University of Toronto
CSC343, Fall 2021

Phase 3

Question 1

Our first investigative question is to determine how a country's wealth impacts its citizens' access to more tested vaccines with higher effectiveness. In order to answer this question, we needed to quantify a country's use of vaccines with high effectiveness. Thus, we created the v-score, defined as follows for any country c,

$$v_c = \sum_{m \in \text{man}} \frac{N_{m,c}}{N_{T,c}} e_m$$

where man is the set of all vaccine manufacturers, $N_{m,c}$ is the number of doses of vaccine m administered in country c, $N_{T,c}$ is $\sum_{m \in \text{man}} N_{m,c}$ or the total number of doses of any vaccine administered in country c, and e_m is the efficacy rating of vaccine m. A v-score of 0 means that a country has only used vaccines with an efficacy of 0%, whereas a v-score of 1 means that a country has only used vaccines with an efficacy of 100%.

For the purpose of this discussion, we will define a wealthy country as having a GDP per capita above US$15,500, and an impoverished country as having a GDP per capita below that value. We analyzed 39 different countries and regions, and we found a clear correlation between a country's wealth and their v-score. The average v-score for a wealthy country is 0.927 (query `WealthyAvg`), whereas the average v-score for an impoverished country is 0.792 (query `PoorAvg`). We noted that European Union (EU) membership is also correlated with the v-score of a country, but this correlation only exists for impoverished nations. Specifically, the average v-score of impoverished EU member states is 0.928 (query `EUPoorAvg`), whereas the average v-score of impoverished non-EU nations is 0.690 (query `NonEUPoorAvg`). One possible explanation is that the EU regulates the use of vaccines across the Union, and it has not approved the use of less effective vaccines. This results in high v-scores for all EU member states. As for wealthy nations, the average v-score of EU member states is 0.930 (query `EUWealthyAvg`), whereas the average score for non-EU nations is 0.916 (query `NonEUWealthyAvg`). Thus, there is no significant difference in this case.

In conclusion, it is clear that the wealth of a non-EU nation impacts its citizens' access to more effective vaccines. However, the same is not true for EU member states because the EU regulates vaccines, so all EU nations only use vaccines with high effectiveness.

Question 2

Our second investigative question is to determine how a country's wealth allows for vaccination priority for its citizens when compared to a country of lesser or greater wealth. For this discussion, we will continue to use the definition of wealthy and impoverished countries from the last section.

Using query `q2`, we graphed the relationship between a country's wealth and the proportion of its population that has been fully vaccinated (Figure 1). The figure shows a clear positive relationship between wealth and the proportion of vaccinated individuals. The orange line is the line of best fit, and it is described by the equation $vac = 0.145 \log(gdp) - 0.880$, where gdp is the GDP per capita and vac is the proportion of the population that is fully vaccinated. The coefficient of correlation is $r = 0.796$, which further corroborates that the wealth of a country and the proportion of vaccinated individuals are highly correlated.

Next, we investigated the proportion of fully vaccinated individuals in wealthy and impoverished countries as a function of time. The results (from queries `WealthyProportion` and `PoorProportion`) are shown in Figure 2. The curves appear to obey a logistic function, where the proportion of fully vaccinated individuals increases exponentially at first, but it flattens out after a certain point. As expected, the rate of growth for

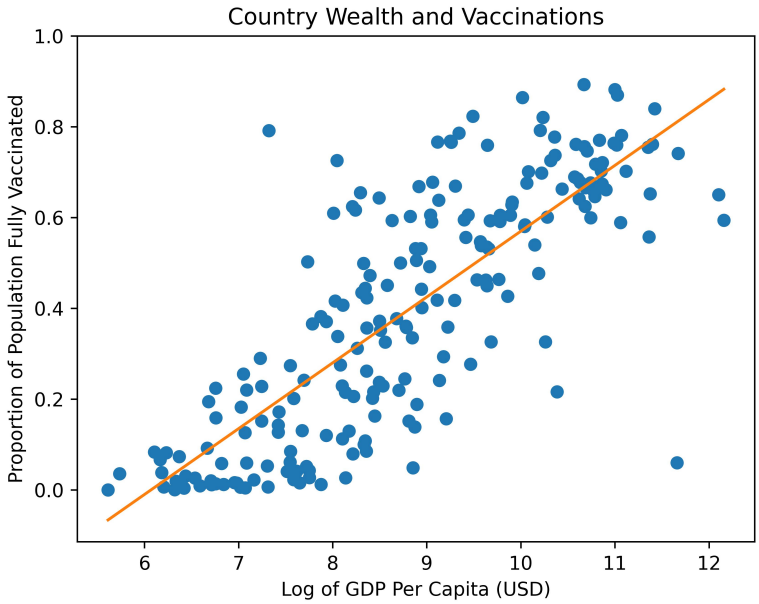

Figure 1

wealthy countries is much higher than that of impoverished countries, and wealthy nations have always had a higher proportion of fully vaccinated individuals.

Using query `EUPoorProportion`, we also investigated impoverished EU member states separately due to their unexpectedly high v-scores in the previous section. Although these countries initially perform better than other impoverished countries, their rate of vaccination flattens out extremely quickly and they are outperformed by the other country groups. This shows that, although impoverished EU member states only administer vaccines with high efficacy rates, they are vaccinating an extremely low number of people.

In conclusion, wealthy nations have higher vaccination rates than impoverished countries. Not only that, but wealthy nations also administer vaccinations faster, and this pattern has been true for all time frames since vaccines started being administered.

Question 3

The third investigation looks into the distribution of vaccines and vaccination priority for citizens of wealthy nations, and how that has impacted the mutations of COVID-19 variants throughout the pandemic.

Initially the metric used to evaluate this problem would be observed by summing over the number of uniquely identified variants in the data set per country. This method was flawed as it did not account for the change in time and was a gross simplification. The new metric measures the total number of confirmed cases per million people for each uniquely variant taken in the past two weeks from the time the data was recorded. This accounts for asynchronous frequencies of updates from different countries' research teams.

Generally, the expected trend was that priority access to vaccinations would severely reduce the number of variants in wealthy countries first, which would single out a resistant strain. This variant would then repopulate and grow exponentially in number and "trickle down" to the impoverished nations, making that strain globally dominant. This trend is faintly observable with the delta variant of COVID-19, however many

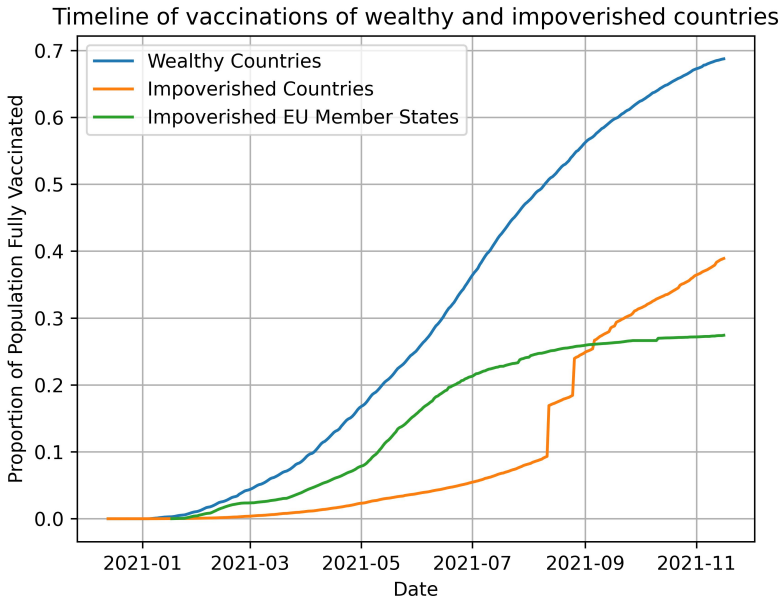

Figure 2

impoverished nations do not have enough data entries to confidently confirm this prediction.

Variant data is significantly more expensive to extract from the population in terms of time and resources, thus it is expected that it is difficult to draw a direct relation between wealth and variant diversity over time for multiple nations. In short, there is little correlation between GDP per capita as a measure for wealth and variant diversity as there are likely other factors which are more important and not accounted for in our data set, such as government policy in handling a pandemic, and population density.

In conclusion, there is no confidently discern-able relationship between the difference in timing of vaccinations for wealthy and impoverished countries, and the number of variants present in countries which receive the vaccination after others. However, vaccinations do reduce the number of variants and create a globally dominant strain.

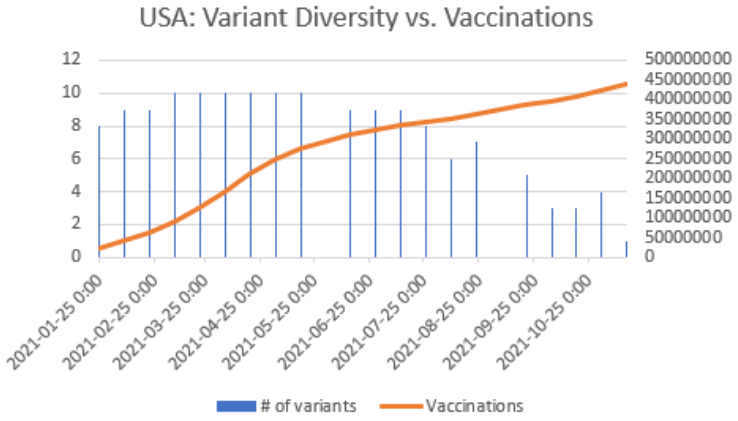

Figure 3

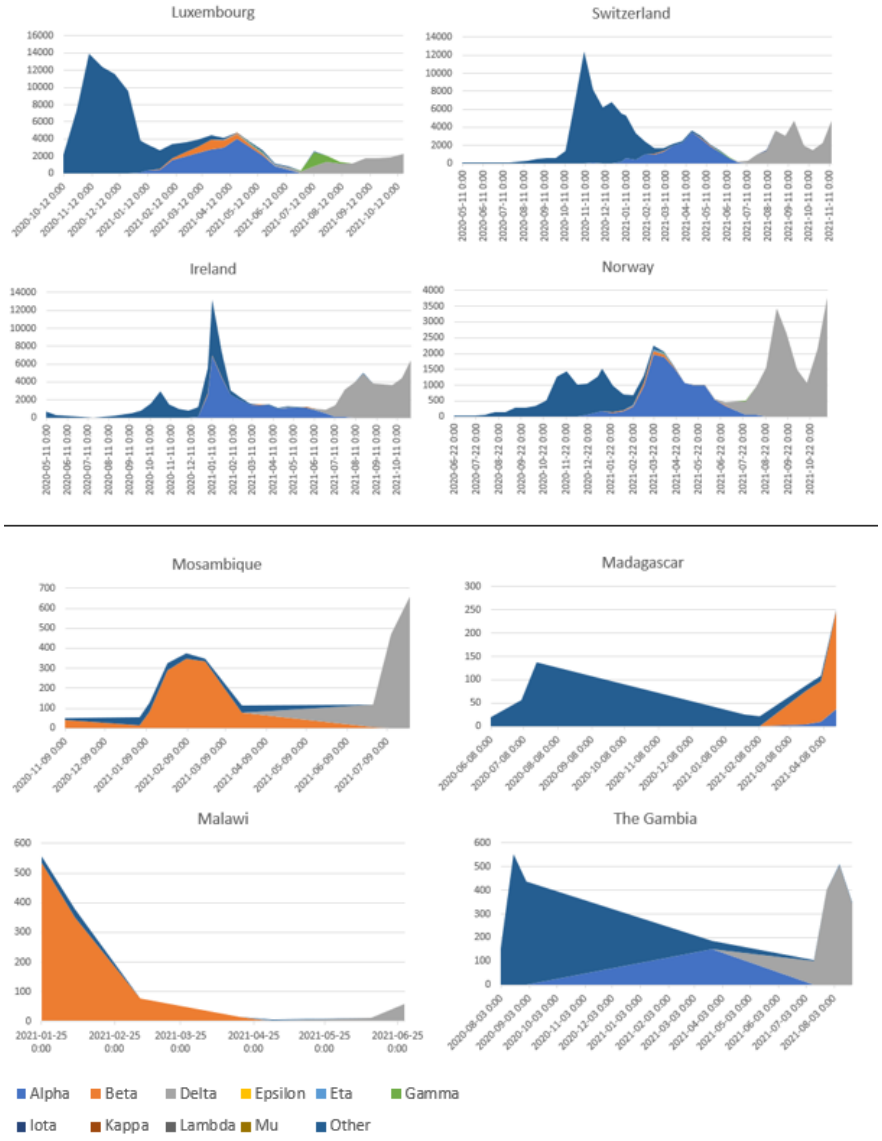

Figure 4

Figure 4 illustrates the 4 countries with the greatest GDP per capita, and their COVID-19 variant diversity over the course of the pandemic above the divider line, and the 4 countries with the smallest GDP per capita under the divider line.