuals, and booster vaccination" or by evaluations "over a 10-year time horizon".

For example, the following approximate values of cumulative ψ at time 0.2 years (after the epidemic wave) occur using the case featured by Fisman et al. (2024) ("Value" column in their Table 1), with differing values of segregation η and vaccine efficacy VE (Table 1, below).

Table 1: Cumulative ψ at 0.2 years, Fisman et al. (2024) featured case, with differing values of η and VE, calculated using their Excel calculator (their reference 26).

η (segregation)	VE (vaccine efficacy)	cumulative ψ at 0.2 years
0.95	0.8	8.5
0.99	0.99	160
0.999	0.99	1500

Following the erroneous interpretation of Fisman et al. (2024), these values of cumulative ψ would mean "that infection among vaccinated people [after 0.2 years] was [8.5 times, 160 times, 1500 times…] as likely to have been acquired from unvaccinated people than would have been expected based on contact rates alone", which is contrary to reason, at these values of segregation η and vaccine efficacy VE (Table 1).

Following the erroneous interpretation of Fisman et al. (2024), the supposed risk would paradoxically increase with increasing segregation η and increasing vaccine efficacy VE (Table 1, above). Again: In the real world, separation from the cause of risk (here, the unvaccinated) reduces the risk. In the real world, there is no risk to the vaccinated, "disproportionate" or other, from the unvaccinated when η = 1 or when VE = 1. The Fisman et al. interpretation of ψ is contrary to what is possible in reality.

6. Is the risk to the vaccinated from the unvaccinated ever actually "disproportionate"?

Fisman et al. use the word "disproportionate" or "disproportionately" regarding the risk from the unvaccinated 5 times in the first paper (2022) and 11 times in the second paper (2024). What do Fisman et al. mean, exactly?

It is virtually never clear what Fisman et al. mean by disproportionate risk, beyond meaning that the considered value of ψ is larger or much larger than 1.

In the Conclusion section of the first paper, Fisman et al. (2022) make a relatively definitive statement about disproportionality, incompatible with other statements they make involving ψ, as:

> "Using simple mathematical modelling, we have shown that, although risk associated with avoiding vaccination during a virulent pandemic accrues chiefly to those who are unvaccinated, the choice of some individuals to refuse vaccination is likely to affect the health and safety

> of vaccinated people in a manner <u>disproportionate to the fraction of</u>
> <u>unvaccinated people in the population</u>."

Well, the "likely[hood] to affect the health and safety of vaccinated people" is exactly the parameter B_v (= H_{vu}/H_v) ("the fraction of all infections among vaccinated people that derived from contact with unvaccinated people"), and "the fraction of unvaccinated people in the population" is $1 - P_v$.

Therefore, adopting this particular explanation by Fisman et al. (2022) quoted above, disproportionality would occur when $B_v > (1 - P_v)$, or when $B_v/(1 - P_v) > 1$, which has nothing to do with ψ.

Actually, $B_v/(1 - P_v)$ is often moderately greater than 1, for moderate segregation η. This is illustrated, for example with VE = 0.8, in **Figure 2**, above. Here, $B_v = (1 - P_v)$ would be the straight line extending from $(P_v , B_v) = (0, 1)$ to $(P_v , B_v) = (1, 0)$.

Contrary to the false interpretation advanced and implied by Fisman et al. (2022, 2024) — that the degree of disproportionality is measured by their ψ — any disproportionality or "underproportionality" ($B_v/(1 - P_v)$) of risk to the vaccinated from the unvaccinated is always moderate (no large or divergent values occur), larger than 1 for small η, and smaller than 1 for large η. Yes, contrary to Fisman et al., the vaccinated are the greatest risk to each other when they have little or no contacts with the unvaccinated, which is an unavoidable consequence.

In general: The actual disproportionality ($B_v/(1 - P_v)$) is a trivial consequence of vaccination and mixing. It is never as large as the large values of the concocted parameter ψ, and it can be greater, smaller, or equal to 1, depending on the parameters η, P_v, VE, NI, waning times, etc.

Fisman et al. (2022, 2024) cannot have it both ways, simultaneously using both an incorrect and a correct meaning of "disproportionate": mostly ψ, and a spattering of $B_v/(1 - P_v)$, respectively.

See also the discussion of Equations 1 and 2 above, arising from contradictory statements in the second article (Fisman et al., 2024).

7. The need to refute ψ in order to avoid harm

As demonstrated herein, Fisman et al. (2022, 2024) define and apply an *ad hoc* parameter ψ in such a way as to imply that the risk of infection to the vaccinated from the unvaccinated is "disproportionate", to a degree ψ, which is artificially and unrealistically large.

The resulting incorrectly inferred risk is unrelated to the actual risk, is virtually always larger than the actual risk, can be unrealistically large, and it nonsensically increases on increasing segregation η and/or increasing vaccinated population fraction P_v and/or increasing vaccine efficacy VE.

The ψ-based interpretation advanced by Fisman et al. (2022, 2024) has a potential to cause harm by encouraging overly aggressive (disproportionate) public health policies of intervention.

Therefore, the error of Fisman et al. should be corrected with clear publishers' notices, or it will make its way into established venues.

For example, a recent cross-sectional survey cites Fisman et al. (2022) as (Are et al., 2024, their reference 15):

> "Modelling studies have explored the impact of homophily in a range of contexts, and its impact on transmission dynamics is well documented [13, 14]. For instance, one modelling study argued that the mixing of vaccinated and unvaccinated groups contributes to a considerable risk of infection for the vaccinated group, <u>occurring at a rate that is disproportionately higher than what would be expected based solely on the contact between the two groups</u> [15]."

As another example, one that is directly political, we have these 29 April 2022 statements by lawmakers in Canada's Parliament referring to and relying on the first paper (Fisman et al., 2022) (Hansard-61, 2022, at pp. 4545-4546):

> **Mr. Blaine Calkins (Red Deer—Lacombe, CPC):**
>
> Madam Speaker, if the NDP-Liberals will not follow the province's lead and give unvaccinated Canadians their rights back, maybe they will follow our international partners. We know that the Prime Minister values his playboy image on the world stage more than anything else, as his travels and selfies prove, but our international partners are bewildered as to why the Canadian government is so reluctant to let life return to normal for all Canadians.
>
> Switzerland and Greece are removing all travel-related restrictions next week and virtually no other country requires them for domestic travel for their citizens, <u>so why will the government not follow the science</u>?
>
> **Mr. Adam van Koeverden (Parliamentary Secretary to the Minister of Health and to the Minister of Sport, Lib.):**
>
> Madam Speaker, I thank my hon. colleague for giving me the opportunity to <u>highlight a recent study indicating that unfortunately the unvaccinated continue to disproportionately risk the safety of those vaccinated against COVID-19</u>, and highlight the fact that in the last week, almost 12,000 Canadians have received their first dose, 30,000 Canadians have received their second, 89,000 received their third and over 220,000 have received their fourth dose.
>
> This pandemic is not over. We all want it to be, but <u>we must continue to follow the science</u>, we must continue to support our neighbours, we must continue to fight for kids to ensure that young people under six do not get COVID-19, as they have been the biggest numbers in the last couple of days.

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