

# Exodus probabilities from a structural-zero category: Illustration of public knowledge, perception, and communication on COVID-19

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## Research

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# EXODUS PROBABILITIES FROM A STRUCTURAL-ZERO CATEGORY: ILLUSTRATION OF PUBLIC, KNOWLEDGE, PERCEPTION, AND COMMUNICATION ON COVID-19

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## Abstract

**Background:** Medical and healthcare professionals and governing agencies have faced big challenges to control, intervene and prevent the spread of COVID-19. In analysis of survey data on COVID-19, some practiced probability laws are nullified. Among those probability laws, the structural-zero (different from sampling zero) category with respect to the people's knowledge, perception, and communication about the COVID-19 pandemics occurs in surveys is an example.

**Results:** Exodus probabilities are derived and utilized. Using a recent survey data on COVID-19, the proposed method to configure such probabilities (proportions) is illustrated.

**Conclusion:** The research question is about a way to configure the proportions who might have transited from the structurally zero category to other viable categories. This research question is answered in a novel manner.

**Keywords:** Conditional probabilities; exodus probabilities; Venn diagram; measure of dependency; odds; odds ratio; survey results.

## **Introduction**

It is quite needless to formally describe the pandemic COVID-19 (otherwise known as coronavirus) ever since January 2020, the whole world is frightened by the viral nature of this pandemic. The virus was detected on 24th January 2020, in the Wuhan city (capital of the Hubei province), China (Cohen, 2020). China reported to have seen 1,287 coronavirus cases and 41 among them have died [7 for details]. When the World Health Organization (WHO) was informed by China, the WHO chose to give the name COVID-19 to this deadly virus and declared it a pandemic as it spread to almost all countries in the world. First, it was falsely understood that the COVID-19 was contagious from dead or alive animals and the virus did not spread from a human to another human [5].

Despite a pandemonium which existed in many nations around the world, China discovered that on 25th March 2020, an estimated 81,285 persons contracted COVID-19 and 3,287 of them died. Alarmed by this rapid increase, many nations quarantined their people in their home and educated the citizens to do social distancing and adapt several personal hygienic practices as the incubation time between the exposure and disease onset was estimated (not medically proven) to be 2 to 14 days [1]. As of 30<sup>th</sup> May 2020, there have been more than 5,817,385 COVID-19 cases worldwide and at least 362,705 deaths have occurred already (see <https://www.who.int/situation-report-131.pdf> for details). The numbers are staggering and changing daily. The gravity of the health hazards and the fear of death cannot be adequately described. The day to day activities were crippled. The productivity reached near zero everywhere on earth.

The COVID-19 has been destructive and challenging to medical and healthcare professionals and governing agencies. For analysis of survey data, some practiced probability laws are nullified. Among those probability laws, the structural-zero (different from sampling zero) category with respect to the people's knowledge, perception, and communication about the COVID-19 pandemics occurs in surveys is an example. Is there a way to configure the proportions who might have transited from the fourth (structurally zero) category to other three viable categories? This question is answered in a novel manner in this manuscript using a recent survey data on COVID-19.

### **Public Knowledge, Perception, and Scientific Communication**

A COVID-19 [3] survey was conducted among the Malaysians to examine their public knowledge, perception, and scientific communication about the COVID-19. The public knowledge is often connected with the risk to survive. The perception is based on more of cultural or gender bias. The Science communication is a skill due to education to effectively disseminate information in the public domain. See also a follow-up article by [4] to raise the awareness of possible epidemic trajectories (due to the second wave of COVID-19) after Malaysia's Movement Control Order (MCO) is lifted. In Malaysia, the first COVID-19 wave occurred between 24 January 2020 and 21 February 2020. The second wave began on 27 February 2020. The Malaysian government announced a MCO, which had been extended already three times by two weeks each time.

The outcome of their online anonymous survey is summarized in Tables 1 through 3. It is this data that provided basic motivation to prepare this article. In the survey, there were five, six,

eight questions posed to the respondents in knowledge, perception, and communication categories. For each question, a respondent answers either (*A*) agree, (*B*) disagree, or ( $\overline{AB}$ ) neither. Notice that the possibility for (*AB*) is void. Consequently, the option (*AB*) is nullified and became a structurally zero category. The structural zero category arises in a situation in which it is impossible to have a response. The literature distinguishes the difference between the structural zero and sampling zero scenarios [2 for details]. In other words, a proportion in this structurally zero category ought to have transited to one of other three categories: (*A*) agree, (*B*) disagree, or ( $\overline{AB}$ ) neither. How much are such proportions who might have done exodus from the structural zero category to the three categories?

**Table 1: Survey data on Malaysians knowledge about COVID-19 [3]**

<b>Knowledge</b>	<b>A (agree)</b>	<b>B (disagree)</b>	<b><math>\overline{AB}</math> (neither)</b>
K1: COVID-19 is a contagious disease that causes symptoms in lungs and airways like coughing, sore throat and difficulty breathing. (True)	0.989	0.008	0.003
K2: COVID-19 is caused by a bacterium called SARS-CoV-2 and can be treated with antibiotics. (False)	0.171	0.182	0.647
K3: COVID-19 is a disease caused by a virus that previously only infected animals but now infects humans. (True)	0.702	0.141	0.157
K4: COVID-19 is a pandemic disease which means it was not making people sick previously, but now has spread all over the world. (True)	0.685	0.121	0.194
K5: There is currently no approved vaccine to prevent COVID-19. (True)	0.935	0.040	0.025

**Table 2: Survey data on Malaysians perception about COVID-19 [3]**

<b>Perception</b>	<b>A (agree)</b>	<b>B (disagree)</b>	<b><math>\bar{AB}</math> (neither)</b>
P1: I believe COVID-19 is a very deadly disease	0.790	0.116	0.094
P2: I am worried about me and my loved ones getting sick with COVID-19	0.963	0.028	0.009
P3: I am worried about spreading COVID-19 to others.	0.944	0.036	0.020
P4: I am worried about the impact of COVID-19 on my work, livelihood and the economy.	0.961	0.027	0.012
P5: I am able to reduce my risk of getting COVID-19 by avoiding crowded public areas, keeping my hands clean, and not touching my face.	0.991	0.005	0.004
P6: The closures of areas of congregations such as schools and places of worship are an extreme and unnecessary measure to control the spread of COVID-19.	0.164	0.086	0.750

**Table 3. Data on Malaysians communication about COVID-19 \* [3]**

<b>Communication</b>	<b>A (agree)</b>	<b>B (disagree)</b>	<b><math>\bar{AB}</math> (neither)</b>
C2: I obtain most of my information on COVID-19 from friends, family and social groups on social media (WhatsApp, Facebook, IG, Twitter, TikTok).	0.668	0.151	0.181
C3: I do not understand details about COVID-19 because they are too technical and complicated.	0.116	0.209	0.675
C4: I am more likely to understand and prefer to receive info about COVID-19 on video rather than articles or static visuals/infographics.	0.430	0.335	0.235
C5: I have received a lot of quality information on COVID-19 on social media	0.773	0.149	0.078
C6: I have received a lot of questionable information/fake news on COVID-19 on social media.	0.779	0.139	0.082
C7: I am eager to share information that I think can help us reduce the risk and spread of COVID-19.	0.798	0.152	0.050
C8: I check information I receive on social media with sources such as health & government agency websites and science news outlets before sharing/forwarding to others	0.879	0.098	0.023
C9: The communication I have received about COVID-19 has strongly influenced how I think about the disease and what I do to protect myself, my loved ones, and my community	0.945	0.047	0.008

- For some reason, the item C1 is not reported in [3].

## Methods

### Exodus probabilities: New Probability Expressions

In conjunction with the stated research aim in the previous section, let the sample space consists of three mutually exclusive possible categories:  $S = \{A, B, \bar{A} \cap \bar{B}\}$  in the Venn diagram. See [6] for the definition and properties of the Venn diagram. An answer to any (knowledge, perception, or communication) question is associated with the options of selecting only anyone of the three mutually exclusive categories since  $\Pr(AB) = 0$  by the default of structural zero. In other words,  $\Pr(S) = 1$ . Also,  $\Pr(\bar{A} \cap \bar{B}) = 1 - \Pr(A \cup B) = 1 - \Pr(A) - \Pr(B)$  due to the DeMorgan's law [6 for details] and the structural zero fact  $\Pr(A \cap B) = 0$ . We now introduce a probability type measure given in (1).

$$\theta_{\bar{A}} = \frac{\Pr(\bar{A}) - \Pr(\bar{A} \cap \bar{B})}{1 - \Pr(\bar{A} \cap \bar{B})} \quad (1)$$

Because the probability of an intersection event is less than the marginal probability (that is  $0 \leq \Pr(\bar{A} \cap \bar{B}) \leq \Pr(\bar{A}) \leq 1$ ), we notice that  $0 \leq \theta_{\bar{A}} \leq 1$ . Hence, we formally define the exodus odds in the definition 1 below to refer the odds of transiting from a structural-zero event.

**Definition1.** The exodus odds of transiting from the structurally zero category,  $A \cap B$  to the category  $\bar{A}$  is

$$\left(\frac{\theta_{\bar{A}}}{1 - \theta_{\bar{A}}}\right) = \frac{\Pr(\bar{A}) - \Pr(\bar{A} \cap \bar{B})}{1 - \Pr(\bar{A})}$$

Likewise, we define its complementary exodus odds for transiting from a structurally zero category,  $A \cap B$  to the category  $\bar{B}$ . Analogous expression is

$$\theta_{\bar{B}} = \frac{\Pr(\bar{B}) - \Pr(\bar{A} \cap \bar{B})}{1 - \Pr(\bar{A} \cap \bar{B})}$$

which possesses properties like what exists for (1). By combining both expressions, we notice that

$$\theta_{\bar{B}} = \theta_{\bar{A}} - \frac{\Pr(\bar{A}) - \Pr(\bar{B})}{1 - \Pr(\bar{A} \cap \bar{B})} \quad (2)$$

where

$$\frac{\Pr(\bar{A}) - \theta_{\bar{A}}}{1 - \theta_{\bar{A}}} = \Pr(\bar{A} \cap \bar{B}) = \frac{\Pr(\bar{B}) - \theta_{\bar{B}}}{1 - \theta_{\bar{B}}}$$

is a proportionality statement and it yields an imbalance measure between the events  $\bar{A}$  and  $\bar{B}$

$$\Delta = \{\theta_{\bar{B}} + (1 - \theta_{\bar{B}}) \Pr(\bar{A})\} - \{\theta_{\bar{A}} + (1 - \theta_{\bar{A}}) \Pr(\bar{B})\} \quad (3)$$

We name  $\theta_{\bar{A}}$  and  $\theta_{\bar{B}}$  the exodus probability to  $A$  and  $B$  respectively. In conjunction with the exodus probabilities, realize that

$$1 - P(A) - P(B) = P(\bar{A} \cap \bar{B}) \quad P(A) = 1 - P(\bar{A}) = P(A \cap \bar{B}),$$

$$P(B) = 1 - P(\bar{B}) = P(\bar{A} \cap B)$$

because  $P(A \cap B) = P(\text{empty}) = 0$ .

Furthermore, we notice from (1) that  $\Pr(\bar{A} \cap \bar{B}) = \frac{\Pr(\bar{A}) - \theta_{\bar{A}}}{1 - \theta_{\bar{A}}}$  implying that

$$1 = (1 - \theta_{\bar{A}}) \Pr(\bar{B} | \bar{A}) + \frac{\theta_{\bar{A}}}{\Pr(\bar{A})}$$

Consequently, the conditional probability could be written as

$$\Pr(\bar{B} | \bar{A}) = \frac{[\Pr(\bar{A}) - \theta_{\bar{A}}]}{[1 - \theta_{\bar{A}}] \Pr(\bar{A})} \quad (4)$$

It is well known that the conditional probability is no lesser than the unconditional probability.

That is,  $\Pr(\bar{B}|\bar{A}) \geq \Pr(\bar{B})$ . Hence, we can assess how much an impact of knowing that  $\bar{A}$  has

occurred on speculating the likelihood of  $\bar{B}$  and such an impact is

$$\delta_{\bar{A} \rightarrow \bar{B}} = \Pr(\bar{B}|\bar{A}) - P(\bar{B}) = \frac{\{\Pr(\bar{A}) - \Pr(\bar{A} \cap \bar{B})\} - \theta_{\bar{A}}\{1 - \Pr(\bar{A} \cap \bar{B})\}}{(1 - \theta_{\bar{A}})\Pr(\bar{A})} \quad (5)$$

An analogous expression to quantify the impact of knowing that  $\bar{B}$  has occurred on speculating the likelihood of  $\bar{A}$  and such an impact is

$$\delta_{\bar{B} \rightarrow \bar{A}} = \Pr(\bar{A}|\bar{B}) - P(\bar{A}) = \frac{\{\Pr(\bar{B}) - \Pr(\bar{A} \cap \bar{B})\} - \theta_{\bar{B}}\{1 - \Pr(\bar{A} \cap \bar{B})\}}{(1 - \theta_{\bar{B}})\Pr(\bar{B})} \quad (6)$$

**Definition2.** The exodus odds of transiting from the structurally zero category,  $A \cap B$  to the category,  $\bar{B}$  is

$$\left(\frac{\theta_{\bar{B}}}{1 - \theta_{\bar{B}}}\right) = \frac{\Pr(\bar{B}) - \Pr(\bar{A} \cap \bar{B})}{1 - \Pr(\bar{B})}.$$

We now could define the exodus odds ratio of transiting from the structurally zero category,

$A \cap B$  is then

$$Odds\_Ratio_{\bar{A}/\bar{B}} = \left(\frac{\theta_{\bar{A}}[1 - \theta_{\bar{B}}]}{\theta_{\bar{B}}[1 - \theta_{\bar{A}}]}\right) = \left\{\frac{\Pr(\bar{B})}{\Pr(\bar{A})}\right\} \left\{\frac{\Pr(\bar{A}) - \Pr(\bar{A} \cap \bar{B})}{\Pr(\bar{B}) - \Pr(\bar{A} \cap \bar{B})}\right\} \quad (7)$$

When the odds ratio,  $Odds\_Ratio_{\bar{A}/\bar{B}}$  is more than one, the exodus odds to the category,

$\bar{A}$  is more likely than its counterpart category,  $\bar{B}$  from the structurally zero category,  $A \cap B$ .

### Illustration Using Malaysian Survey Data on COVID-19

We now illustrate the derived expressions of Section 2 using the survey data about the

Malaysians' public knowledge, perception, and scientific communication on the COVID-19. See

Table 1 through Table 3 for the observed proportions in each category given in [3]. There were five, six, and eight questions in the survey covering the respondents' knowledge, perception, and communication about the COVID-19. Some of the questions are true and others are false. The truth or falseness of the questions were not revealed to the respondents. The entries in the table are the proportions who agree (disagree) with the question. The events  $A$  and  $B$  denote respectively the agreement and disagreement by the respondents.

The simultaneous occurrence of the event  $A \cap B$  is therefore nullified and hence, the category  $A \cap B$  is structurally zero category. The proportion that would have been in the category  $A \cap B$  if the category were to be not structurally zero type ought to have migrated to  $A$ ,  $B$ , or  $\bar{A} \cap \bar{B}$  category. What are such exodus proportions in their transit? That is what explained in this section. For this purpose, the expressions (1) through (7) are calculated and displayed in the Table 4, Table 5, and Table 6 below for the Malaysians' knowledge, perception, and communication, respectively.

**Table 4. Exodus probabilities for knowledge on COVID-19**

<b>Question</b>	$\theta_{\bar{A}}$ <b>in (1)</b>	$\theta_{\bar{B}}$ <b>in (2)</b>	$\delta_{\bar{A} \rightarrow \bar{B}}$ <b>in (5)</b>	$\delta_{\bar{B} \rightarrow \bar{A}}$ <b>in (6)</b>	<i>Odds _ Ratio</i> $_{\bar{A} \bar{B}}$ <b>on (7)</b>
K1	0.008	0.991	0.003	1.4E-14	6.543E-05
K2	0.515	0.484	-0.168	1.3E-16	1.132
K3	0.167	0.832	0.006	0	0.040
K4	0.150	0.849	-0.024	0	0.031
K5	0.041	0.958	0.011	-2.8E-15	0.001

**Table 5. Exodus probabilities for perception on COVID-19**

<b>Question</b>	$\theta_{\bar{A}}$ <b>in (1)</b>	$\theta_{\bar{B}}$ <b>in (2)</b>	$\delta_{\bar{A} \rightarrow \bar{B}}$ <b>in (5)</b>	$\delta_{\bar{B} \rightarrow \bar{A}}$ <b>in (6)</b>	<i>Odds _ Ratio</i> $_{\bar{A} \bar{B}}$ <b>on (7)</b>
P1	0.128	0.872	0.023	0	0.021
P2	0.028	0.972	0.015	-4E-15	0.001
P3	0.037	0.963	0.011	3.1E-15	0.002
P4	0.027	0.973	0.011	0	0.001
P5	0.005	0.995	0.001	0	3E-05
P6	0.344	0.656	-0.254	1.8E-16	0.275

**Table 6. Exodus probabilities for communication on COVID-19**

Question	$\theta_{\bar{A}}$ in (1)	$\theta_{\bar{B}}$ in (2)	$\delta_{\bar{A} \rightarrow \bar{B}}$ in (5)	$\delta_{\bar{B} \rightarrow \bar{A}}$ in (6)	<i>Odds _ Ratio</i> $_{\bar{A} \bar{B}}$ on (7)
C2	0.184	0.816	0.002	-7.1E-16	0.051
C3	0.643	0.357	-0.065	0	3.246
C4	0.438	0.562	0.277	-1.9E-16	0.606
C5	0.162	0.838	0.071	0	0.037
C6	0.151	0.849	0.056	0	0.031
C7	0.160	0.840	0.103	-8.2E-16	0.036
C8	0.100	0.900	0.071	1.23E-15	0.012
C9	0.047	0.953	0.035	-2.5E-15	0.002

In Tables 4 through 6, we notice that  $\theta_{\bar{A}}$  in (1) is negligible in almost all knowledge, perception, and communication questions but is significantly high only in the false knowledge question, K2 (COVID-19 is caused by a bacteria called SARS-CoV-2 and can be treated with antibiotics) and in the communication question, C3 (I do not understand details about COVID-19 because they are too technical and complicated).

On the contrary, in Tables 4 through 6, we notice that  $\theta_{\bar{B}}$  in (2) is moderate only in false question K2 (COVID-19 is caused by a bacteria called SARS-CoV-2 and can be treated with antibiotics) and true question C3 (I do not understand details about COVID-19 because they are too technical and complicated) but is quite high in other all knowledge, perception, and communication questions of COVID-19.

The data analytic results in Tables 4 through 6 suggest that the impact of knowing  $\bar{A}$  on the likelihood of  $\bar{B}$  in (5) is negative in the false knowledge question K2 (COVID-19 is caused by a bacteria called SARS-CoV-2 and can be treated with antibiotics) and the true knowledge question K4 (COVID-19 is a pandemic disease which means it was not making people sick previously, but now has spread all over the world), in the perception question P6 (The closures of areas of congregations such as schools and places of worship are an extreme and unnecessary measure to control the spread of COVID-19), in the true communication question C3 (I do not understand details about COVID-19 because they are too technical and complicated). For all other questions, the impact has been positive but mild.

Interestingly, the impact of knowing  $\bar{B}$  on the likelihood of  $\bar{A}$  in (6) is negligible, consistently in all questions of knowledge, perception, and communicative categories. The exodus odds ratio in (7) of transiting from the structural event  $A \cap B$  is only in false knowledge question K2 (COVID-19 is caused by a bacteria called SARS-CoV-2 and can be treated with antibiotics) and in the true communication question C3 (I do not understand details about COVID-19 because they are too technical and complicated). For all other questions in knowledge, perception, and communication categories, the exodus odds ratio is less than one. The exodus odds to the event  $\bar{A}$  is more likely than its counterpart exodus odds to the event  $\bar{B}$  from the structurally zero category,  $A \cap B$ .

### **Concluding Remarks**

This research article has introduced new concepts called exodus probabilities from a structural-zero category. The structural zero is unavoidable if the surveys consist of two mutually exclusive

questions or options. A respondent could not be counted in both places. For such a scenario, this article derived new probability expressions (not seen in the journals or books so far). With the availability of the new expressions in this article, we have successfully interpreted and sorted out how the Malaysians have felt about the COVIDS-19 in a recent survey.

### **Abbreviations**

SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2;

COVID-19: Coronavirus disease 2019;

WHO: World Health Organization;

MCO: Movement control order.

### **Declarations**

#### **Ethics approval and consent to participate**

No ethical approval required and no consent requirement to participate since the used data are from a public domain.

#### **Consent for publication**

Yes, we approve.

#### **Availability of data and materials**

No issue here. The data are from a public domain.

#### **Funding**

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#### **Competing interests**

None.

## Authors' Contributions

The first and second author have done all the work collaboratively

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