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ABSTRACT

The global COVID-19 vaccination campaign is the largest public health campaign in history, with over 2 billion people fully vaccinated within the first 8 months. Nevertheless, the impact of this campaign on all-cause mortality is not well understood. Leveraging the staggered rollout of vaccines, we find that the vaccination campaign across 141 countries averted 2.4 million excess deaths, valued at $6.5 trillion. We also find that an equitable counterfactual distribution of vaccines, with vaccination in each country proportional to its population, would have saved roughly 670,000 more lives. However, this distribution approach would have reduced the total value of averted deaths by $1.8 trillion due to redistribution of vaccines from high-income to low-income countries.

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1. INTRODUCTION

The COVID-19 pandemic inflicted enormous economic, social, and health costs (Agrawal et al. 2023; Cutler and Summers 2020; Viscusi 2023; Qiu et al. 2020; Chetty et al. 2020). As of October 1, 2023, over 6.9 million COVID-19 deaths have been reported globally ("WHO Coronavirus (COVID-19) Dashboard" 2023). The pandemic has also led to several spillover effects, including reduced health care utilization (Cantor et al. 2022; Whaley et al. 2020; Ziedan, Simon, and Wing 2020), declines in economic activity (Chetty et al. 2020), and mental health challenges (Breslau et al. 2021; Raviv et al. 2021; Ettman et al. 2020). Contrary to a typical vaccine development timeline of 5-10 years, the first COVID-19 vaccine was approved for use in the US by the Food and Drug Administration on December 11, 2020, less than a year after the start of the pandemic. Following the approval of the first COVID-19 vaccine, several other COVID-19 vaccines were approved for emergency use by countries across the world. The approval of these vaccines led to the launch of a global campaign to vaccinate people to protect from COVID-19 infection. Within eight months, over 2 billion people were vaccinated globally, making it the largest public health campaign in history. Prior studies have examined the impact of COVID-19 vaccines on COVID-19 deaths (Gupta et al. 2021; Steele et al. 2022; Haas et al. 2022; He et al. 2022; Watson et al. 2022). However, the impacts of the global COVID-19 vaccination campaign, on worldwide all-cause mortality are not fully understood.

While data from clinical trials suggested that vaccines are safe and effective (Polack et al. 2020; Baden et al. 2021; Voysey et al. 2021), the real-world effectiveness of COVID-19 vaccines in averting deaths might differ from clinical trial evidence for a variety of reasons. First, individuals in real-world might change protective behaviors in response to vaccinations compared to participants in clinical trials as participants in clinical trials did not have evidence on the effectiveness of the vaccine and they were blinded to whether they received the experimental vaccine or placebo (Agrawal, Sood, and Whaley 2022). Second, the effectiveness of vaccines might depend on the variant of infection. The dominant variants when vaccines underwent clinical trials were different than the variants that were widespread when vaccines were introduced (Katella 2023). Third, the effectiveness of the vaccines might depend on prior infection status and most clinical trial participants did not have a prior infection. Fourth, the effectiveness of vaccines might reduce with time since vaccination due to wanning antibody levels (Tartof et al. 2021; Eyre et al. 2022; Menni et al. 2022; Ferdinands 2022). Fifth, COVID-19 vaccines might influence all-cause mortality by affecting mental health, social isolation, health care use and economic activity (Agrawal et al. 2021; Díaz et al. 2023; Deb et al. 2022; Kwok et al. 2021); and clinical trials were underpowered to estimate the effects of vaccines on all-cause mortality. Sixth, clinical trials are not suitable for estimating general equilibrium effects, such as the effects of vaccination on reduced transmission of disease.

There is a growing literature examining the effects of vaccines on mortality. Existing observational studies have focused on the effects of vaccination campaign in single countries (e.g., the U.S. and Israel) and have examined the effects on COVID-19 mortality only (Gupta et al. 2021; Steele et al. 2022; Haas et al. 2022). Other studies have estimated the effects of vaccination campaign in multiple countries. However, these studies do not study the real-world effectiveness of the COVID-19 vaccination campaign, but instead use mathematical models to extrapolate the evidence from clinical trials to real world settings (He et al. 2022; Watson et al. 2022). As discussed before, evidence from clinical trials in unlikely to generalize to real world settings and clinical trials were under powered to detect effects on all-cause mortality. To our knowledge, no studies have examined the real-world impacts of COVID-19 vaccination campaign in multiple countries on all-cause mortality using observational data.

In this paper, we examine the real-world effectiveness of the global COVID-19 vaccination campaign on all-cause mortality, which accounts for both direct and indirect effects of the COVID-19 vaccines. Furthermore, because recorded COVID-19 deaths could be incorrectly reported, all-cause mortality is a better measure to estimate the total benefit of COVID-19 vaccines on mortality. Our model allows for long-lived protection from deaths due to vaccination, but with waning effectiveness of vaccines overtime. Similarly, the model allows for diminishing marginal benefit from vaccines with increase in population fully vaccinated. This adjustment accounts for the fact that, in most countries, the elderly, who have much higher mortality from COVID-19 were vaccinated prior to younger populations. The global distribution of vaccines has been uneven with higher income countries having earlier access to vaccines (Deb et al. 2023). Therefore, we also examine the potential impact of a more equitable counterfactual distribution of vaccines across countries, where vaccination in each country is proportional to its population.

To examine these questions, we use event studies and two-way fixed effects models to estimate the effects of COVID-19 vaccines on all-cause mortality. Using weekly data on the share of population fully vaccinated and weekly excess deaths from March 2, 2020 to August 29, 2021, we find that the COVID-19 vaccination campaign led to a large reduction in excess deaths. Because the availability of weekly data on excess deaths is restricted to a limited number of countries, our primary estimation is conducted using a sample of 43 countries. We find that at the beginning of vaccination, a 1-percentage point increase in vaccination rates leads to a 0.000453-unit reduction in weekly excess deaths per 100 population. Due to declining marginal effectiveness, the marginal impact of COVID-19 vaccination on excess deaths at 80 percent vaccination rate is approximately

1/10th the marginal impact at the beginning of vaccine rollout. These findings are robust to several specifications and functional forms.

To place these results in a global context, we use the estimated effects from our main specification and vaccination data from 141 countries with a combined population of 5.25 billion people to calculate the global number of deaths averted due to the vaccination campaign. We find that vaccines averted approximately 2.36 million excess deaths by August 2021. To estimate the value of this large mortality reduction, we use country and region-specific estimates of the value of a statistical life (VSL). Using these VSL estimates, we calculate that mortality reductions due to the first 8 months of the global COVID-19 vaccination campaign were valued at $6.5 trillion, which is approximately equal to 9% of the combined GDP of these 141 countries.

While our estimates show a large benefit from the global COVID-19 vaccination campaign, the impacts of other vaccine distribution strategies are not known. We estimate the hypothetical impacts of an alternative, more equitable counterfactual distribution of vaccine, where countries received vaccines proportional to their population. We did so because vaccine distribution was inequitable, with higher income countries gaining access to vaccines much faster than lower income countries (Katz et al. 2021; Hyder et al. 2021; *UN News* 2021), despite efforts by the WHO, UNICEF and GAVI to accelerate vaccine distribution in low income countries through the COVAX initiative (*Time* 2021). Due to diminishing marginal health benefits of vaccination, redistributing vaccines from countries with high vaccination rates to countries with low vaccination rates can increase the number of deaths averted. We estimate that with equitable distribution among the 141 countries, the global COVID-19 vaccination campaign would have averted 3.03 million excess deaths by August 2021, but with an economic value of approximately $4.69 trillion. Therefore, relative to the status-quo, we estimate that an additional 670,000 lives would have been saved, but with a $1.8 trillion decrease in the total economic value of deaths averted.

This paper contributes to the growing literature on the benefits of the global COVID-19 vaccination campaign in several ways. To the best of our knowledge, this is the first study that estimates the effect of COVID-19 vaccines on the global all-cause mortality using observational data. Second, unlike existing studies, this study considers the waning effect of vaccines instead of assuming a constant effectiveness of vaccines over time. Finally, following the WHO suggestion on equitable distribution of vaccines ("Fair Allocation Mechanism for COVID-19 Vaccines through the COVAX Facility" 2020), the study estimates the benefits of COVID-19 vaccination in a counterfactual scenario, where vaccines are distributed equitably among 141 countries proportional to their population.

The rest of the paper proceeds as follows. We start with data on deaths and vaccination in section 2, followed by our empirical strategy in section 3. We present our results and estimates of global lives saved in sections 4 and 5, respectively. Finally, we discuss our results, limitations, and implications for vaccine distribution policy.

2. DATA

2.1. Excess Deaths and COVID-19 Deaths Data

To estimate the effects of the global COVID-19 vaccination campaign on all-cause mortality, we use weekly excess deaths and weekly COVID-19 deaths data for 43 countries from The Economist COVID-19 excess deaths tracker GitHub ("The Economist, 2020. Tracking Covid-19 Excess Deaths across Countries" 2023) (Appendix Table A1). Because our analysis is focused on the first 8 months of the vaccination campaign, we use data from March 2, 2020 to August 29,

2021. We standardized weekly excess deaths based on each country's population to create our primary outcome variable, "excess deaths per 100 population". The population data for all 43 countries comes from the same Economist dataset. The Economist's model calculates weekly excess deaths within a specific country and timeframe by comparing total deaths during the pandemic with the projected number of deaths in that country and timeframe using historical data. We use excess deaths as our primary outcome because it overcomes several limitations associated with the COVID-19 death data. First, several countries count COVID-19 deaths conditional on prior positive test, which could be substantially influenced by the testing capacity. Second, as discussed earlier, it considers both direct and indirect impacts of the pandemic, such as delayed preventative care, economic hardship, impact on mental health due to social isolation, etc.

2.2. COVID-19 Vaccine Data

COVID-19 vaccination data is sourced from Our World In Data (OWID) (Mathieu et al. 2020). For each country, the dataset provides the cumulative number of individuals who have completed the initial vaccination protocol by a given day. We use these data to estimate the number of new people vaccinated in each week, from March 2020 to August 2021, within a specific country.

A notable feature of COVID-19 vaccinations is their waning effectiveness over time. As a result, vaccines administered several months earlier have less protective effect compared to more recently administered vaccines. To account for this waning effectiveness, we created a new variable – *Vaccine Stock* – as our primary explanatory variable. This variable accounts for the vaccination history in prior weeks and incorporates the waning effect of vaccines.

To calculate *Vaccine Stock*, we did the following. First, we depreciated the number of newly vaccinated individual for every week at the weekly rate of 0.03, until the end of August 2021. Based on the existing studies on waning effectiveness of COVID-19 vaccines, we calculated the depreciation rate by reducing the effectiveness of vaccines to half over a 24 week period (Tartof et al. 2021; Eyre et al. 2022; Menni et al. 2022; Ferdinands 2022). Next, for each week, we aggregated the depreciated number of newly vaccinated individuals from the beginning of the vaccination campaign until 2 weeks prior to a given week. The two-week delay accounts for the fact that vaccines take two weeks to achieve their protective effect. Lastly, we standardized this variable per 100 population, which is called $Vaccine\ Stock_{it}$ and is the primary explanatory variable in our study.

$$Vaccine\ Stock_{it} = \frac{\sum_{week=0}^{t-2} Depreciated(Number\ of\ newly\ vaccinated\ people)i}{(Population)i} * 100 \qquad (1)$$

3. ESTIMATION APPROACH

3.1. Effects of COVID-19 Vaccines on Deaths – Sun Abraham Event Study

To examine the effect of the global COVID-19 vaccination campaign on all-cause mortality, we begin by descriptively plotting cumulative excess deaths per 100,000 people against percentage people fully vaccinated with COVID-19 vaccines for the 43 countries from March 2020 to August 2021 (Appendix Figure A1). We observe a decline in the rate of excess deaths after the start of vaccinations, which suggests a negative association between vaccines and all-cause mortality. However, this association could be confounded by other secular trends such as less lethal COVID-19 variants becoming dominant in the post vaccination period.

To account for secular trends, we next evaluate the association between the share of people fully vaccinated in a given country and cumulative deaths in that country in the post vaccination period (Figure 1, Panel A). We find an inverse relationship between the fraction of population fully vaccinated in the first 8 months of the campaign and excess deaths in the post-vaccination period. Next, we evaluated whether the successful distribution of vaccines was correlated with excess mortality prior to the vaccination campaign. We find that countries that suffered fewer excess deaths before the availability of vaccines were more successful in vaccinating a larger share of their population (Figure 1, Panel B). Given the protective effect of vaccines, this finding suggests that the vaccination campaign exacerbated the disparities in excess deaths rates among countries. This finding could be attributed to the possibility that richer countries with better healthcare infrastructure were better able to prevent deaths during the pre-vaccination period and these countries also were able to vaccinate a larger fraction of their population in the post vaccination period. Lastly, we evaluated the association between the change in excess deaths from the pre-vaccination period to post vaccination period and the share of population fully vaccinated. We expected larger reductions in deaths among countries that achieved higher vaccination rates. Consistent with our hypothesis, we find that a 1-percentage point increase in cumulative vaccination rate in 2021 is associated with a decrease of 1.56 excess deaths per 100,000 people in the post vaccination period (Figure 1, Panel C). Although these findings are suggestive of a protective effect of vaccines, they could be confounded by country specific time trends. That is, the above model implicitly assumes that trends in excess deaths in each country would be identical in the absence of vaccination.

To account for country specific time trends, we begin with an event study approach to estimate the dynamic effect of staggered distribution of COVID-19 vaccines on excess deaths per 100 population. Because COVID-19 vaccines were distributed at different times in different countries and the rate of vaccination varied across countries, there is likely heterogeneity in treatment effects. This heterogeneity in treatment raises concern about the validity of two-way fixed effects models because it violates the treatment effect homogeneity assumption (Goodman-Bacon 2021; Weill et al. 2021). As a solution, we apply the 3-step dynamic treatment effect approach outlined by Sun and Abraham (2020). For each event study, we estimated a regression model of the form below:

$$Y_{it} = \alpha + \sum_{\substack{l=-20 \\ l\neq -1}}^{20} \beta_l \, 1\{t - E_i = l\} + \gamma_i + \delta_t + \varepsilon_{it} \tag{1}$$

In this model, the outcome of interest, Y_{it}, represents excess deaths per 100 population for country i in week t. The $1\{t - E_i = l\}$ terms are indicator variables for leads and lags relative to start of vaccination campaign at time E_i in a given country. In our analysis, we denoted the first week in which *Vaccine Stock* exceeded 5% as the start of the vaccination campaign in that country.[1] Negative l represent the pre-treatment periods, while positive l represent the post-treatment periods. The first lead period (l = -1) is chosen as the baseline period; hence it is omitted from the model specification (Sun and Abraham 2020). γ_i and δ_t are country and week fixed effects, respectively, and ε_{it} is the error term. We cluster standard errors at the country level. As all countries in our analysis administered COVID-19 vaccines, our primary identification of the β_t Treatment effects come from the staggered distribution of COVID-19 vaccines across countries. The coefficients on the leads help us identify any pre-existing differences in time trends between the treatment countries that launched the vaccination campaign and the control countries that had to yet launch a campaign.

3.2. Effects of COVID-19 Vaccines on Deaths – TWFE Regression

The event study approach can measure the dynamic effects of launching a COVID-19 campaign but does not allow us to estimate the marginal effect of vaccinating a higher fraction of

[1] By the end of March 2021, the average share of population fully vaccinated among 43 countries in our analysis was approximately 5 percent.

population on excess deaths. To examine the marginal benefit of COVID-19 vaccination on excess deaths, we estimate two-way fixed effects OLS regressions. We start with a naïve model that assumes a linear relationship between our outcome variable – weekly excess deaths per 100 population, and the primary explanatory variable - $Vaccine\ Stock_{it}$. We control for time-invariant country specific characteristics and common time trend using country and week fixed effects. This model is limited because it assumes that the marginal benefit of vaccination is constant, and it also assumes that time trends do not vary by country.

In our next set of models, we relax these assumptions. It is likely that the marginal benefit of vaccination is declining with a higher fraction of the population vaccinated because vaccination campaigns typically gave priority to individuals at high-risk, and a greater share of fully vaccinated population has the effect of lowering disease transmission through herd immunity. To account for declining marginal benefit of vaccination we implement two different specifications. The first specification models excess deaths as a function of $Vaccine\ Stock_{it}$ and $Vaccine\ Stock_{it}$- squared. This quadratic model allows for diminishing marginal benefit of vaccination but in this model the marginal benefit of vaccination could be negative. A negative marginal benefit would imply that after a certain threshold vaccinating more people will increase excess deaths which is unlikely given that the vaccines have been shown to be safe in clinical trials (See Appendix Figure A2, Panel A). The second specification models excess deaths as a function of the square root of $Vaccine\ Stock$. This is our preferred specification because it accounts for diminishing marginal benefits of vaccination, but the marginal benefits of vaccination are always positive (See Appendix Figure A2, Panel B).

Lastly, we relax the common time trend assumption, as the trajectory of excess deaths could be different in different countries due to different trajectory of COVID-19 variants or differences in COVID-19 mitigation policies. We allow for country specific quadratic time trends in our main specification:

$$Weekly\ Excess\ Deaths\ per\ 100_{it} = \alpha_0 + \alpha_1 \sqrt{VaccineStock_{it}} + \\ + \gamma_i + \gamma_i * \tau_t + \gamma_i * \tau_t^2 + u_{it} \quad (2)$$

In our main specification , weekly excess deaths per 100 population is the primary outcome of interest and $\sqrt{VaccineStock_{it}}$ represents the primary regressor. Additionally, we include country (γ_i) fixed effects, and country specific quadratic time trends – $(\gamma_i * \tau_t) + (\gamma_i * \tau_t^2)$. Standard errors are clustered at the country level.

4. RESULTS

4.1. Sun Abraham Event Study Results

Figure 2 shows the trend of excess deaths per 100 population before and after the start of the COVID-19 vaccination campaign. We find a significant decrease in excess deaths after the start of the COVID-19 vaccination campaign with the protective effect increasing over time. We also find no evidence of difference in time trends in the pre-treatment period – all coefficients on leads are statistically insignificant. On average, across the 20 weeks following the start of vaccination campaign, we observe a decrease of 0.00234 per 100 population in weekly excess deaths.

4.2. TWFE Regression Results

Table 1, Panel A presents the results from the TWFE models. Column 1 displays the estimates from the linear specification, which shows a negative but insignificant relationship between weekly *Vaccine Stock* and weekly excess deaths. Column 2 displays the estimates from the quadratic specification, and column 3 displays the results from quadratic specification but with country specific quadratic time trends. In both quadratic models, *Vaccine Stock* has a negative and significant effect on excess deaths, however, the marginal effect of *Vaccine Stock* on excess deaths decreases as the share of population fully vaccinated increases. Notably, in the column 3 specification, we observe that the marginal benefit of weekly *Vaccine Stock* becomes negative after 30 percent of the population is fully vaccinated (See Appendix Figure A2, Panel A). Lastly, column 4 displays the estimates of our preferred specification, where weekly deaths per 100 population is regressed on square root of *Vaccine Stock*, while controlling for country fixed effects and country specific quadratic time trend. We find that a 1 percent point increase in *Vaccine Stock* is associated with a $\frac{0.000906}{2*(\sqrt{Vaccine\ Stock})}$ unit reduction in weekly excess deaths per 100 population. These findings show that COVID-19 vaccination had significant effect in reducing excess deaths during the pandemic. However, it is important to note that the marginal benefit of COVID-19 vaccine decreases with increase in the vaccination rate, but it always stays positive, unlike the quadratic relationship (See Appendix Figure A2, Panel B). We find that at the beginning of vaccination, a 1-percentage point increase in vaccination rate leads to a 0.000453-unit reduction in weekly excess deaths per 100 population. The marginal impact of COVID-19 vaccination on excess deaths at 80 percent vaccination rate is approximately $1/10^{th}$ the marginal impact at the beginning of the vaccination campaign.

Figure 3 juxtaposes estimates from the above model with actual data to illustrate our identification strategy. It shows the actual number of deaths (solid blue line) in the pre and post vaccination periods across the 43 countries and the predicted number of deaths (dotted blue line) under status-quo based on the regression coefficients from the model and data on vaccinations in each country. Finally, it shows the predicted number of deaths implied by our model in the counterfactual scenario that vaccinations in each country were zero. The difference between the predicted deaths in the counterfactual scenario with no vaccinations and predicted deaths under status-quo with vaccinations identifies the effects of the global vaccination campaign on deaths averted. There are several points to note in Figure 3. First, the model does a good job of predicting level and trends in excess deaths in the pre-vaccination period. Second, the counterfactual deaths in the no vaccine scenario extends this pre-existing quadratic trend to the post vaccination period. Third, the model does a good job of predicting excess deaths in post vaccination period. These facts not only hold in the aggregate across 43 countries, but also hold in country-by-country analysis presented in Appendix figure A6 for the top 10 countries that account for approximately 80 percent of lives saved among these 43 countries. Take together these facts give us confidence that our model does a reasonable job of estimating deaths with and without vaccinations which is key to identifying the causal effects of vaccines on excess deaths.

Finally, we also estimated the effect of *Vaccine Stock* on weekly COVID-19 deaths per 100 population using the same specifications as for excess deaths (Table 1, Panel B). The results are qualitatively similar.

4.3. Robustness Test

Using our preferred model specification, we examine whether the marginal effect of COVID-19 vaccination remain consistent for both the depreciated and undepreciated vaccination variable. We regress weekly excess deaths per 100 population on cumulative share of population fully vaccinated two weeks prior to a specific week. We find that a 1 percentage point increase in weekly vaccination rate (without accounting for depreciation) is associated with a $\frac{0.000886}{2*(\sqrt{Vaccination\ Rate})}$ unit reduction in weekly excess deaths per 100 population. The estimated effect of unadjusted vaccination variable on weekly excess deaths per 100 population is consistent with the findings from our primary specification in Column 4 of Table 1.

4.4. Effects of Vaccines on Excess Deaths Across 43 Countries

We use the marginal benefit estimates from our preferred model to calculate the total lives saved by COVID-19 vaccination from January 2021 to August 2021 across the 43 countries that are included in our regression analysis. As explained before, we followed the following steps. First, we used our preferred model specification to predict weekly excess deaths for each of the 43 countries, both in scenarios with and without the vaccination campaign. Next, we calculated the cumulative number of excess deaths across the 43 countries by the end of August 2021 in these two scenarios. The difference between the cumulative excess deaths in these two scenarios suggests that vaccines averted approximately 1.14 million excess deaths across these 43 countries in the first 8 months of the vaccination campaign (Figure 3), which is an approximately 26 percent reduction in deaths compared to the counterfactual scenario without the global vaccination campaign.

5. LIVES SAVED WORLDWIDE

Our main regression models include the 43 countries that have reliable weekly data on both COVID-19 vaccination and all-cause mortality. Nevertheless, the effects of the global COVID vaccination campaign among a broader set of countries remain unclear. To estimate the global effect, we extrapolate our findings from the main regression model to a broader set of 141 countries that have reliable vaccination data but lack reliable mortality data. These countries collectively have a combined population of 5.25 billion. This data limitation restricts their inclusion in our regression analysis. China is absent for both datasets, due to inconsistent vaccination and mortality reporting. Details on these countries and their vaccination data are outlined in Appendix Section 9.1 and Table A3.

Using the estimates from our preferred specification, we estimate the number of lives saved for each week in each of the 141 countries until August 2021, as outlined above. Appendix Table A3 presents the number of lives saved by the vaccination campaign in each of the 141 countries during the first 8 month of the vaccine distribution. Among these 141 countries, the global COVID-19 vaccination campaign saved 2.36 million lives by August 2021. In terms of absolute numbers, India and United States are the largest beneficiaries, with 451,778 and 429,486 lives saved, respectively. Together, they account for 37 percent of the total lives saved in these 141 countries.

To test the robustness of our findings we also used the results from the event study model to estimate the deaths averted by the global COVID-19 vaccination campaign. As noted before, the event study implies that the global COVID-19 vaccination campaign averted on average 2.34 deaths per week per 100,000 population. Given that the total population of the countries included in the study is 5.25 billion, it implies that the campaign averted roughly 123,000 deaths each week. Therefore, the number of deaths averted in the first 20 weeks of the campaign (from March to August 2021) is about 2.46 million. Hence, both the event study and our preferred model specification imply similar benefits of the global vaccination campaign.

5.1. Value of COVID-19 Vaccination

To provide an economic value of these large mortality reductions due to the global COVID-19 vaccination campaign, we calculated the value of lives saved using country and region-specific estimates of the value of statistical life (VSL) (Sweis 2022). Countries with missing VSL estimates are assigned the average VSL estimate of their respective region.[2] The VSL estimates range from

[2] Regions: East Asia & Pacific, Europe & Central Asia, Latin America & Caribbean, Middle East & North Africa, North America, South Asia, and Sub-Saharan Africa.

$0.06 million in Afghanistan to $9.4 million in Switzerland. The VSL estimate of an average American is $7.2 million compared to the world VSL estimate of $1.3 million.

We find that the first 8 months of the global COVID-19 vaccination campaign saved 2.36 million excess deaths valued at $6.50 trillion (Appendix Table A3). In terms of value of deaths averted, United States is the largest beneficiary of the vaccination campaign in the initial 8 months, with value of deaths averted being $3.09 trillion. This constitutes roughly 48 percent of the total value of lives saved in these 141 countries, even though the number of deaths averted in the US is 18 percent of the worldwide deaths averted. This substantially large value of deaths averted for the United States is attributable to a combination of three factors – a high rate of vaccination, a sizeable population, and a high value of statistical life. For example, although, the number of lives saved in India and the Unites States are approximately similar, with 451,778 and 429,486 lives, respectively, the economic benefits vary significantly. In contrast to the United States, in India, vaccines averted deaths valued at approximately $90 billion, accounting for just 1.4 percent of the total value of statistical lives saved among these 141 countries.

5.2. Global Impacts of Equitable Distribution Strategy

Finally, we estimated the impact of the global COVID-19 vaccination campaign for a counterfactual scenario where the weekly number of vaccines were distributed equitably among 141 countries proportional to their population. We conducted this analysis for two primary reasons. First, vaccine distribution under the current market-based approach has been inequitable, with high-income countries having more immediate access compared to low and middle-income countries (Katz et al. 2021; Hyder et al. 2021; *UN News* 2021), despite efforts by the WHO, UNICEF and GAVI to accelerate vaccine distribution in low income countries through the COVAX initiative (*Time* 2021). We find that high-income countries were quicker to launch their vaccination campaigns (Appendix Figure A3) and were also able to fully vaccinate a larger share of their population by August 2021 (Appendix Figures A4 and A5). Second, our regression findings indicate that the marginal benefit of vaccines decreases as the share of population that is fully vaccinated increases. As a result, we expect that the total benefit of COVID-19 vaccination campaign in averting deaths would likely have been larger if more vaccines had been provided to countries with a smaller share of fully vaccinated population.

To examine the impact of a more equitable distribution of COVID-19 vaccines among the 141 countries, we allocated the weekly supply of vaccines to each country in proportion to their population. Because each country gets a share of total weekly vaccines corresponding to its population percentage, the weekly vaccination rate was the same in each country in this counterfactual equitable distribution scenario (Appendix Table A2). Importantly, in this equitable distribution scenario, the overall global vaccine supply per week does not change; the only change is how the existing vaccine supply is distributed among countries.

Using the estimates from our preferred specification, we estimate that with equitable distribution of vaccines among the 141 countries, the global COVID-19 vaccination campaign would have averted 3.03 million excess deaths by August 2021 valued at $4.7 trillion. These findings suggest that relative to the status-quo, an equitable distribution would have saved roughly 670,000 more lives, but with a $1.8 trillion decrease in the value of deaths averted.

Finally, to provide a perspective on how the redistribution of vaccines would have impacted these 141 countries, Figures 4 and 5 visually display the geographical shift in the number of lives saved, and percentage change in lives saved between the equitable distribution and the current distribution strategies, respectively. These figures show a decrease in the number of lives saved in high-income countries and a corresponding increase in lives saved in low-and-middle income countries. Moreover, it is important to note that the gain in lives saved for low-and-middle countries is larger than the decline in benefit for high-income countries. In addition, Figures 6 and 7 show the absolute and percentage change in the value of lives saved between the equitable distribution and the current distribution strategies across these 141 countries, respectively. We find that the decrease in value of lives saved in high-income countries is larger than the increase in value of lives saved for low-and-middle income countries. This difference is primarily reflected due to significantly higher value of a statistical life in high-income countries compared to low-and-middle income countries.

6. DISCUSSION

While clinical trials show that COVID-19 vaccines are safe and effective, the real-world effectiveness of the global COVID-19 vaccination campaign on all-cause mortality is not well understood. This study addresses the gap in the literature in three key ways. First, we find that COVID-19 vaccines have a significant effect in preventing all-cause mortality in the first 8 months of the global COVID-19 vaccination campaign. We estimate that the vaccination campaign in 141 countries averted approximately 2.36 million excess deaths from January 2021 to August 2021. Using country and region-specific VSL estimates, we calculated that mortality reductions due to the first 8 months of the vaccination campaign were valued at $6.5 trillion, which is approximately equal to 9 percent of the combined GDP of these 141 countries. Second, due to the decreasing marginal benefit of vaccines and the existing inequitable global distribution of COVID-19 vaccines, we examine the effects of an equitable counterfactual distribution strategy, in which countries receive the weekly vaccine supply in proportion to their population. We find that an equitable distribution of vaccines would have saved roughly 670,000 more lives, but with a reduction of $1.8 trillion in the value of deaths averted due to redistribution of vaccines from high-income to low-income countries. Lastly, among 43 countries included in our empirical model, the vaccination campaign saved 1.14 million lives – a 26 percent reduction in excess deaths compared to the scenario without vaccination. It is worth noting that this estimated 26 percent reduction in excess mortality is consistent with clinical trial evidence on vaccine effectiveness. In particular, several studies based on clinical trials as well as vaccine registry data from single countries suggest that vaccines reduced COVID-19 hospitalizations or mortality conditional on infections by about 80 to 90 percent (Wu et al. 2023). Combining these estimates of vaccine effectiveness with estimates of the fraction of population infected during the first 8 months of the vaccine program and all cause mortality rates of infected and uninfected populations yields a 23 to 26 percent reduction in all-cause mortality.[3] This estimate is very similar to our estimated finding of 26 percent reduction in excess deaths.

This study has several limitations. First, the Economist excess deaths model provides complete weekly excess deaths data for 43 countries. Consequently, while we estimate the impact of the global COVID-19 vaccination campaign for 141 countries, we used only 43 countries in our empirical model to estimate the effect of weekly vaccination rate on weekly excess death rate. Notably, our study does not include China due to the lack of reliable data. Second, the study relies on a quasi-experimental design that exploits the staggered rollout of vaccines. We do not observe deaths in the counterfactual scenario in which these countries did not implement COVID-19 vaccination campaign. We predict these counterfactual deaths with no vaccines using country

[3] The percent reduction in mortality due to vaccination can be expressed as: $\frac{ve*w_I*m_I}{w_I*m_I+(1-w_I)*m_{UI}}$, where ve is vaccine effectiveness, w_I is fraction infected in the first eight months of vaccination, m_I is all cause mortality rate among infected and m_{UI} is all cause mortality rate among uninfected. Prior research suggests that w_I is about 22 percent (Barber et al. 2022). Data from OWID on all-cause deaths in 2019 suggests that m_{UI} is about 0.75 percent. Combining these data with 20 percent global population infected in 2020 (Barber et al. 2022) and OWID all-cause mortality rate of 0.85 percent in 2020 suggests that m_I is 1.1 percent. These estimates combined with ve in the range of 80 to 90 percent imply a mortality reduction of 23 to 26 percent.

specific quadratic time trends or using an event study approach. However, we cannot test whether our predictions are accurate, and it is possible that the estimates are biased due to confounding by unobservable factors. It is important to note that both approaches - event studies and country specific quadratic time trends - give similar estimates suggesting that our results are not sensitive to the identifying assumptions implicit in different models. Third, in our analysis, we did not account for the different type of vaccines administered in different countries.

Despite these limitations, our study contributes to the existing literature on the benefits of the global COVID-19 vaccination campaign. To the best of our knowledge, our study is the first attempt to estimate the impact of the global COVID-19 vaccination campaign on all-cause mortality using observational data. We find that the vaccination campaign across 141 countries prevented approximately 2.36 million excess deaths from January 2021 to August 2021, valued at $6.5 trillion. These findings suggest that pharmaceutical interventions in the form of vaccination and therapeutics have a much larger protective effect on mortality compared to non-pharmaceutical interventions (NPIs) such as shelter-in-place policies (Agrawal et al. 2023). Furthermore, our study adds to the literature on the most effective distribution strategy for "essential medicines" during a global public health crisis. We find that the number of lives saved would have been much higher if vaccines were distributed more equitably. However, the value of deaths averted is smaller as a more equitable distribution involves redistribution of vaccines from high income to low-income countries. These findings leave us with an unanswered question at the intersection of economics and public health: should we seek to maximize the number of lives saved or maximize the economic value of lives saved? We leave answering this question as an important future endeavor for ethicists and economists.

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8. TABLES AND FIGURES

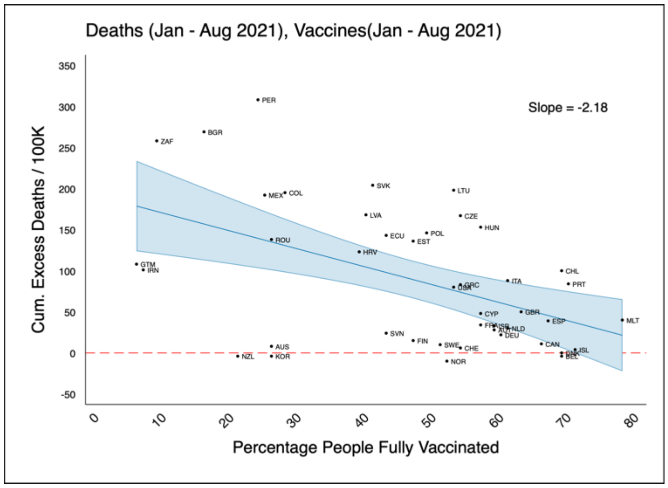
Table 1: Effects of COVID-19 Vaccines on Deaths

	(1)	(2)	(3)	(4)
Panel A: Weekly Excess Deaths / 100				
Vaccine Stock	-0.0000406 (0.0000254)	-0.000208*** (0.0000585)	-0.000204*** (0.0000627)	
Vaccine Stock^2		0.00000317*** (0.00000088)	0.00000335*** (0.00000094)	
$\sqrt{\text{Vaccine Stock}}$				-0.000906*** (0.000256)
Country FE	X	X	X	X
Week FE	X	X		
Country X Week			X	X
Country X Week^2			X	X
Observations	3,354	3,354	3,354	3,354
R-squared	0.322	0.329	0.395	0.398
Panel B: Weekly COVID-19 Deaths / 100				
Vaccine Stock	-0.0000397** (0.0000156)	-0.000136*** (0.0000293)	-0.000358*** (0.0000665)	
Vaccine Stock^2		0.00000183*** (0.0000005)	0.00000457*** (0.00000095)	
$\sqrt{\text{Vaccine Stock}}$				-0.00150*** (0.000326)
Country FE	X	X	X	X
Week FE	X	X		
Country X Week			X	X
Country X Week^2			X	X
Observations	3,354	3,354	3,354	3,354
R-squared	0.444	0.450	0.489	0.494

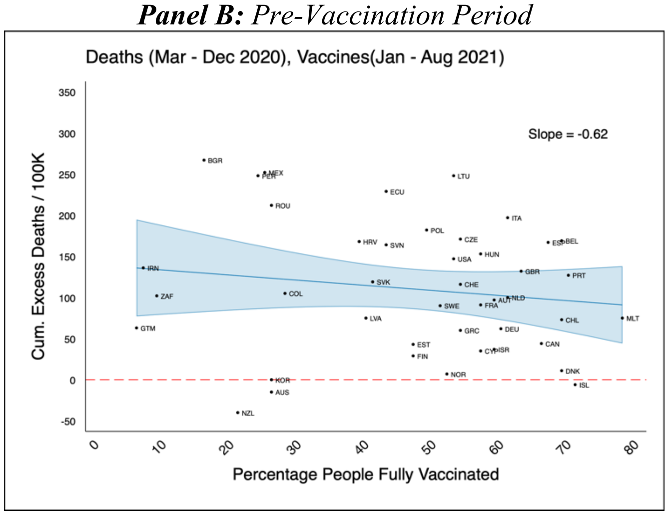
This table estimates the effect of COVID-19 vaccines *(i.e., Vaccine Stock)* on weekly excess deaths per 100 population and weekly COVID-19 deaths per 100 population. Column 1 is the basic model, where deaths per 100 population for a given week is regressed on *Vaccine Stock* – the stock of fully vaccinated people per 100 population until 2 weeks prior to that week after taking into account the waning effect of vaccines over time. Columns 2 and 3 use second degree polynomial of *Vaccine Stock*. Column 4 uses square root of *Vaccine Stock*. Columns 1 and 2 control for country and week fixed effects. Columns 3 and 4 control for country fixed effect and country specific quadratic time trend - country*time and country*time^2. Standard error is clustered at country-level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Figure 1: Cumulative Excess Deaths vs Percentage People Fully Vaccinated – 43 Countries

Panel A: *Post-Vaccination Period*



Panel B: *Pre-Vaccination Period*



Panel C: *Change from Pre-Vaccination to Post-Vaccination Period*

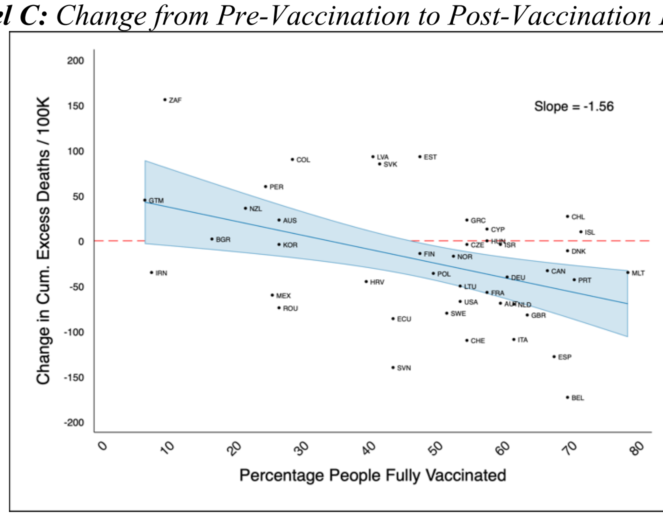
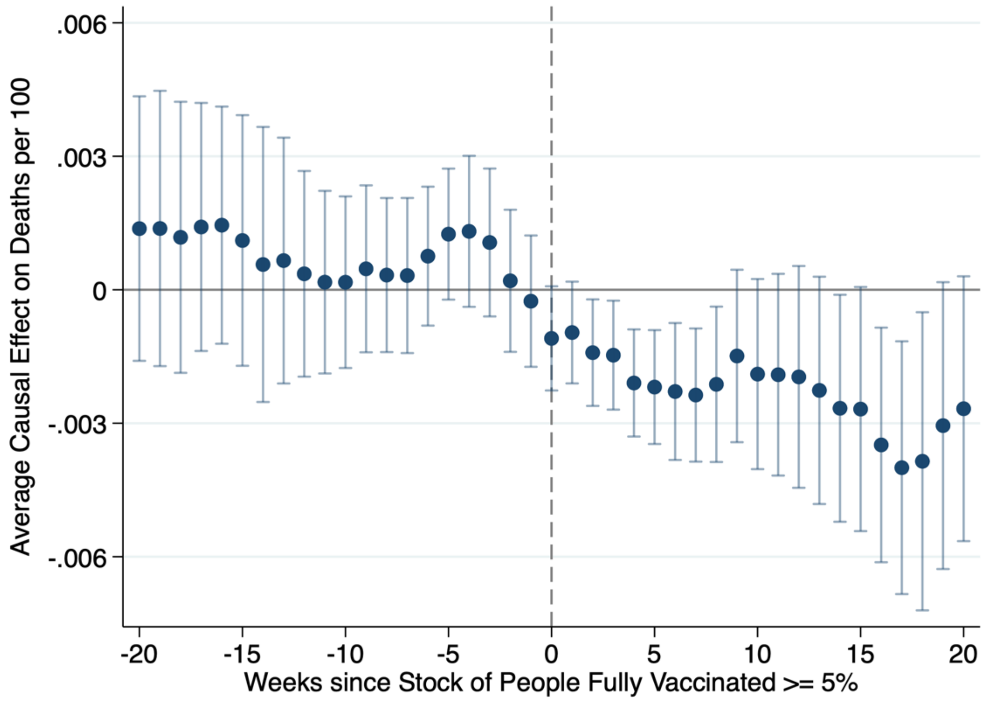


Figure 2: Change in Excess deaths per 100 people Pre and Post Vaccination



The above event study is estimated using the 3-step dynamic treatment effect approach outlined in Sun and Abraham (2020).

Figure 3: Trends in Excess Deaths and Vaccination – 43 Countries

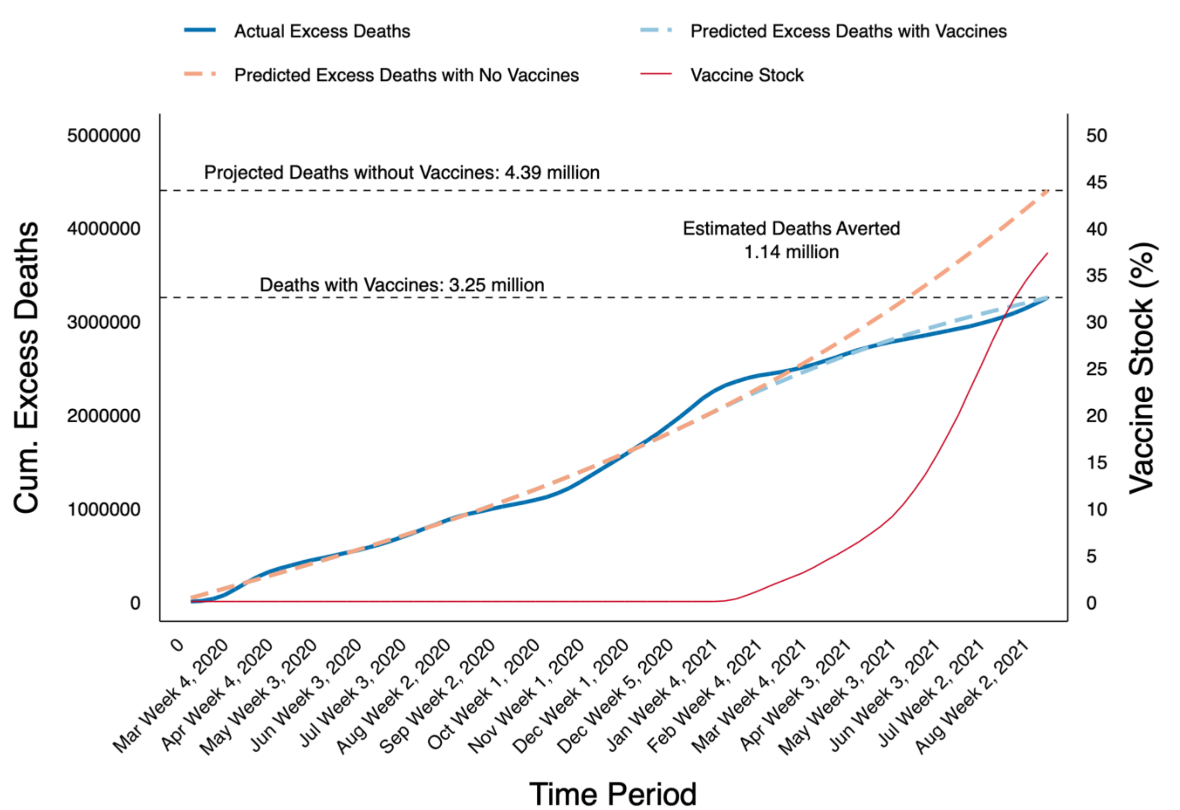


Figure 4: Change in Excess Deaths Averted (From Actual to Equitable Distribution Scenario)

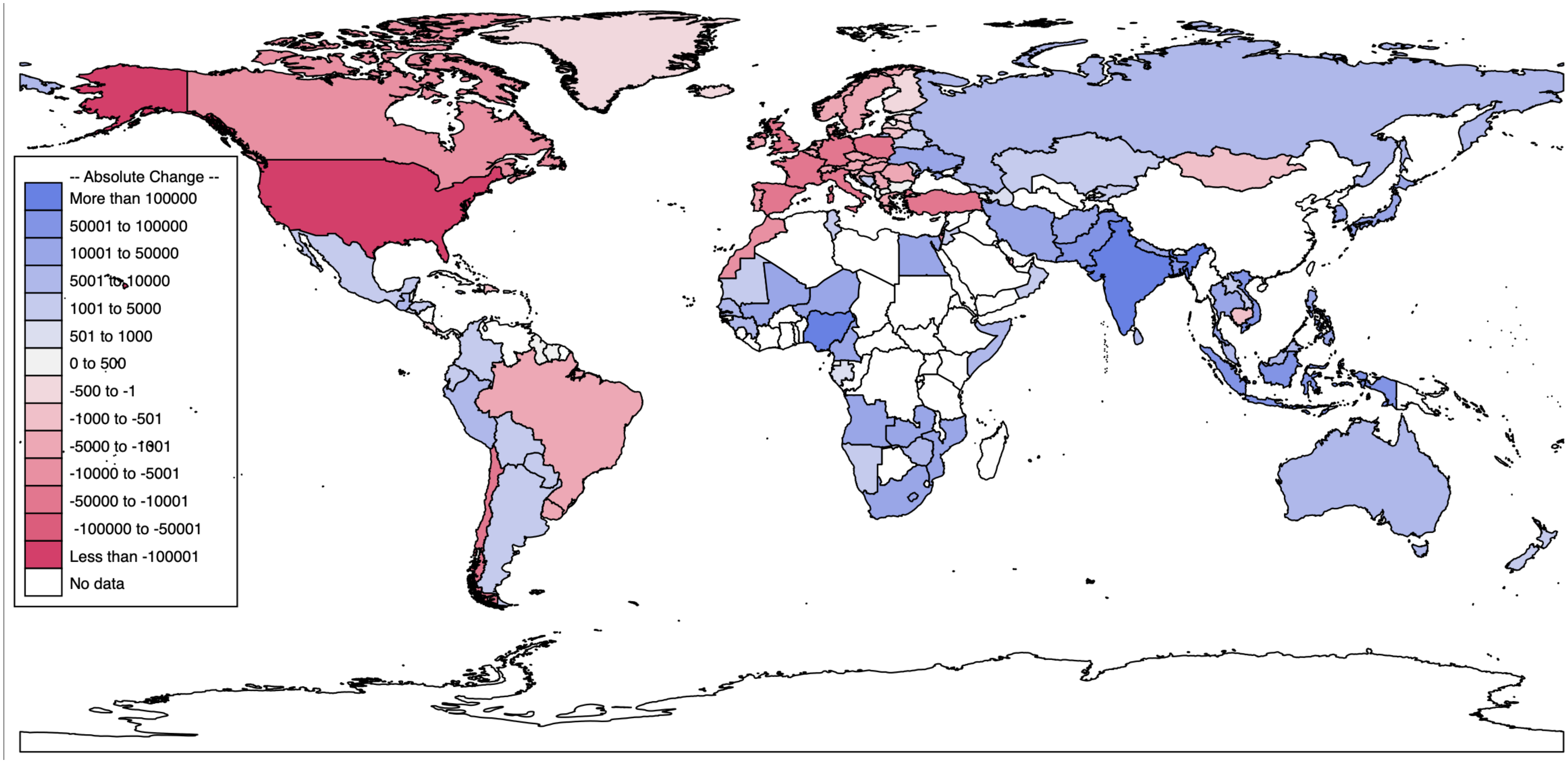


Figure 5: Percentage Change in Excess Deaths Averted (From Actual to Equitable Distribution Scenario)

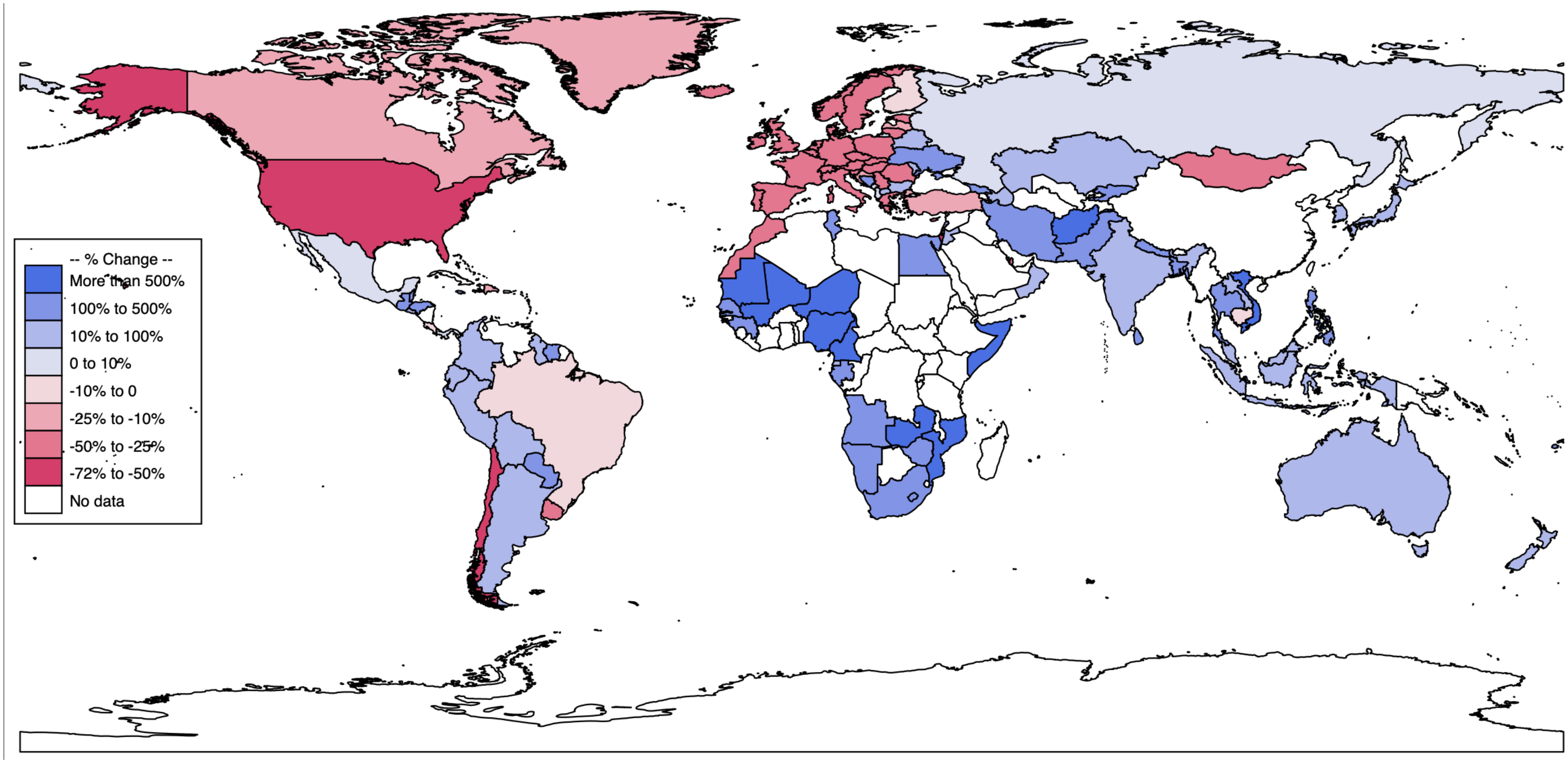


Figure 6: Change in Value of Excess Deaths Averted (From Actual to Equitable Distribution Scenario)

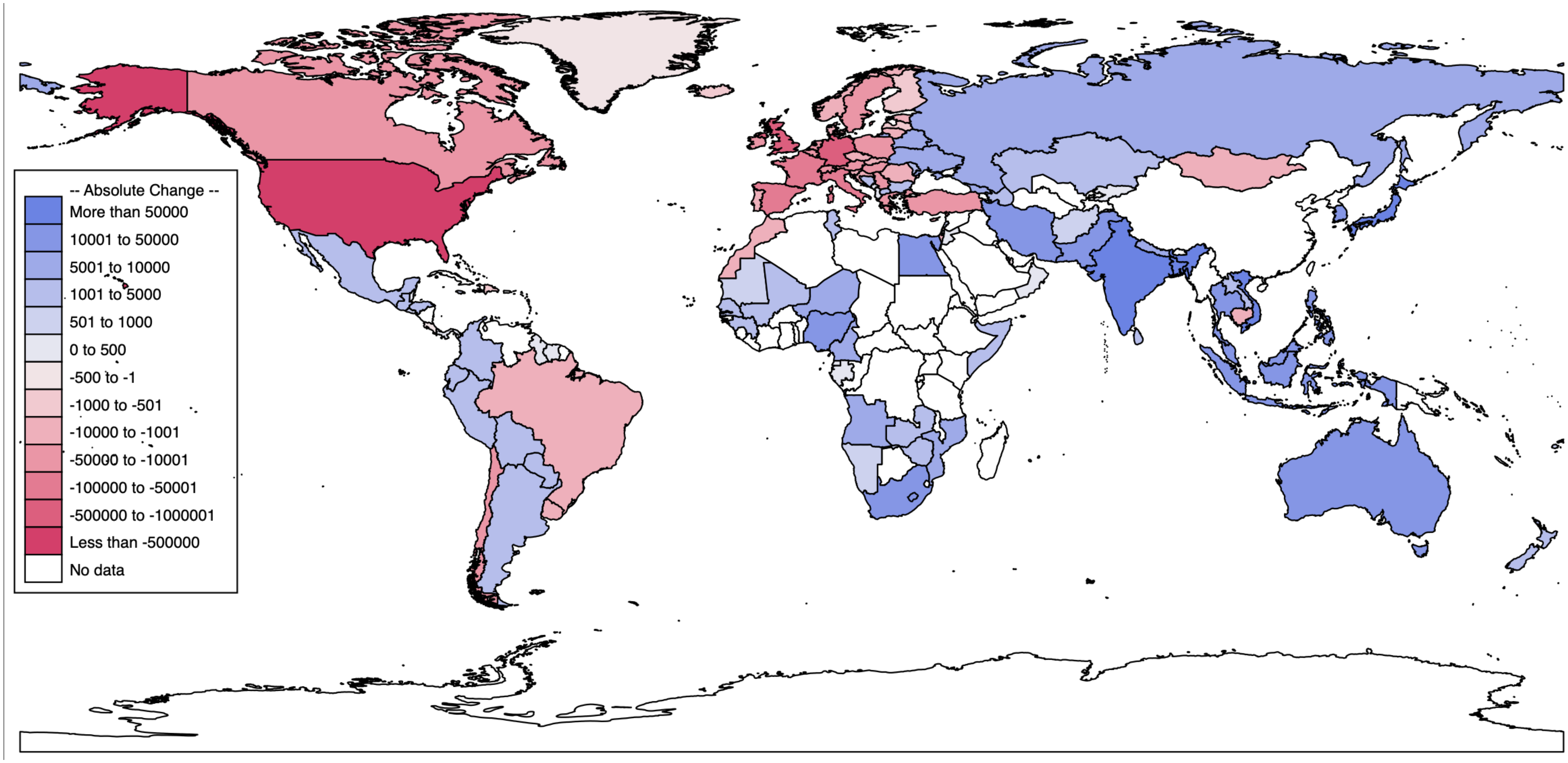
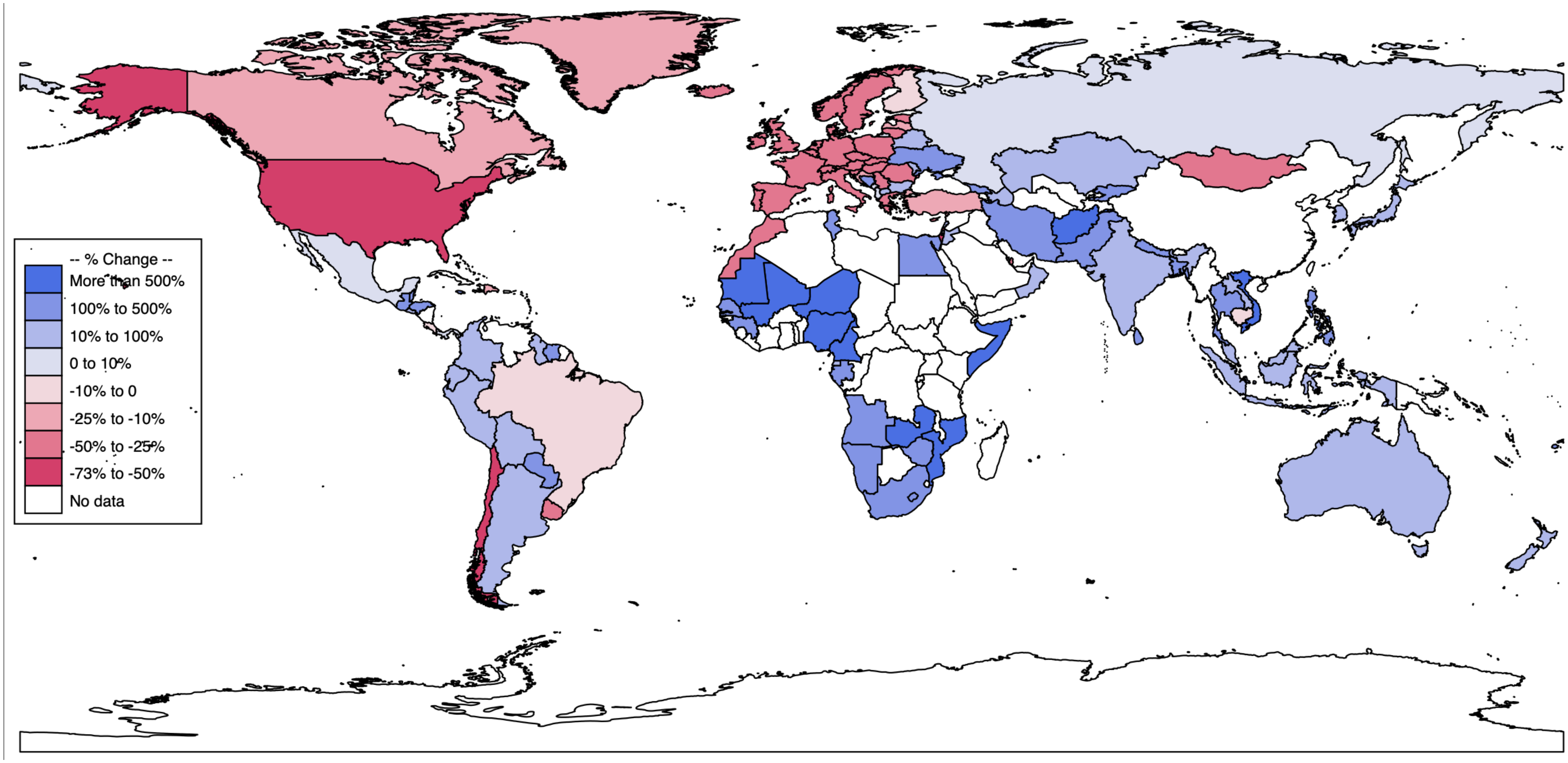


Figure 7: Percentage Change in Value of Excess Deaths Averted (From Actual to Equitable Distribution Scenario)



9. APPENDIX

9.1. 141 Countries – Weekly Vaccination Data

The Our World In Data (OWID) (Mathieu et al. 2020) provides complete vaccination data for all countries and regions, however, several countries have gaps in their data. For each country, the dataset provides the daily data on the cumulative number of people that are fully vaccinated, which includes individuals who have completed the initial vaccination protocol. Since the study focuses on weekly analysis, we create weekly dataset on the cumulative number of people that are fully vaccinated, from March 2020 to August 2021, within a specific country.

Next, given the scope of our analysis which is focused on the first 8 months of the vaccine distribution, we excluded countries that lack vaccination data until May 2021. This exclusion is made because we are not sure whether the absence of data is due to missing information or the unavailability of vaccines. Out of the remaining countries, we excluded those that have data for less than half of the total number of weeks from January 2021 to August 2021, i.e., fewer than 34 weeks. Lastly, we used interpolation to fill in the missing data between the first week of vaccination and the last week of August 2021 for each of the 141 countries. Weeks preceding the first week when the vaccination coverage is greater than zero were assigned zero. Additionally, 14 countries have weekly vaccination data available up to the early-to-mid August period. For these 14 countries, we extrapolated the weekly vaccination data until the last week of August 2021 (week 34 of 2021). In the final dataset, we have weekly data on the cumulative number of people that are fully vaccinated from week 51 of 2020 (December 2020) to week 34 of 2021 (August 2021) for 141 countries. Using the weekly vaccination data, we construct our primary explanatory variable – Weekly *Vaccine Stock* for each of the 141 countries, as outlined in section 2.2.

Table A1: List of 43 Countries included in the Regression Analysis

Country	**Population**
Australia	25,921,089
Austria	8,922,082
Belgium	11,611,420
Bulgaria	6,885,868
Canada	38,155,012
Chile	19,493,184
Colombia	51,516,562
Croatia	4,060,135
Cyprus	896,007
Czech Republic	10,510,750
Denmark	5,854,240
Ecuador	17,797,737
Estonia	1,328,701
Finland	5,535,992
France	67,422,000
Germany	83,408,554
Greece	10,445,365
Guatemala	17,608,483
Hungary	9,709,786
Iceland	370,335
Iran	87,923,432
Israel	9,291,000
Italy	59,240,330
Latvia	1,873,919
Lithuania	2,786,651
Malta	526,748
Mexico	12,6705,138
Netherlands	17,501,696
New Zealand	5,129,728
Norway	5,403,021
Peru	33,715,472
Poland	38,307,726
Portugal	10,290,103
Romania	19,328,560
Slovakia	5,447,622
Slovenia	2,119,410
South Africa	59,392,255
South Korea	51,830,139
Spain	47,486,935
Sweden	10,467,097
Switzerland	8,691,406
United Kingdom	67,281,040
United States	336,997,624

Table A2: Equitable Distribution Scenario – Weekly Share of Fully Vaccinated Population in 141 Countries

Week	Share of Population Fully Vaccinated (%)
Jan 4 – Jan 10, 2021	.01
Jan 11 – Jan 17, 2021	.05
Jan 18 – Jan 24, 2021	.1
Jan 25 – Jan 31, 2021	.18
Feb 1 – Feb 7, 2021	.32
Feb 8 – Feb 14, 2021	.49
Feb 15 – Feb 21, 2021	.69
Feb 22 – Feb 28, 2021	.93
Mar 1 – Mar 7, 2021	1.22
Mar 8 – Mar 14, 2021	1.52
Mar 15 – Mar 21, 2021	1.89
Mar 22 – Mar 28, 2021	2.25
Mar 29 – Apr 4, 2021	2.7
Apr 5 – Apr 11, 2021	3.19
Apr 12 – Apr 18, 2021	3.79
Apr 19 – Apr 25, 2021	4.39
Apr 26 – May 2, 2021	5.13
May 3 – May 9, 2021	5.88
May 10 – May 16, 2021	6.65
May 17 – May 23, 2021	7.33
May 24 – May 30, 2021	7.98
May 31 – Jun 6, 2021	8.66
Jun 7 – Jun 13, 2021	9.41
Jun 14 – Jun 20, 2021	10.25
Jun 21 – Jun 27, 2021	11.15
Jun 28 – Jul 4, 2021	12.14
Jul 5 – Jul 11, 2021	13.17
Jul 12 – Jul 18, 2021	14.32
Jul 19 – Jul 25, 2021	15.47
Jul 26 – Aug 1, 2021	16.63
Aug 2 – Aug 8, 2021	17.94
Aug 9 – Aug 15, 2021	19.2
Aug 16 – Aug 22, 2021	20.52
Aug 23 – Aug 29, 2021	21.82

Table A3: Lives Saved and their Corresponding Value in 141 Countries

Country	Population	% Fully Vaccinated[1]	VSL[2] (in million $)	Excess Deaths Averted[3]	Value of Lives Saved, (in million $)	Equitable – Excess Deaths Averted[4]	Equitable – Value of Lives Saved, (in million $)
Afghanistan	32941000	1.44	0.06	2815	168	18973	1140
Albania	2878000	20.90	3.58	1632	5842	1658	5935
Andorra	78000	55.30	3.58	56	201	45	159
Angola	31031000	2.36	0.45	4131	1859	17872	8044
Antigua and Barbuda	98000	33.78	0.88	51	44	56	50
Argentina	45388000	26.98	1.20	22277	26731	26141	31371
Aruba	111000	61.99	0.88	112	96	64	55
Australia	25694000	25.90	1.80	8350	15029	14799	26638
Austria	8901000	59.41	3.58	8347	29882	5127	18352
Azerbaijan	10067000	24.83	3.58	5219	18684	5798	20758
Bahamas	385000	14.66	0.88	111	99	222	194
Bahrain	1472000	73.46	0.43	1915	823	848	364
Bangladesh	164689000	4.07	2.20	36758	80869	94854	208678
Barbados	288000	32.10	0.88	171	150	166	146
Belarus	9410000	13.51	3.58	2989	10701	5420	19402
Belgium	11522000	69.84	5.20	10472	54454	6636	34510
Belize	419000	16.08	0.88	116	101	241	210
Bermuda	63000	66.54	6.15	87	536	36	222
Bolivia	11630000	21.19	0.40	4182	1672	6698	2681
Bosnia and Herzegovina	3279000	12.46	3.58	828	2966	1889	6761
Brazil	211756000	27.32	1.00	124217	124216	121962	121962
Brunei	461000	17.24	1.80	100	180	266	475
Bulgaria	6917000	16.42	3.58	3509	12563	3984	14259
Cambodia	15678000	51.80	1.80	9585	17254	9030	16253
Cameroon	26546000	0.29	0.45	853	383	15289	6878
Canada	37973000	66.24	5.10	27322	139340	21871	111544
Cape Verde	557000	11.92	0.45	72	35	321	145
Cayman Islands	65000	75.52	0.88	96	85	37	33
Chile	19458000	68.84	1.60	23535	37656	11207	17930
Colombia	50372000	28.67	0.70	24653	17258	29012	20309
Comoros	897000	4.61	0.45	199	91	517	232
Costa Rica	5128000	19.57	0.88	3151	2773	2953	2603
Croatia	4042000	39.43	3.58	2915	10434	2328	8335

Curacao	163000	52.62	0.88	150	133	94	83
Cyprus	888000	58.00	3.58	826	2956	511	1831
Czech Republic	10694000	52.77	3.58	8947	32031	6159	22052
Denmark	5823000	70.05	3.58	5553	19881	3354	12008
Dominica	73000	27.65	0.88	50	44	42	36
Dominican Republic	10448000	43.94	0.90	6942	6246	6018	5415
Ecuador	17511000	43.93	0.70	6740	4719	10086	7062
Egypt	100878000	2.98	0.30	10403	3122	58101	17431
El Salvador	6486000	38.01	0.88	3138	2762	3736	3287
Equatorial Guinea	1406000	10.38	0.45	492	222	810	364
Estonia	1329000	47.67	3.58	1194	4272	765	2740
Fiji	900000	26.10	1.80	177	316	518	930
Finland	5525000	46.89	3.58	3429	12273	3182	11395
France	65124000	59.47	4.70	56350	264842	37509	176288
Gabon	2108000	2.52	0.45	241	109	1214	549
Georgia	3717000	8.75	3.58	644	2305	2141	7663
Germany	83161000	59.84	5.30	74845	396676	47897	253856
Gibraltar	34000	115.32	3.58	71	254	20	69
Greece	10719000	52.86	3.58	9567	34251	6174	22101
Greenland	57000	54.79	3.58	43	154	33	118
Grenada	113000	16.39	0.88	47	40	65	56
Guatemala	17974000	5.47	0.50	1906	953	10352	5177
Guinea	13967000	2.57	0.45	2060	927	8044	3619
Guyana	787000	19.93	0.88	324	285	453	398
Honduras	9942000	10.86	0.30	1109	332	5726	1718
Hong Kong	7428000	43.42	1.80	4581	8245	4278	7700
Hungary	9770000	56.34	3.58	10605	37967	5627	20147
Iceland	364000	72.33	3.58	385	1377	210	752
India	1378595000	9.78	0.20	451778	90355	794009	158800
Indonesia	270204000	12.24	0.40	100839	40336	155625	62251
Iran	84139000	7.31	0.60	12917	7749	48460	29077
Ireland	4994000	67.49	6.80	4644	31581	2876	19559
Isle of Man	85000	71.32	3.58	100	358	49	177
Israel	9214000	59.64	0.43	15227	6549	5307	2285
Italy	59641000	60.11	3.80	53944	204990	34351	130531
Jamaica	2737000	5.14	0.88	484	427	1576	1387
Japan	125849000	46.04	4.60	54828	252207	72483	333424
Jordan	10209000	27.56	0.43	4823	2075	5880	2530

Kazakhstan	18877000	27.14	0.90	8020	7220	10872	9783
Kyrgyzstan	6517000	6.19	0.10	766	77	3754	375
Laos	7276000	23.37	1.80	2341	4213	4191	7544
Latvia	1908000	39.11	3.58	1337	4788	1099	3933
Lebanon	6825000	15.44	0.43	2590	1114	3931	1690
Lithuania	2795000	52.72	3.58	2583	9247	1610	5764
Malaysia	32939000	42.76	1.80	12683	22827	18971	34148
Maldives	378000	79.54	0.67	384	258	218	146
Mali	19658000	0.44	0.45	1025	461	11322	5093
Malta	515000	79.78	0.43	626	268	297	126
Mauritania	4147000	0.64	0.45	217	99	2388	1073
Mauritius	1267000	55.62	0.45	629	284	730	329
Mexico	127792000	24.94	1.00	71308	71309	73602	73604
Moldova	2634000	24.19	3.58	925	3312	1517	5431
Monaco	39000	56.29	3.58	45	162	22	80
Mongolia	3355000	61.69	1.80	2833	5097	1932	3476
Montenegro	621000	28.37	3.58	349	1250	358	1280
Morocco	35952000	37.98	0.40	27945	11179	20707	8285
Mozambique	31255000	2.09	0.45	2436	1095	18001	8102
Namibia	2504000	4.03	0.45	277	123	1442	646
Nepal	28840000	13.60	0.67	6131	4109	16611	11130
Netherlands	17408000	61.66	5.80	15009	87053	10026	58150
New Zealand	5087000	21.26	1.80	1919	3457	2930	5272
Niger	24207000	0.36	0.45	794	355	13942	6274
Nigeria	206140000	0.69	0.20	12944	2588	118727	23747
North Macedonia	2069000	24.76	3.58	715	2562	1192	4266
Norway	5385000	52.39	3.58	4464	15983	3102	11102
Oman	4445000	23.46	0.43	1507	647	2560	1100
Pakistan	208570000	7.01	0.20	30363	6070	120127	24027
Panama	4279000	23.57	1.60	2238	3579	2465	3945
Paraguay	7253000	22.81	0.88	1431	1259	4177	3677
Peru	33494000	23.68	0.70	14129	9893	19291	13503
Philippines	108800000	12.16	0.40	22134	8854	62664	25066
Poland	37958000	48.99	1.70	33357	56704	21862	37166
Portugal	10310000	69.94	2.50	9749	24375	5938	14845
Qatar	2684000	74.86	0.43	2392	1028	1546	664
Romania	19329000	26.31	1.40	15432	21604	11133	15585
Russia	146171000	24.11	1.20	77571	93084	84188	101027

Saint Kitts and Nevis	57000	36.87	0.88	31	30	33	29
Saint Lucia	181000	15.19	0.88	67	59	104	91
Sao Tome and Principe	218000	5.45	0.45	46	21	126	55
Senegal	16744000	3.37	0.45	1744	786	9644	4339
Serbia	6927000	40.27	3.58	7194	25753	3990	14281
Seychelles	97000	72.67	0.45	154	69	56	23
Singapore	5686000	73.08	1.80	5760	10371	3275	5897
Sint Maarten	42000	54.48	0.88	32	28	24	20
Slovakia	5458000	41.29	3.58	4623	16551	3144	11255
Slovenia	2096000	43.70	3.58	1864	6672	1207	4323
Solomon Islands	685000	2.29	1.80	76	137	395	709
Somalia	15046000	0.63	0.45	822	370	8666	3897
South Africa	59622000	8.62	0.70	13219	9256	34340	24036
South Korea	51781000	25.61	1.80	18508	33315	29824	53683
Spain	47111000	67.81	3.30	43887	144828	27134	89542
Sri Lanka	21920000	27.70	0.67	5378	3604	12625	8458
Suriname	603000	19.44	0.88	151	133	347	304
Sweden	10379000	50.53	6.10	8078	49274	5978	36468
Switzerland	8606000	54.17	9.40	8075	75906	4957	46594
Thailand	69800000	9.55	1.80	16100	28979	40202	72365
Timor-Leste	1318000	13.76	1.80	170	304	759	1367
Tonga	100000	25.78	1.80	24	44	58	104
Trinidad and Tobago	1399000	27.01	0.88	318	278	806	709
Tunisia	11903000	14.73	0.43	3189	1372	6856	2948
Turkey	83614000	42.91	1.10	63559	69916	48158	52974
Ukraine	41512000	8.09	0.40	5712	2286	23909	9562
United Kingdom	67081000	62.95	4.70	72834	342317	38636	181588
United States	335275000	53.31	7.20	429486	3092298	193103	1390344
Uruguay	3531000	70.82	0.88	3228	2840	2034	1791
Vietnam	97406000	2.19	1.80	4807	8651	56102	100981
Zambia	18882000	1.33	0.45	778	349	10875	4895
Zimbabwe	15189000	10.09	0.45	3585	1614	8748	3936
Total	**5,253,202,000**			**2,356,320**	**$6,503,494 million**	**3,025,610**	**$4,690,516 million**

[1] Percentage Fully Vaccinated by August 2021. [2] VSL estimate is used from (Sweis 2022). Countries with missing VSL estimates are assigned the average VSL estimate of their respective region – East Asia & Pacific, Europe & Central Asia, Latin America & Caribbean, Middle East & North Africa, North America, South Asia, and Sub-Saharan Africa. [3]Weekly excess deaths averted in each of the 141 countries is calculated using estimates from the preferred square root model. Total Excess deaths averted from Jan to Aug 2021 in each country is equal to the sum of deaths averted in each week. [4]Equitable - Excess deaths averted: number of lives that would have been saved if vaccines were distributed among 141 countries proportional to their population.

Figure A1: Trends in Excess Deaths per 100K people and Percentage People Fully Vaccinated – 43 Countries

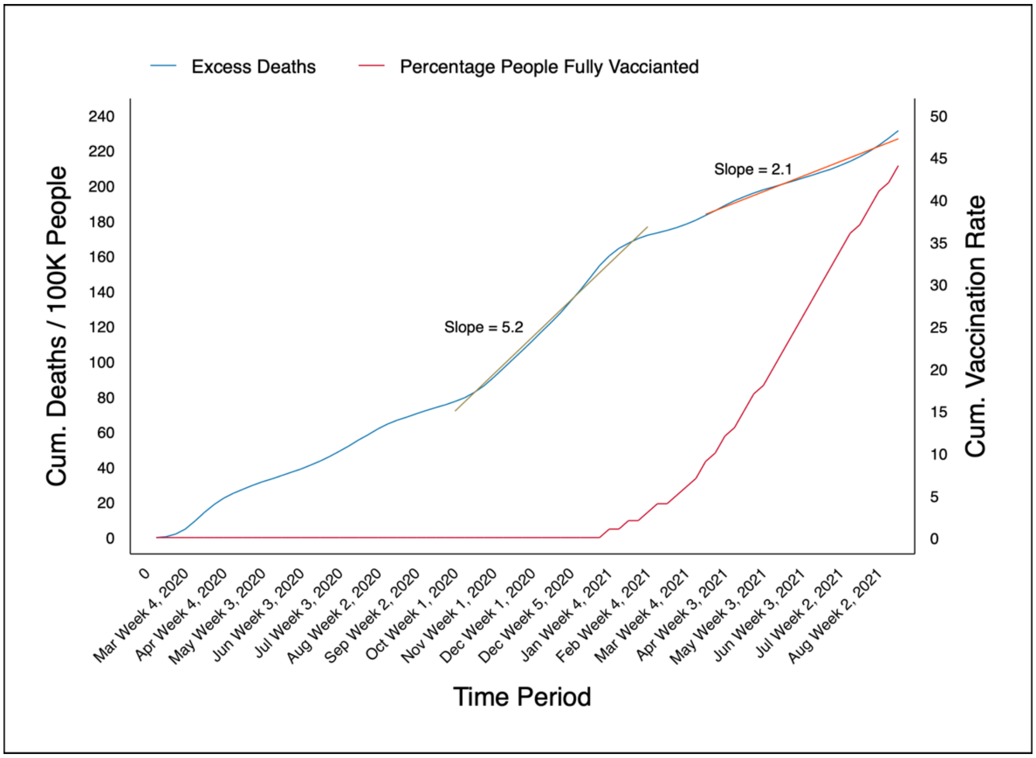
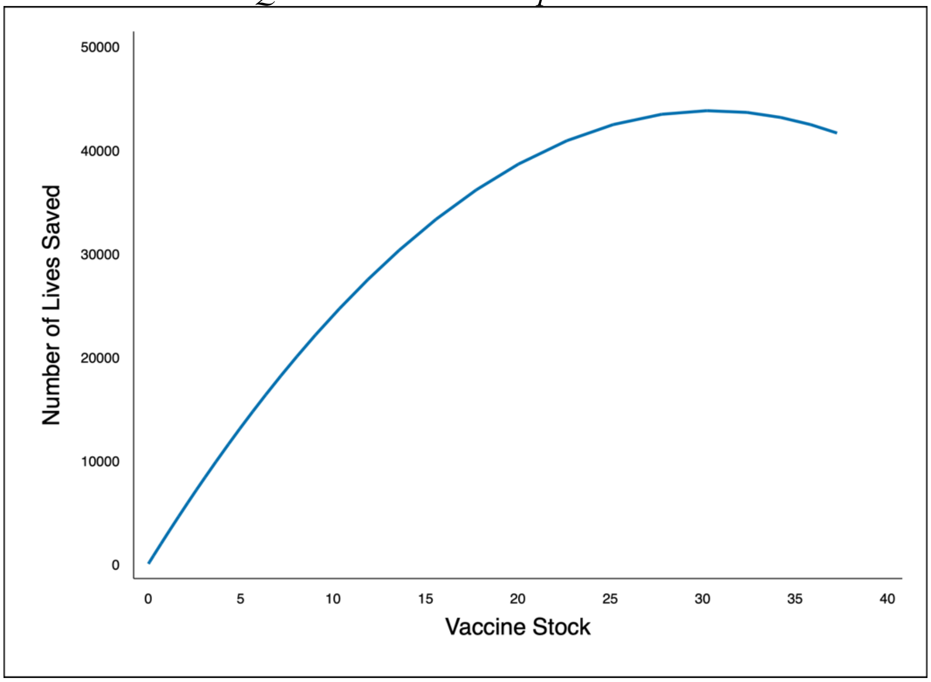


Figure A2: Total Benefit of COVID-19 Vaccines with Increase in Vaccination Rate

Panel A: *Quadratic Relationship – 43 Countries*



Panel B: *Square Root Relationship – 43 Countries*

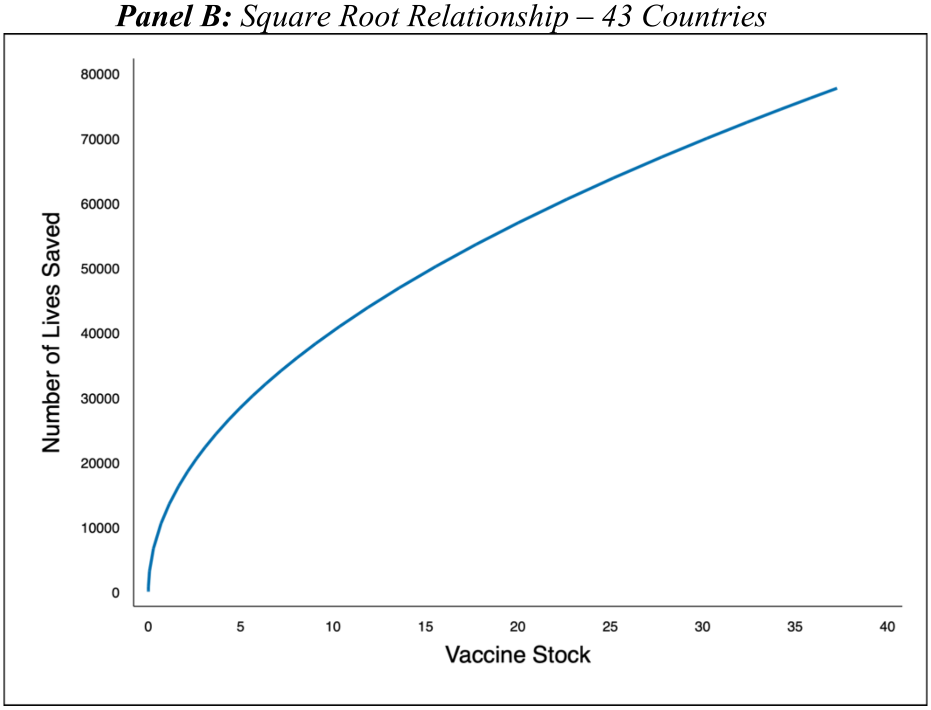
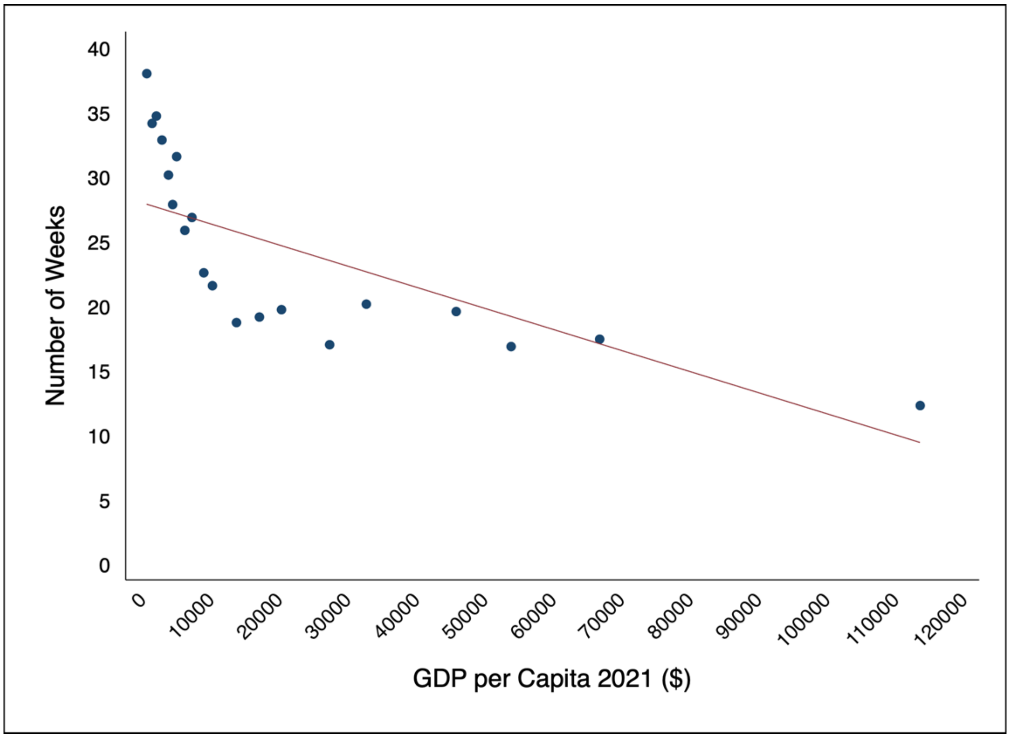


Figure A3: Speed of Vaccines Rollout vs. Income Level



Note: Number of weeks it took to fully vaccinate 5 percent of population

Figure A4: Share of Population Fully Vaccinated by August 2021 vs. Income Level

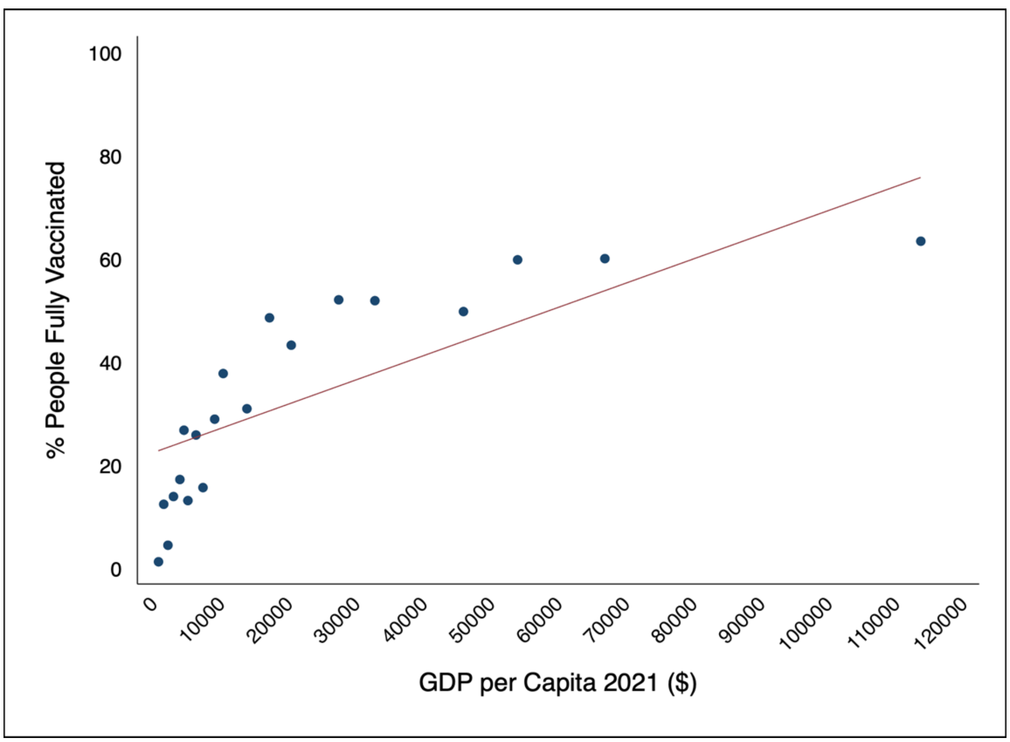


Figure A5: Worldwide - Share of Population Fully Vaccinated by August 2021

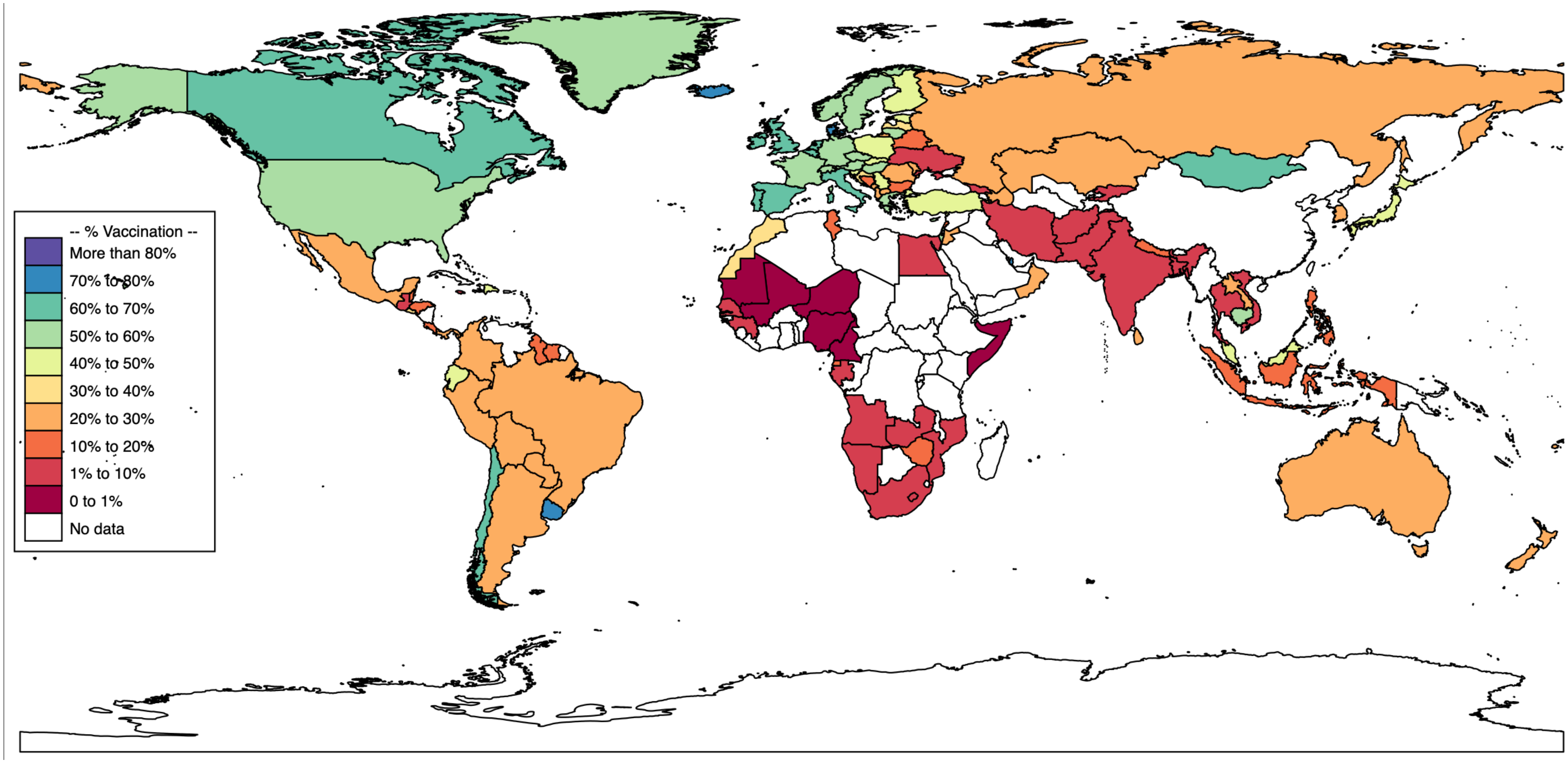
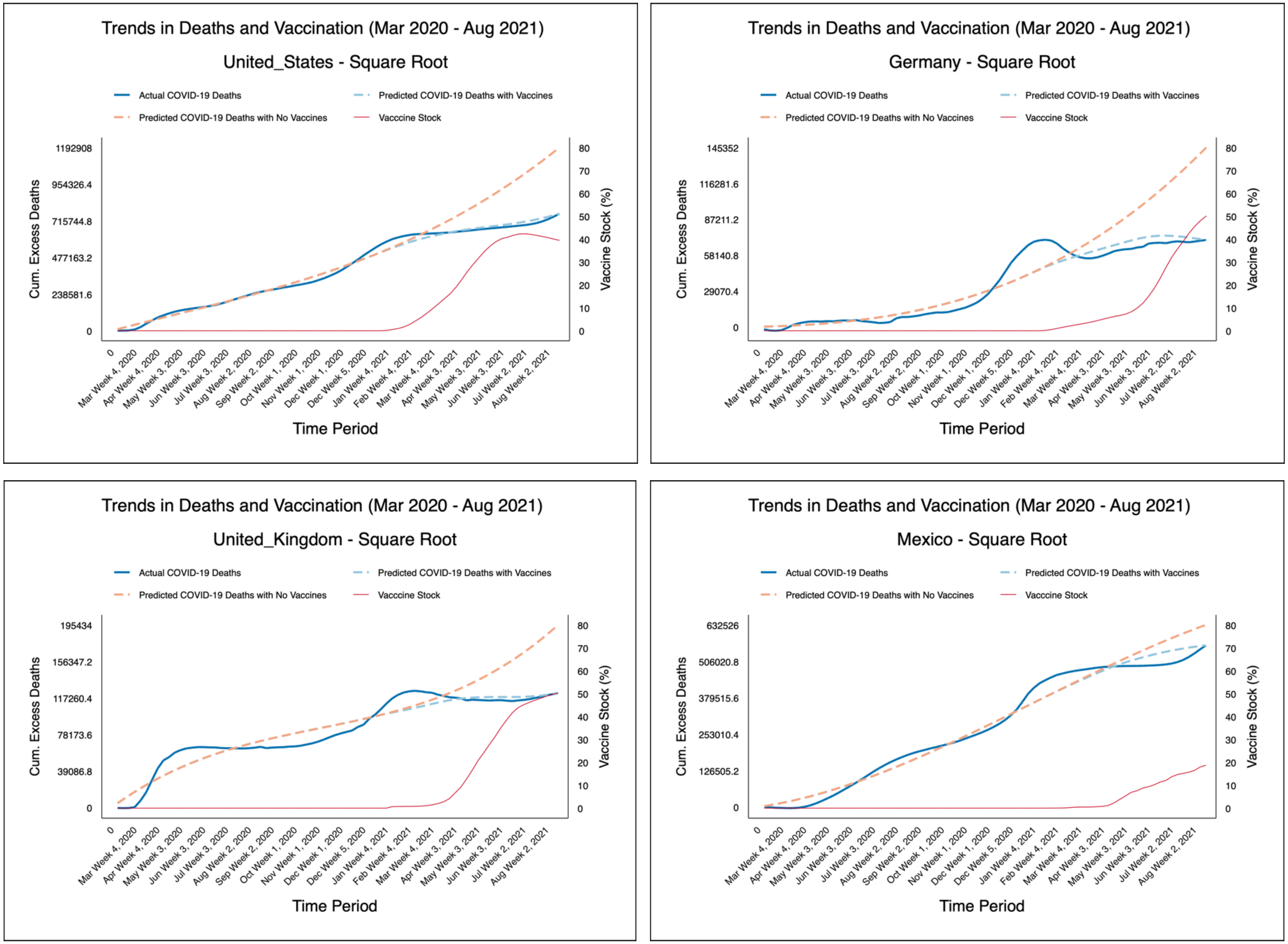
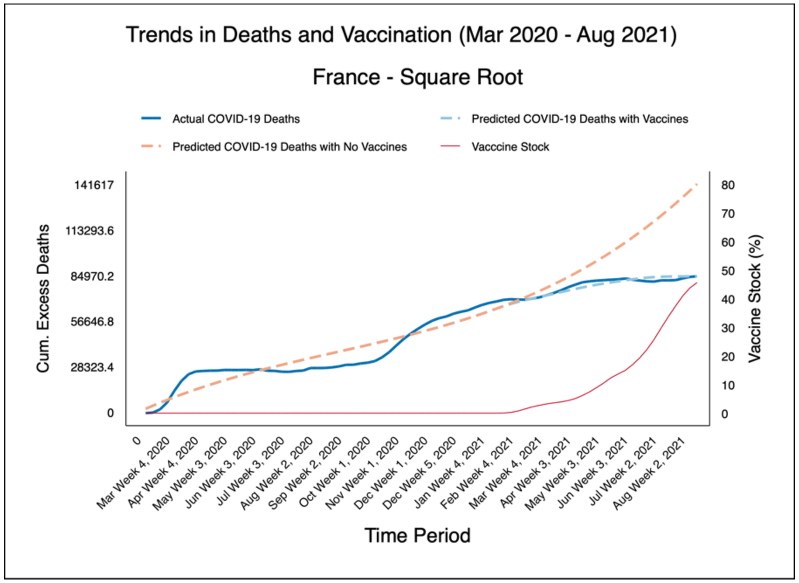
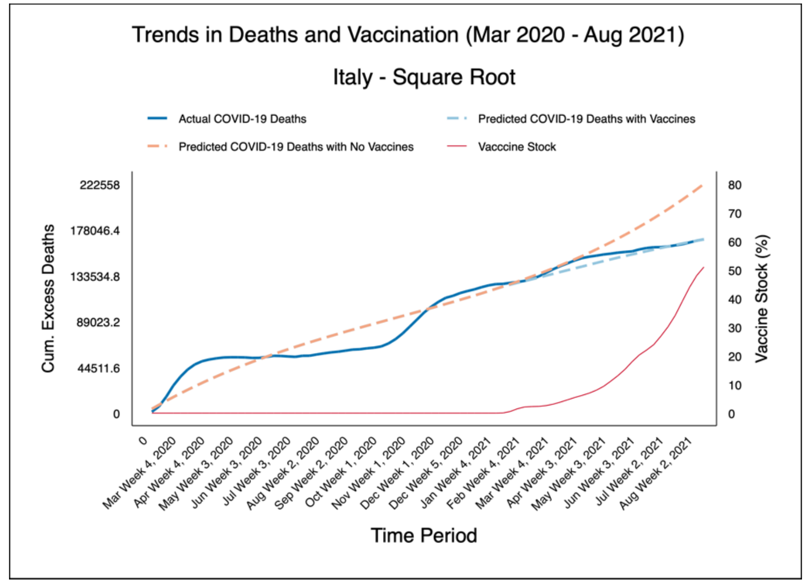
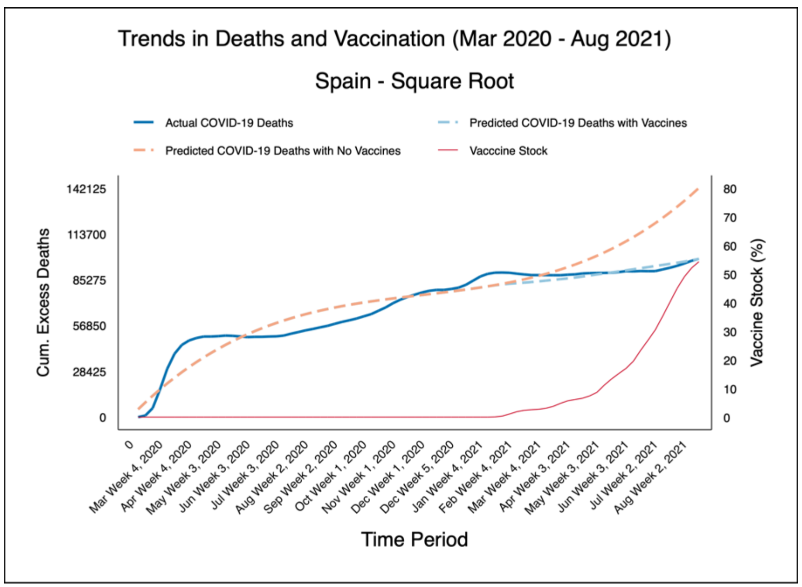


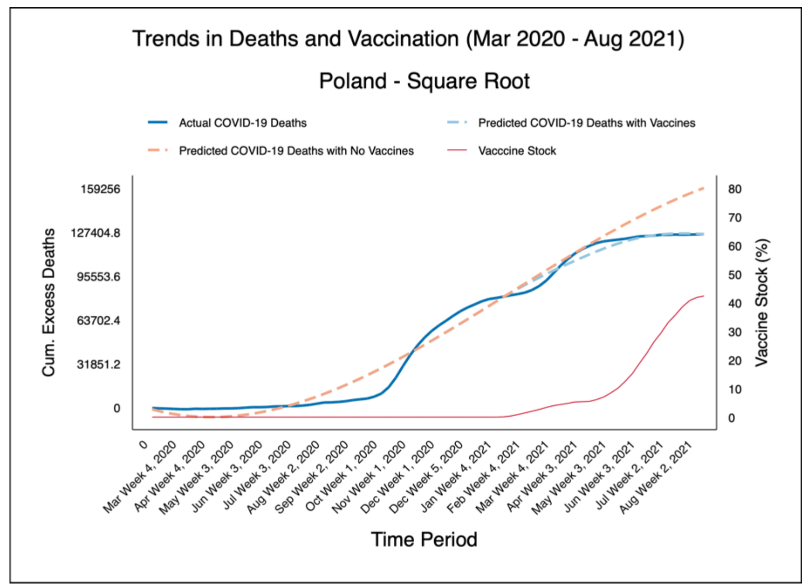
Figure A6: Country-wise Prediction of Excess Deaths – Square Root Model

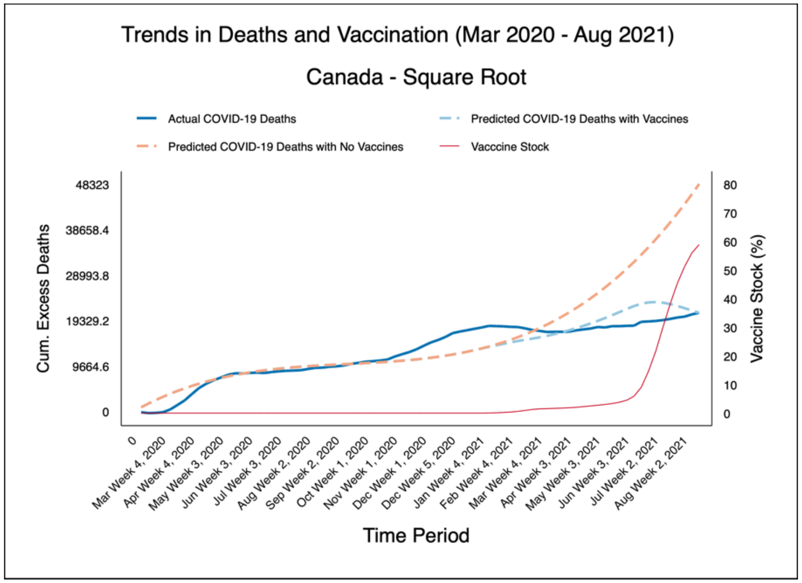


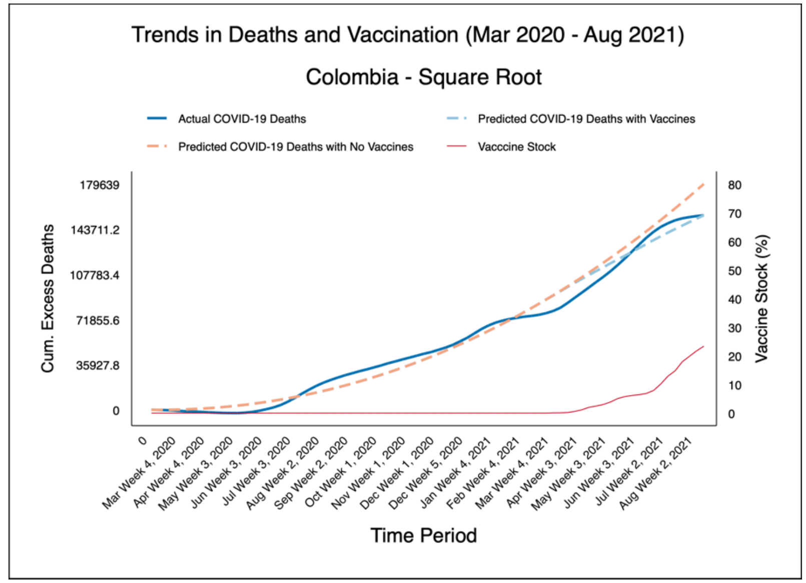

Trends in Deaths and Vaccination (Mar 2020 - Aug 2021)
France - Square Root
Actual COVID-19 Deaths
Predicted COVID-19 Deaths with Vaccines
Predicted COVID-19 Deaths with No Vaccines
Vacccine Stock
Cum. Excess Deaths
141617
113293.6
84970.2
56646.8
28323.4
0
Vaccine Stock (%)
80
70
60
50
40
30
20
10
0
0
Mar Week 4, 2020
Apr Week 4, 2020
May Week 3, 2020
Jun Week 3, 2020
Jul Week 3, 2020
Aug Week 2, 2020
Sep Week 2, 2020
Oct Week 1, 2020
Nov Week 1, 2020
Dec Week 1, 2020
Dec Week 5, 2020
Jan Week 4, 2021
Feb Week 4, 2021
Mar Week 4, 2021
Apr Week 3, 2021
May Week 3, 2021
Jun Week 3, 2021
Jul Week 2, 2021
Aug Week 2, 2021
Time Period


Trends in Deaths and Vaccination (Mar 2020 - Aug 2021)
Italy - Square Root
Actual COVID-19 Deaths
Predicted COVID-19 Deaths with Vaccines
Predicted COVID-19 Deaths with No Vaccines
Vacccine Stock
Cum. Excess Deaths
222558
178046.4
133534.8
89023.2
44511.6
0
Vaccine Stock (%)
80
70
60
50
40
30
20
10
0
0
Mar Week 4, 2020
Apr Week 4, 2020
May Week 3, 2020
Jun Week 3, 2020
Jul Week 3, 2020
Aug Week 2, 2020
Sep Week 2, 2020
Oct Week 1, 2020
Nov Week 1, 2020
Dec Week 1, 2020
Dec Week 5, 2020
Jan Week 4, 2021
Feb Week 4, 2021
Mar Week 4, 2021
Apr Week 3, 2021
May Week 3, 2021
Jun Week 3, 2021
Jul Week 2, 2021
Aug Week 2, 2021
Time Period


Trends in Deaths and Vaccination (Mar 2020 - Aug 2021)
Spain - Square Root
Actual COVID-19 Deaths
Predicted COVID-19 Deaths with Vaccines
Predicted COVID-19 Deaths with No Vaccines
Vacccine Stock
Cum. Excess Deaths
142125
113700
85275
56850
28425
0
Vaccine Stock (%)
80
70
60
50
40
30
20
10
0
0
Mar Week 4, 2020
Apr Week 4, 2020
May Week 3, 2020
Jun Week 3, 2020
Jul Week 3, 2020
Aug Week 2, 2020
Sep Week 2, 2020
Oct Week 1, 2020
Nov Week 1, 2020
Dec Week 1, 2020
Dec Week 5, 2020
Jan Week 4, 2021
Feb Week 4, 2021
Mar Week 4, 2021
Apr Week 3, 2021
May Week 3, 2021
Jun Week 3, 2021
Jul Week 2, 2021
Aug Week 2, 2021
Time Period


Trends in Deaths and Vaccination (Mar 2020 - Aug 2021)
Poland - Square Root
Actual COVID-19 Deaths
Predicted COVID-19 Deaths with Vaccines
Predicted COVID-19 Deaths with No Vaccines
Vacccine Stock
Cum. Excess Deaths
159256
127404.8
95553.6
63702.4
31851.2
0
Vaccine Stock (%)
80
70
60
50
40
30
20
10
0
0
Mar Week 4, 2020
Apr Week 4, 2020
May Week 3, 2020
Jun Week 3, 2020
Jul Week 3, 2020
Aug Week 2, 2020
Sep Week 2, 2020
Oct Week 1, 2020
Nov Week 1, 2020
Dec Week 1, 2020
Dec Week 5, 2020
Jan Week 4, 2021
Feb Week 4, 2021
Mar Week 4, 2021
Apr Week 3, 2021
May Week 3, 2021
Jun Week 3, 2021
Jul Week 2, 2021
Aug Week 2, 2021
Time Period


Trends in Deaths and Vaccination (Mar 2020 - Aug 2021)
Canada - Square Root
Actual COVID-19 Deaths
Predicted COVID-19 Deaths with Vaccines
Predicted COVID-19 Deaths with No Vaccines
Vacccine Stock
Cum. Excess Deaths
48323
38658.4
28993.8
19329.2
9664.6
0
Vaccine Stock (%)
80
70
60
50
40
30
20
10
0
Time Period


Trends in Deaths and Vaccination (Mar 2020 - Aug 2021)
Colombia - Square Root
Actual COVID-19 Deaths
Predicted COVID-19 Deaths with Vaccines
Predicted COVID-19 Deaths with No Vaccines
Vacccine Stock
Cum. Excess Deaths
179639
143711.2
107783.4
71855.6
35927.8
0
Vaccine Stock (%)
80
70
60
50
40
30
20
10
0
Time Period