Dispelling Misconceptions about the Effectiveness of COVID-19 Vaccines: A Statistical Analysis

Abstract

This study aimed to investigate the impact of vaccination on COVID-19. Data from four countries (Japan, America, Luxembourg, and Israel) was collected and analyzed using a logistic model to assess the effect of vaccination on the number of COVID-19 cases. Our initial hypothesis was that vaccination would decrease the number of new COVID-19 cases and deaths. However, our analysis of the vaccine data revealed an increase in the growth rate of total cases after vaccination but a decrease in the rate of growth of total deaths. Additionally, the results showed that vaccination leads to a reduction in positive rates in all countries except for Israel.

I. Background and significance

Germs and bacteria are all around the air we breathe. Everyone is susceptible to the harmful virus. With low Immunity, a virus may assault the human body and make individuals sick, hence vaccines were developed. Vaccines trigger an immune response in the body and protect the human body against serious illness and even deaths. Vaccines have helped reduce the number of harmful human infectious diseases worldwide. Moreover, it drastically reduced the child mortality rates and achieved eradication of major pathogens, such as smallpox [1]. However, it may also have side effects such as redness, soreness, fever, or allergic reactions. Severe complications, including seizures and Guillain-Barre syndrome, as well as deaths, are rare but it can occur. Not only that, other aspects of irregularity such as diabetes and allergies could impact highly on the individual acceptance to vaccines [2]. Vaccine hesitancy remains a concern in more than 90% of countries.

Vaccine hesitancy phenomenon characterized by the reluctance or delay of individuals in receiving vaccines or allowing their loved one receiving it despite their availability. It is frequently perpetuated by erroneous beliefs about the potential adverse effects of vaccines. However, statistical evidence demonstrates that the risks associated with vaccination are significantly lower compared to the risks of contracting COVID-19 or other vaccine-preventable illnesses [3]. The risk of COVID-19 reinfection may be reduced by prior infection, and immunization may help to stabilize the rate of cases. However, COVID-19 pandemic has never come to an end even after the vaccines and several regulations. Thus, ongoing evaluation of vaccine efficacy is crucial and should be done for a comprehensive understanding of the impact of COVID-19 vaccines.

Based on a review of literature, we hypothesized that vaccination may significantly reduce the number of new cases and deaths due to COVID-19. The aim of this study is to determine the effect of vaccination on COVID-19 cases.

II. Materials and Methods

The daily data of countries worldwide from February 2020 to October 2022 were retrieved from github (https://github.com/owid/covid-19-data/blob/master/public/data/owid-covid-data.csv). However, we are interested in analyzing data from four developed countries (United States, Japan, Israel, and Luxembourg) with four seasons (spring, summer, fall, and winter), population density greater than 35 per square kilometer, and life expectancy greater than 75 years. Normalized data of new cases and new deaths for each country are plotted with vaccine, booster, and omicron border lines to see how vaccine, booster, and omicron influence new cases and new deaths. The logistic model has been utilized to model the S-shaped curve total cases and total deaths data for each country, both before and after vaccination, and the parameter estimates are compared. The number of confirmed covid cases at time t is represented by the following model:

$$N(t) = \frac{N_0 K}{N_0 + (K - N_0)e^{-rt}} \quad \text{...} (1)$$

where N_0 is the total covid cases starts from zero, K is the carrying capacity; the potential number of contaminated and r is the rate of total deaths growth. The model parameters were estimated by means of Growthcurver R-Package. Positive rate (the number of positive tests divided by the total test taken daily) of COVID-19 cases in each of the four sampled countries is plotted and statistically described to determine the correlation towards both before and after vaccination.

III. Results

To gain a better understanding of the data, here we provide a plot of normalized new cases and new deaths using the ggplot package (see **Figure 1**).

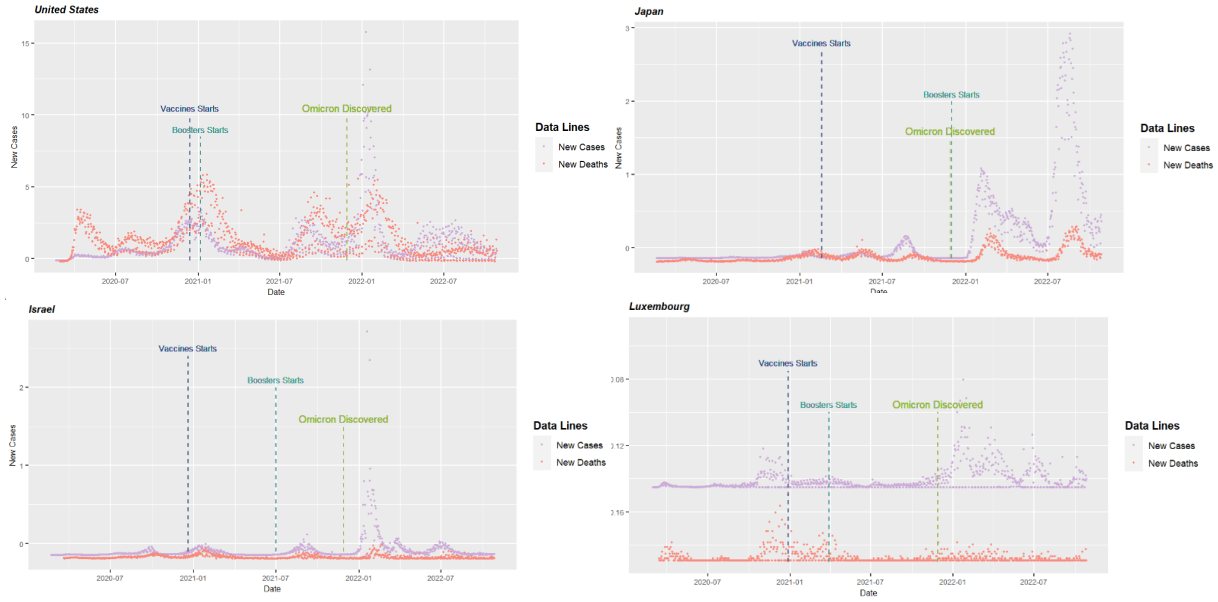

Figure 1. New cases and New Deaths on each countries

There is a significant increase in the number of new COVID-19 cases after the discovery of omicron, indicating a change in the data pattern. So the goal is to predict the effect of vaccinations on COVID-19 before the emergence of omicron. For the model, we have divided the pre-omicron data from each country into two categories, pre-vaccination and post-vaccination, and applied the logistic model to the data. The model demonstrates that the growth rate of COVID-19 cases is significantly higher after vaccination than before vaccination in each of the four countries (see **Appendix Table 2**). We have also applied the logistic model to the total number of deaths in each country based on pre- and post-vaccination data (represents the total number of deaths starting from zero, is the growth rate of total deaths), and we see a decrease in the overall rate of growth of total deaths in all countries, except Israel.

We suspect that the observed increase in COVID-19 cases is due to a growing population. To further investigate this hypothesis, we calculated the positive rate (the number of positive tests divided by the total test taken daily) of COVID-19 cases in each of the four sampled countries. Interestingly, the positive rates are significantly lower after vaccination than before vaccination in all countries except for Japan (see **Figure 2**).

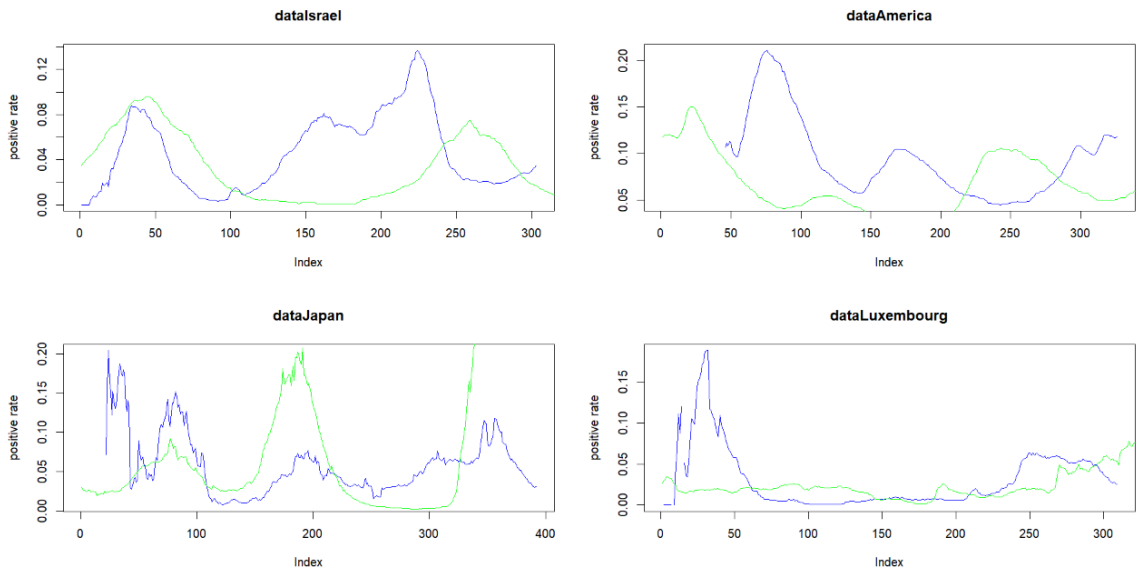

Figure 2. The positive rate post omicron (green = after vaccines, blue = before vaccines)

IV. Discussion and Conclusion

The COVID-19 pandemic continues to be a global problem, and this study aims to evaluate the impact of vaccines on the ongoing COVID-19 pandemic. The results of our analysis of vaccine efficacy suggest that vaccines may not significantly reduce the number of new COVID-19 cases, but do appear to decrease the rate of growth of total deaths. Further analysis also revealed that vaccination leads to a decrease in the positive rates of COVID-19.

Future research should examine how different types of vaccines impact different variants of COVID-19, whether population growth truly affects the number of new COVID-19 cases and deaths and analyze the impact of vaccination in worldwide scales. However, limitations of this analysis, including insufficient data and ongoing COVID-19 cases worldwide, as well as the lack of COVID-19 data from many countries, should be considered. Despite these limitations, using the available data to increase COVID-19 awareness and preparedness may help individuals and communities better navigate future waves of the pandemic.

V. References

[1] Rey-Jurado, Emma, et al. "Assessing the importance of domestic vaccine manufacturing centers: an overview of immunization programs, vaccine manufacture, and distribution." *Frontiers in immunology* 9 (2018): 26.

[2] Wiedermann, Ursula, Erika Garner-Spitzer, and Angelika Wagner. "Primary vaccine failure to routine vaccines: Why and what to do?." *Human vaccines & immunotherapeutics* 12.1 (2016): 239-243.

[3] Chaney, Damien, and Michael SW Lee. "COVID-19 vaccines and anti-consumption: Understanding anti-vaxxers hesitancy." *Psychology & Marketing* 39.4 (2022): 741-754.

APPENDIX

Table 2. Model estimates and accuracy results

country	K	N_0	r	RMSE	R^2	category
United States	2.1E+0	20.3E-3	12.0E-3	406.3E-6	982.1E-3	before vaccines
	543.2E-3	4.0E-3	40.5E-3	89.3E-6	997.5E-3	after vaccines
	353.6E-3	6.2E-3	61.1E-3	251.7E-6	986.7E-3	before vaccines (total deaths)
	646.3E-3	9.3E-3	28.4E-3	139.0E-6	994.9E-3	after vaccines (total deaths)
Japan	76.8E-3	263.3E-6	16.3E-3	215.9E-9	988.0E-3	before vaccines
	35.6E-3	42.4E-6	81.4E-3	612.5E-9	997.2E-3	after vaccines
	2.5E-3	4.2E-6	89.9E-3	400.7E-12	999.6E-3	before vaccines (total deaths)
	8.5E-3	120.7E-6	75.4E-3	5.0E-9	999.4E-3	after vaccines (total deaths)
Israel	15.4E-3	154.9E-6	37.1E-3	108.0E-9	991.2E-3	before vaccines
	17.8E-3	5.3E-6	75.1E-3	11.9E-9	999.8E-3	after vaccines
	8.4E-3	35.5E-6	34.0E-3	17.7E-9	996.7E-3	before vaccines (total deaths)
	4.5E-3	10.4E-6	66.6E-3	6.2E-9	998.2E-3	after vaccines (new deaths)
Luxembourg	2.1E+0	20.3E-3	12.0E-3	406.3E-6	982.1E-3	before vaccines
	543.2E-3	4.0E-3	40.5E-3	89.3E-6	997.5E-3	after vaccines
	290.6E-6	13.0E-6	100.0E-3	120.7E-12	986.2E-3	before vaccines (new deaths)
	878.7E-6	68.3E-6	38.7E-3	381.9E-12	995.1E-3	after vaccines (new deaths)

Table 3. Cutting point before and after vaccines (before omicron exists)

country	category	cutting points
America	before vaccines	[1:298]
	after vaccines	[448:647]
	before vaccines (new deaths)	[1:160]
	after vaccines (new deaths)	[448:647]
Japan	before vaccines	[100:364]
	after vaccines	[464:647]
	before vaccines (new deaths)	[1:125]
	after vaccines (new deaths)	[514:614]
Israel	before vaccines	[100:250]
	after vaccines	[454:647]
	before vaccines (new deaths)	[70:280]
	after vaccines (new deaths)	[479:646]
Luxembourg	before vaccines	[50:309]
	after vaccines	[310:644]
	before vaccines (new deaths)	[1:175]
	after vaccines (new deaths)	[310:534]

Table 4. Descriptive statistics of positive rate on each country

country	min	max	range	mean	category
Israel	0	0.14	0.14	0.05	before vaccines
	0	0.1	0.1	0.04	after vaccines
America	0.04	0.21	0.17	0.09	before vaccines
	0.02	0.15	0.13	0.07	after vaccines
Japan	0.01	0.2	0.19	0.06	before vaccines
	0	0.21	0.21	0.05	after vaccines
Luxembourg	0	0.19	0.19	0.03	before vaccines
	0	0.06	0.06	0.02	after vaccines

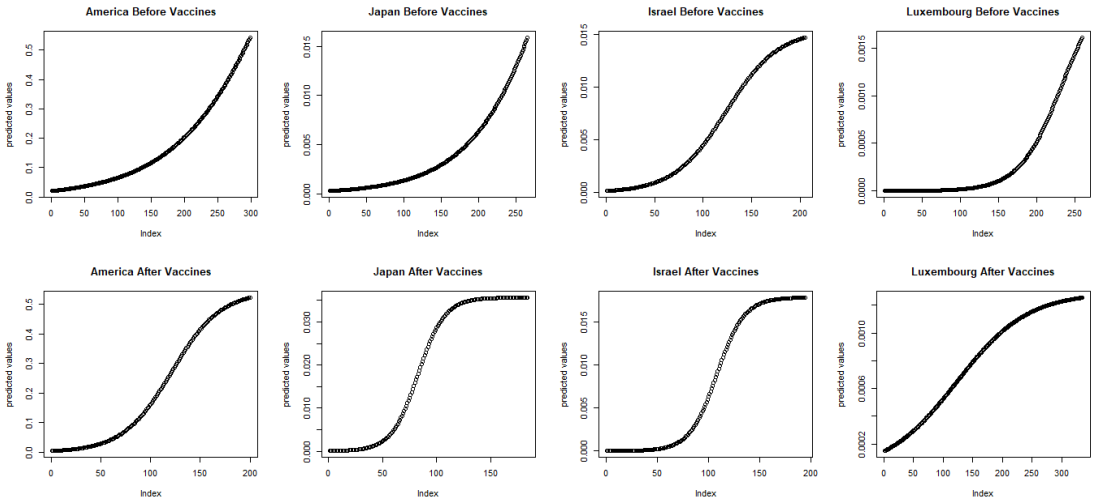

Figure 3. Predicted total cases before and after vaccines

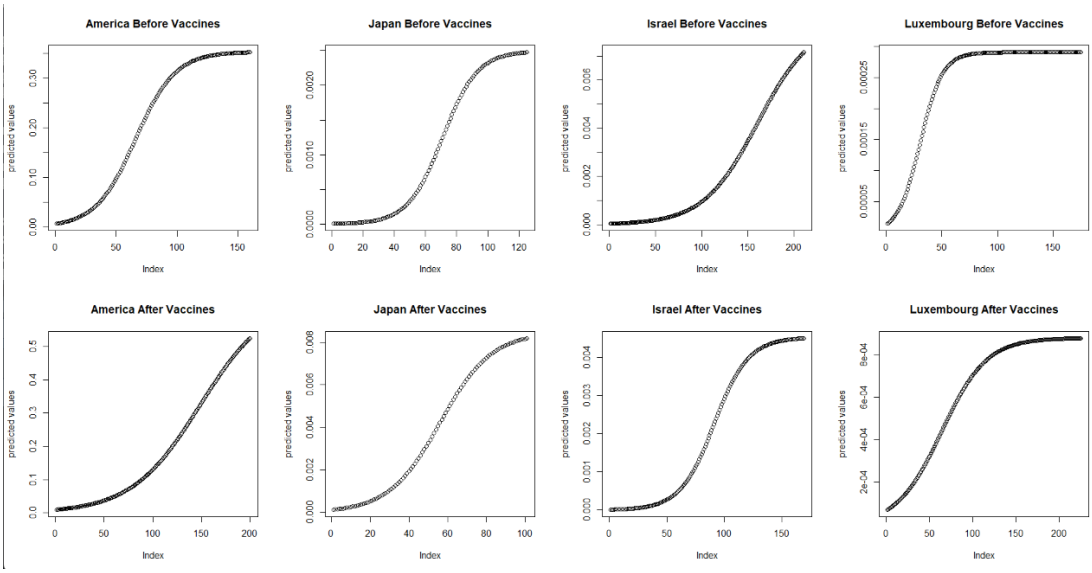

Figure 4. Predicted total deaths before and after vaccines