Jurnal Ilmu Medis Indonesia (JIMI)
ISSN 2807-1697 Vol 2, No 1, 2022, 45-54 https://doi.org/10.35912/jimi.v2i1.1276

Vaksinasi COVID-19 ditinjau dari Perspektif Ekonomi Kesehatan *(COVID-19 Vaccination from a Health Economic Perspective)*

Yuliana Yuliana
Universitas Udayana, Bali
yuliana@unud.ac.id

Riwayat Artikel
Diterima pada 23 Juni 2022
Revisi 1 pada 8 Agustus 2022
Revisi 2 pada 14 Oktober 2022
Disetujui pada 1 November 2022

Abstract

Purpose: To describe the COVID-19 vaccination from the aspects of cost-effectiveness, monetary benefit, fiscal modeling, and health efficacy.

Method: It is a systematic literature review. This systematic review described COVID-19 vaccination effectiveness from health economic perspectives, cost-effectiveness, monetary benefit, fiscal modeling, and heath efficacy. Literatures were taken from PubMed and Science Direct. There were 10 papers from PubMed, 3 papers from Science Direct, and 186 from Google Scholar at the beginning. After being selected for title, abstract and full content, 11 journals were left. PRISMA guidelines were used. Inclusion criteria are review and research articles. The excluded articles that were not peer-reviewed and unavailable full-text paper. Articles were read twice to reduce the bias. The selected articles were summarized and narrated descriptively.

Results: Results revealed that vaccination is cost-effective and cost-saving based on economic model analysis such as QALY rate, global COVID-19 VAR model, and ICER. The mortality and morbidity of the COVID-19 infection are depended on the vaccination program.

Limitations: There were only some articles included in the systematic review. Therefore, the result might be not complete and comprehensive.

Contribution: This paper can be used as a review for implementing the vaccination program based on the effectiveness from health economic perspectives.

Keywords: *COVID-19 vaccination, cost-effectiveness, fiscal modeling, heath efficacy, monetary benefit*

How to cite: Yuliana, Y. (2022). Vaksinasi COVID-19 ditinjau dari Perspektif Ekonomi Kesehatan. *Jurnal Imu Medis Indonesia*, 2(1), 45-54.

1. Introduction

The COVID-19 vaccination program has been implemented for a few months in some countries. Mass testing and case isolation are also effective strategies besides the SARS-CoV-2 vaccination for controlling the rapid transmission besides face masking and social distancing. Those programs are considered effective as safeguard steps of preventing the spread of the COVID-19 infection. The vaccination programs are used to reach the high levels of immunity of the community as fast as possible (Du et al. 2022). Many kinds of SARS-CoV-2 vaccines have been developed by scientists and pharmaceutical companies. They tried to develop the most effective vaccine. More than 90 vaccine candidates were tested in humans. Finally, some vaccines have got emergency-use authorization after the Phase III trials. The US started to give vaccines to priority groups, such as healthcare personnel and the elderly. Although the vaccination programs had been rigorously implemented, some people are still hesitant about the benefits and risks deployed by the vaccination program (Du et al. 2022).

The studies revealed that a vaccine would be more beneficial in cost-saving rather than no vaccination. Nevertheless, the study did not analyze specific conditions such as vaccine prioritization in the condition of less vaccination available (Kohli et al. 2021). Unvaccinated countries will face a continuously decreasing economic activity in a long-term period (Arndt et al. 2020). Vaccination COVID-19 has two positive sides from the health and economic perspective. When the vaccination program is successful, the economic flow will be better. Vaccination will lower the infection rate. Long-term effects, transmission remodeling, real-world data calibration, and specific cost-effectiveness methodologies must be taken into consideration. Data are limited in the economic models for low and middle-income countries that cannot afford vaccination programs factors (Kohli et al. 2021).

Producing an ideal COVID-19 vaccine means can handle public health crises with the correct price, pharmacy, and shareholders' expectations. Vaccine manufacturers just take very minimal profits from their products. Regulation, unclear information among customers, low prices, and the need to make safe products make the production of new vaccines quite difficult (Neumann et al. 2021). Economic values for the vaccine is not only for the public but it is also important for the government. COVID-19 pandemic can affect fiscal consequences for governments. Job loss and bad economic conditions will lower taxes income for governments. The fiscal modeling evaluates public health investments. It can be used in the case of vaccination. This model translates morbidity and mortality outcomes that are associated with disability, related costs, early retirement, and death. Finally, it causes tax revenue losses for the government (Connolly and Kotsopoulos 2020).

The efficacy COVID-19 vaccine has been questioned by people. Based on a computational model in the United States, it was shown that the minimal vaccine efficacy must be 60% when vaccination coverage is 100%. The vaccine efficacy threshold increases to 70% when the coverage range is 75% and up to 80% when coverage is only 60%. Therefore, the minimal vaccine efficacy is at least 70% to prevent an epidemic and at least 80% without any other prevention strategy such as social distancing (Bartsch et al. 2020). People decide to be vaccinated or not based on the efficacy of COVID-19 (from the health perspective) and economic point of view. There is still hesitancy among people about doing vaccination. Therefore, this paper aims to describe COVID-19 and the health economic perspective of vaccination in systematic review literature.

2. Literature Review

Multiple SARS-CoV-2 infections have many variants. Those variants are the Alpha, Gamma, and Delta variants. Concern has arisen worldwide. Those new variants are considered to spread faster and cause more lethal diseases. Therefore, vaccines are needed to be renewed and researched. When the vaccination program is successful, the logistic and resources will evolve. However, with the continuous mutation of the virus, the vaccine should be renewed. Vaccination programs can avoid socioeconomic burdensome restrictions. Economic analysis includes the salary loss while isolation and quarantine, hospitalization, and death loss. The duration of immunity after vaccination is still uncertain. The immunity is getting low after several months post-vaccination. Immunity is transient. Therefore, policymakers have new challenges in controlling the infection rate (Cavanaugh et al. 2021; Du et al. 2019, 2022).

Vaccines were developed by several technologies. Those technologies included genetic, viral, also inactivated vaccines. A more sophisticated technology, namely protein-based vaccinology was also being studied. Therefore, there are several variations of the vaccines. These conditions affect efficacy, safety, and delivery (Jiang, Cai, and Shi 2022). In China, CoronaVac and Sinopharm vaccines are the dominant vaccines given to the population globally. However, the studies showed that the immunity after the second dose of vaccination wanes rapidly. Therefore, the World Health Organization (WHO) recommended giving the third dose to make sure a good protection for the people globally. The immunologists also recommended the third dose. It is necessary and sensible from the immunologist's point of view. Meanwhile, virologists gave the opinion that the vaccine should be optimized. Some limited clinical-trial data revealed that the efficacy of CoronaVac was 51% and Sinopharm 79% in preventing symptomatic disease. On the other sides, 63% efficacy was reported for the University of Oxford–AstraZeneca's viral-vector vaccine (Mallapaty 2021).

Other technology of vaccines showed a similar trend of decreasing protection against infection. However, the vaccines revealed better protection against severe disease and also death. Meanwhile, some scientists said that the inactivated vaccines started at a lower base of neutralizing antibodies, therefore the protection would drop faster than other vaccines (Mallapaty 2021).

The schematic flow of the individual-based mathematical model of COVID-19 transmission, vaccination, and testing can be described specifically. It is depicted in Figure 1. After getting infected, susceptible individuals (S) come into an exposed state (E). This state is unique because they are not infectious nor symptomatic. It is also called a non-infectious incubation period. This state is followed by a moderately-infectious asymptomatic state (A). However, not all of the cases remain asymptomatic. The remaining cases develop into a moderately-infectious pre-symptomatic state (P) before changing into highly infectious and symptomatic (Y). Symptomatic cases are more infectious than asymptomatic and pre-symptomatic cases. Some of these cases will be hospitalized (H), and the rest of them will die (D). Meanwhile, asymptomatic and symptomatic individuals recover (R). These groups are usually remain protected from future infection for a while. In the proactive testing, the individuals will be tested at a certain time. It could be daily to monthly, based on the schedule. When the test showed a positive result, the individual will be isolated and their close contacts are quarantined for a certain time. Meanwhile, vaccinated individuals are given the first and second doses for the vaccine efficacy consideration (Du et al. 2022).

Vaccines that are produced by Pfizer-BioNTech, Moderna, and Johnson & Johnson have been recommended for mass vaccination. Within two weeks after the first vaccination dose, the susceptibility to infection is decreased by 47%. Meanwhile, after 14 days of the second dose, it is decreased to 33% of baseline susceptibility. When people get infected after a second dose of vaccination, the risks of developing symptoms are decreased by more than 80% (Du et al. 2019, 2022). Vaccines that are produced by Pfizer-BioNTech, Moderna, and Johnson & Johnson have been recommended for mass vaccination. Within two weeks after the first vaccination dose, the susceptibility to infection is decreased by 47%. Meanwhile, after 14 days of the second dose, it is decreased to 33% of baseline susceptibility. When people get infected after a second dose of vaccination, the risks of developing symptoms are decreased by more than 80% (Du et al. 2019, 2022).

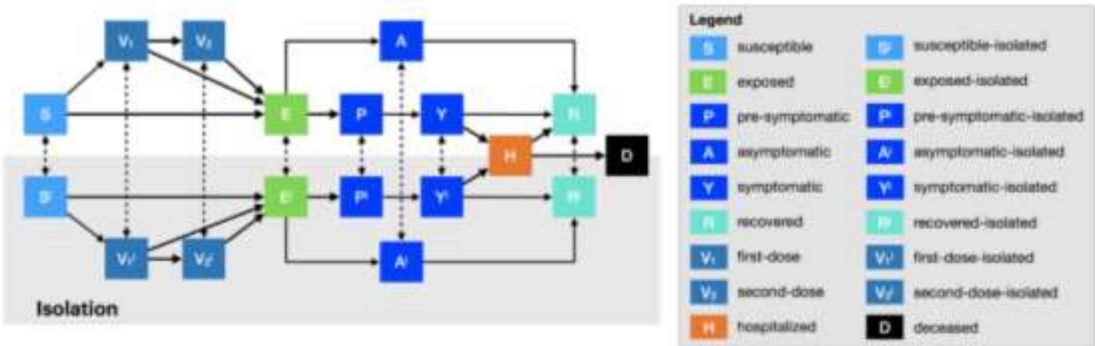

Figure 1. The schematic flow of the individual-based mathematical model of COVID-19 transmission, testing, and vaccination (Du et al. 2022).

2. Methodology

Eligibility criteria

Criteria are created based on the PICO framework. PICO criteria can be seen in Table 1.

Table 1. PICO Criteria of the Study

Patient/population	Vaccination
Intervention	COVID-19 vaccination
Comparator	Non vaccinated

Outcome	Economic (cost-effectiveness, Monetary Benefit, fiscal modeling) and health efficacy

Type of studies
This review included review and original research studies in English about the economic and health perspectives of COVID-19 vaccination. Exclusion criteria are articles that were not peer-reviewed, duplicated articles, and unavailable free full text.

Type of participants
This review included studies from any countries that implemented COVID-19 vaccination. Unvaccinated countries were also included as a comparison.

Type of interventions
The intervention was the COVID-19 vaccination

Type of outcomes
The results investigated in this review were the health and economic perspective of COVID-19 vaccination. It is focused on cost-effectiveness, monetary benefit, fiscal modeling, and health efficacy.

Information sources
We used keywords using the Boolean operator. In this study, we used keywords ("COVID-19 vaccination") AND ("cost-effectiveness") AND ("monetary benefit") AND ("fiscal modeling") AND ("health efficacy") AND (2020) in PubMed, Science Direct, and Google Scholar databases as search engines to find suitable journals.

Study selection
The study selection began with the removal of duplicate records. The irrelevant studies were excluded by screening the titles and abstracts. Firstly, the title and abstract must contain at least COVID-19 vaccination keywords with one of the other keywords such as cost-effectiveness or monetary benefit or fiscal modeling or health efficacy. After that, if the free full text is available in English or Indonesian, then the reading and selection will be continued. Otherwise, it will be removed. Full-text screening steps are reading the abstract and conclusion and examining the type of the text. Case reports, letters to the editor, and narrative review were excluded.

3. Results and Discussions

Study selection
The study selection began with the removal of duplicate records. The irrelevant studies were excluded by screening the titles and abstracts. Firstly, the title and abstract must contain at least COVID-19 vaccination keywords with one of the other keywords such as cost-effectiveness or monetary benefit or fiscal modeling or health efficacy. After that, if the free full text is available in English or Indonesian, then the reading and selection will be continued. Otherwise, it will be removed. Full-text screening steps are reading the abstract and conclusion and examining the type of the text. Case reports, letters to the editor, and narrative review were excluded.

Study Characteristics
We included 11 full-text articles which are 1 cohort model study, 7 economic analyses, and 3 reviews. The articles were published in 2020 and 2021. *The Joanna Briggs Institute* (JBI) score is also provided in Table 1 for each study.

Table 2. Characteristic, JBI score, measurement, and outcome of Inclusion Studies

No	Author, year, place, study design	Number of the participant,	Analysis	Method for measurement	Result	Conclusion

		demographic characteristic				
1	Kohli *et al*., 2021 Cohort model study (Kohli et al. 2021)	Population group is based on age; risk and age; and occupation and age (Kohli et al. 2021)	JBI Score 8/11	A Markov cohort model was used to estimate COVID-19 related direct medical costs and deaths in the United States (US), with and without implementation of a 60% efficacious vaccine (Kohli et al. 2021)	Results were most sensitive to infection incidence, the price of the vaccine, the treatment cost of COVID-19 infection, and the efficacy of the vaccine (Kohli et al. 2021)	A COVID-19 vaccine revealed some good values for money based on cost per QALY gained < $50,000). The morbidity and mortality prevention depends on the speed and effectiveness of vaccine delivery (Kohli et al. 2021).
2	Neumann et al., 2021 Review (economic analysis) (Neumann et al. 2021)	None It is an economic review analysis (Neumann et al. 2021)	JBI Score 8/11	Value-based pricing analyses conducted from a health system and a societal perspective (Neumann et al. 2021)	Cost-effectiveness analyses can inform pricing (Neumann et al. 2021)	Cost-effectiveness analyses depend on social benefit in society (Neumann et al. 2021)
3	Arndt et al., 2020 South Africa Review (Text and opinion)	-	JBI Score 5/6	No vaccination program yet when the literature was written (Arndt et al. 2020)	GDP at factor cost falls by 34%. Decrease of earnings are 30% (Arndt et al. 2020)	Low-income households will choose to work for preventing starvation. They accept the risk of being infected (Arndt et al. 2020)

4	Connolly and Kotsopoulos, 2020 Concept Paper (Connolly and Kotsopoulos 2020)	-	JBI Score 5/6	Fiscal health modeling has been proposed as a complementary approach to cost-effectiveness analysis for considering the broader consequences for governments attributed to vaccines (Connolly and Kotsopoulos 2020).	The fiscal costs of healthcare can lower morbidity and mortality influence transfer payments (Connolly and Kotsopoulos 2020).	The fiscal health modeling framework is useful for understanding the economic impact of vaccination investing programs (Connolly and Kotsopoulos 2020).
5	Bartsch et al., 2020. Computational model using Microsoft Excel version 16. (Bartsch et al. 2020)	357,157,434 people (computational model for the US population)	JBI Score 8/11	Vaccine efficacy	The vaccine efficacy is minimal 60% if the vaccination coverage is 100%. The lower the vaccination coverage, the higher vaccine efficacy must be reached.	Minimum vaccine efficacy is at least 70% to prevent an epidemic. It is a minimum of 80% without any other preventive strategy such as social distancing.
6	Wouters et al., 2020 Review (text and opinion, health policy) (Wouters et al. 2021)	-	JBI Score 6/6	Production, affordability, allocation, and deployment of COVID-19 vaccination	From a 32-country survey, vaccine acceptance was high in Vietnam, India, China, Denmark, and South Korea.	The social value of safe and effective COVID-19 vaccines is very huge. The vaccine must be available, affordable, and

					reachable by all societies.
7	Marco-Franco, et al., 2021 Economy analysis in Spain (Marco-franco et al. 2021)	JBI Score 8/11	Mathematical Model	Incremental cost-effectivenes s ratio (ICER) is 5132 € as of 17 February 2021	vaccination against COVID-19 is highly cost-effective.
8	Hagens et al., 2021 Economy analysis in Turkey (Hagens et al. 2021)	JBI Score 8/11	SIRD (Susceptible, Infectious, Recovered, Death) model	The incremental cost-effectivenes s ratio (ICER) of 511 USD/QAL Y and 1045 USD/QAL Y if vaccine effectivenes s on transmissio n is equal or reduced to only 50% of effectivenes s on disease, respectively , at the 90% baseline effectivenes s of the vaccine.	COVID-19 vaccination is highly cost-effective or cost-saving.
9	(Volodymyrovyc h et al. 2021) Economic analysis for vaccination in Ukraine	JBI Score 8/11	Transmission model	The high transmitters ' ratio was found to be 8.8% higher than for the elderly.	Vaccinating the elderly was the most cost-effective method.
10	(Chudik, Mohaddes, and Raissi 2021)	JBI Score 8/11	Global VAR Model	Countries that implemente d higher	Fiscal policy is effective in preventing a worse

	Global VAR model in some countries in the world, such as Europe, America, China, Asia, including Indonesia			fiscal support will have fewer output contractions	economic downturn
11	(Jiang et al. 2022) Hong Kong SAR, Indonesia, China, Philippines, Singapore, and Thailand Decision tree models	JBI Score 8/11	Decision tree model	The vaccination strategy is effective based on QALY.	Inactivated COVID-19 vaccines are cost-saving

Results revealed that there are 11 studies. There are some models and analyses for counting the vaccine effectiveness, namely a Markov Cohort model, value-based pricing analysis, fiscal health modeling, production, affordability, mathematical model, Susceptible, Infectious, Recovered, and Death (SIRD) Model, also transmission model, decision tree model, and Global VAR Model. Results showed that vaccinating the elderly first was the most effective method to reduce the burden of the COVID-19 treatment cost.

This systematic literature review had 11 included studies. There are some models and analyses for counting the vaccine effectiveness, namely a Markov Cohort model, value-based pricing analysis, fiscal health modeling, production, affordability, mathematical model, Susceptible, Infectious, Recovered, and Death (SIRD) Model, also transmission model, and Global VAR Model. Results showed that vaccinating the elderly first was the most effective method to reduce the burden of the COVID-19 treatment cost. The limitations are this paper is not a meta-analysis, therefore we need a meta-analysis to comprehend the impact of COVID-19 vaccination on health economic perspective. The implication is COVID-19 vaccination program must be done to all of the countries as quickly as possible because it is beneficial from the health economic perspective. Vaccination is highly cost-saving and cost-effective based on some economic model analysis. The vaccination priority must be given to the elderly to have a better effective result. The elderly has a higher transmission rate based on the studies (Volodymyrovych et al. 2021).

Cost-effectiveness

Kohli et al. studied the public health and economic impact of a vaccine in the US by using a model cohort. After combining the most recent evidence to date from March to May and future mortality in the next year, they estimated the incremental cost per quality-adjusted life-year (QALY) gained and COVID-19 treatment costs. They found that vaccination is cost-saving in the highest-risk groups (Kohli et al. 2021). The incremental cost per QALY gained for the US adult population was $8,200 versus no vaccination. For those ages 65 years and older, vaccination was cost-saving. The cost per QALY gained increased to over $90,000 for people with a low risk of hospitalization and death after infection. Therefore, by implementing the most optimistic scenario, the hypothetical vaccine may prevent at least 30% of expected deaths. Maximizing the number of prevented death is the priority (Kohli et al. 2021).

Monetary benefit
Prices send important clues about customer favorites. It helps producers to make favorable products. This thing can be more complicated in the pandemic. The policy forces to ensure lower prices and easy access to the vaccine. The alternative price strategy involves cost recovery models, monetary conditions, and future market commitments. Hybrid pricing strategies are essential. Value measurement is the ratio of incremental costs to incremental benefits. Incremental benefits include quality-adjusted life-years, or QALYs in cost-effectiveness analysis (Neumann et al. 2021).

Marco-Franco studied that the Incremental cost-effectiveness ratio (ICER) is 5132 € as of 17 February 2021 in Spain (Marco-franco et al. 2021). Another study by Hagens et al in Turkey found that incremental cost-effectiveness ratio (ICER) of 511 USD/QALY and 1045 USD/QALY if vaccine effectiveness on transmission is equal or reduced to only 50% of effectiveness on disease, respectively, at the 90% baseline effectiveness of the vaccine. Therefore, vaccination is highly cost-effective and cost-saving (Hagens et al. 2021). However, the best priority for vaccination should be the elderly. It is based on a transmission model analysis (Volodymyrovych et al. 2021).

Fiscal modeling
The fiscal modeling framework contributes to consideration for the broader cross-sectoral impact of vaccines on government public accounts. This framework can be used together with other health economic evaluations to inform a range of stakeholders, especially the future funding and ongoing programs (Connolly and Kotsopoulos 2020).

Bartsch et al. developed a computational transmission, clinical, and economic outcomes model for the U.S. population. The model predicted the longest epidemic duration as 2.5 years. The model participants were 357,157,434 people. Each individual in the model is in 1 of 5 mutually exclusive SARS-CoV-2 states such as susceptible, exposed, infectious and asymptomatic, infectious and symptomatic, and recovered/immune (Bartsch et al. 2020). Another study based on the Global VAR model concluded that higher fiscal support is needed in most of the countries in the world to prevent the deterioration of economic turndown (Chudik et al. 2021).

Health efficacy
An ideal COVID-19 vaccine must be affordable, globally, produced at scale, and widely deployed in local society. Affordable prices enable a large volume of purchases. Continuous funding can be done for the vaccination program. Infrastructures have to be prepared in delivering the COVID-19 vaccine locally, regionally, and widespread. When the acceptance rate is high, the vaccination program will be more easily to be implemented (Wouters et al. 2021).

4. Conclusion
Funding for COVID-19 vaccine production is a good investment from the health and economic perspective. Based on health economic perspective, vaccination is highly cost-effective. It was proven on the mathematical models and economic analysis. The priority should be the elderly because they have a higher transmission rate.

Limitation and study forward
The limitation of this study is only some articles were found suitable to be included in the systematic review. Therefore, the result might be not complete and comprehensive. There might be a broader result when the vaccination program has been implemented for a longer time.

Referensi
Arndt, Channing, Rob Davies, Sherwin Gabriel, Laurence Harris, Konstantin Makrelov, Sherman Robinson, Stephanie Levy, Witness Simbanegavi, Dirk Van Seventer, and Lillian Anderson. 2020. "Covid-19 Lockdowns, Income Distribution, and Food Security: An Analysis for South Africa." *Global Food Security* 26(100410):1–6.

Bartsch, Sarah M., Kelly J. O. Shea, Marie C. Ferguson, Maria Elena Bottazzi, Patrick T. Wedlock, Ulrich Strych, James A. Mckinnell, Sheryl S. Siegmund, Sarah N. Cox, Peter J. Hotez, and Bruce Y. Lee. 2020. "Vaccine Efficacy Needed for a COVID-19 Coronavirus Vaccine to Prevent or Stop an Epidemic as the Sole Intervention." *American Journal of Preventive Medicine* 59(4):493–503.

Cavanaugh, Alyson M., Kevin B. Spicer, Douglas Thoroughman, Connor Glick, and Kathleen Winter. 2021. "Reduced Risk of Reinfection with SARS-CoV-2 After COVID-19 Vaccination —." *Morbidity and Mortality Weekly Report* 70(32):1081–83.

Chudik, Alexander, Kamiar Mohaddes, and Mehdi Raissi. 2021. "Covid-19 Fiscal Support and Its Effectiveness." *Economics Letters* 205:1–5.

Connolly, Mark P., and Nikolaos Kotsopoulos. 2020. "Estimating the Fiscal Consequences of National Immunization Programs Using a ' Government Perspective ' Public Economic Framework." *Vaccines* 8(495):1–11.

Du, Zhanwei, Lin Wang, Yuan Bai, Xutong Wang, Abhishek Pandey, Meagan C. Fitzpatrick, Matteo Chinazzi, Benjamin J. Cowling, and Lauren Ancel. 2022. "Articles Cost-Effective Proactive Testing Strategies during COVID-19 Mass Vaccination : A Modelling Study." *The Lancet Regional Health - Americas* 8:1–10.

Du, Zhanwei, Lin Wang, Abhishek Pandey, Wey Wen Lim, Matteo Chinazzi, Ana Pastore, Eric H. Y. Lau, Peng Wu, Anup Malani, Sarah Cobey, and Benjamin J. Cowling. 2019. "Modeling Comparative Cost-Effectiveness of SARS-CoV-2 Vaccine Dose Fractionation in India." *Nature Medicine* 1–18.

Hagens, Arnold, Ahmet Ça˘gkan Inkaya, Kasirga Yildirak, Mesut Sancar, Jurjen Van Der Schans, Aylin Acar Sancar, Serhat Ünal, Maarten Postma, and Selen Yegenoglu. 2021. "COVID-19 Vaccination Scenarios : A Cost-Effectiveness Analysis for Turkey." *Vaccines* 9(399):1–19.

Jiang, Yawen, Dan Cai, and Si Shi. 2022. "Economic Evaluations of Inactivated COVID-19 Vaccines in Six Western Paci Fi c and South East Asian Countries and Regions : A Modeling Study." *Infectious Disease Modelling* 7(1):109–21.

Kohli, Michele, Michael Maschio, Debbie Becker, and Milton C. Weinstein. 2021. "The Potential Public Health and Economic Value of a Hypothetical COVID-19 Vaccine in the United States : Use of Cost-Effectiveness Modeling to Inform Vaccination Prioritization." *Vaccine* 39(7):1157–64.

Mallapaty, Smriti. 2021. "China's Covid Vaccines Have Been Crucial: Now Immunity Is Waning." *Nature* 598:398–99.

Marco-franco, Julio Emilio, Pedro Pita-barros, Silvia Gonz, Iryna Sabat, and David Vivas-consuelo. 2021. "Simplified Mathematical Modelling of Uncertainty : Cost-Effectiveness of COVID-19 Vaccines in Spain." *Mathematics* 9(566):1–15.

Neumann, By Peter J., Joshua T. Cohen, David D. Kim, and Daniel A. Ollendorf. 2021. "Consideration Of Value-Based Pricing For Treatments And Vaccines Is Important, Even In The COVID-19 Pandemic." *Health Affairs* 40(1):53–61.

Volodymyrovych, Tsekhmister Yaroslav, Stepanenko Viktor Ivanovich, Konovalova Tetiana, and Tsekhmister Bogdan Yaroslavovych. 2021. "Pharmaco Economics Analysis of COVID-19 Vaccines in Ukraine." *Journal of Pharmaceutical Research International* 33(May):140–47.

Wouters, Olivier J., Kenneth C. Shadlen, Maximilian Salcher-konrad, Andrew J. Pollard, Heidi J. Larson, Yot Teerawattananon, and Mark Jit. 2021. "Health Policy Challenges in Ensuring Global Access to COVID-19 Vaccines: Production, Affordability, Allocation, and Deployment." *The Lancet* 397(10278):1023–34.