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# A Cross-country Comparative Study on the Socioeconomic Impacts of Vaccines


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# Abstract

This study compared data from 3 different countries representing different stages of development, namely the United States, China, and Ethiopia, over nearly 40 years to demonstrate that vaccines have positive economic benefits for countries at all stages of development. At the same time, this study also made some policy recommendations, based on the current vaccination coverage situation in various countries. That is, developed countries should continue to maintain high vaccination coverage to prevent possible outbreaks. Developing countries should, in accordance with their actual incidence patterns, maximize existing vaccination rates while incorporating more basic vaccines into their national immunization schedules. For LDCs, more health spending should be spent on vaccines. And the international community should prioritize vaccine assistance when providing health assistance to least-developed countries. In addition, there are also other influence factors, such as religion, culture, bias, and so on, which will also affect the vaccination popularity rate within countries. Based on their actual conditions, countries can promote cooperation with large pharmaceutical companies internally, accelerate research and development and popularization of science, and increase the vaccination rate of their citizens as much as possible, at the same time, global cooperation plays an important role, cooperate closely with other countries abroad, take their respective responsibilities, and make efforts to comprehensively eliminate infectious diseases.

# Keywords

**Vaccine, Health economic, Socioeconomic, Policy recommendations**

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# Introduction

Vaccines are biological preparations used to prevent diseases by stimulating the immune system to produce immunity to a specific disease-causing agent. They are among the most significant innovations in human history since the 18th century.

However, in reality, humans learned to use similar principles to prevent disease much earlier. The ancient variola treatment named for smallpox, also known as variola or "la variole" was widely used in some parts of Asia and Africa. This involved transferring small amounts of material from smallpox sores to healthy people, thereby triggering a milder form of smallpox infection and thus reducing the mortality rate from natural infection. Some sources indicate that variolation therapy was practiced as early as 200 B.C. Written accounts from the mid-1500s describe a form of variolation used in China known as insufflation, where smallpox scabs were dried, ground and blown into the nostril using a pipe. In India, similar practices were carried out through inoculation, using a lancet or needle to transfer material from smallpox pustules to the skin of healthy children. Written records from the mid-15th century describe a variant therapy known as "inflatable" used in China, in which smallpox scabs are dried, ground, and then blown into the nostrils with a tube[1]. From the 17th century, in Qing Dynasty, Emperor Kangxi (1662-1722) was keen to fight the disease since he survived from smallpox when he was a kid. He had summoned smallpox experts to the court to variolate, the royal family and the noble army stationed in the capital. This policy continued long after his death[2]. In India, a similar practice is carried out by inoculation, in which substances from smallpox pustules are transferred to the skin of healthy children with a long-handled needle or needle.

In 1796, English physician Edward Jenner discovered that vaccinating people with cowpox could protect them from smallpox, which made this the first vaccine in human history. At the time, smallpox was a very deadly disease that spread out really speedily and often led to death. Edward Jenner, a rural British doctor, noticed that nurses (cow-fed women) did not seem to contract smallpox but often

[1] History of smallpox vaccination (2022) WHO. Available at: https://www.who.int/news-room/spotlight/history-of-vaccination/history-of-smallpox-vaccination?topicsurvey=ht7j2q)&gclid=Cj0KCQjwlPWgBhDHARIsAH2xdNfGAuxlf18aw54ZHhMoGYW9Y2qzK80b0aO5rzR_5XtFmkTQI5lsgLkaArAEEALw_wcB (Accessed: 24 March 2023).

[2] Plotkin, S.A. (ed.) (2011) *History of Vaccine Development*. New York, NY: Springer New York. Available at: https://doi.org/10.1007/978-1-4419-1339-5.

suffered from cowpox, a disease similar to smallpox but not fatal. Jenner then made a hypothesis that afterward exposure to cowpox, the body may develop immunity to smallpox. In 1796, he gathered fluid from the arm of a cowpox patient with bird's beak forceps and injected it into the arm of a young boy, James Phipps. A few days later, he was vaccinated with the smallpox virus, but he did not contract smallpox. Jenner's experiment proved his hypothesis and became the world's first successful vaccine trial. In 1798 Jenner' *The Causes and Effects of Smallpox Vaccine*, which described his findings and research in detail was published. The book caused a great sensation at the time and was translated into several languages and widely distributed worldwide.

Another major milestone in the history of vaccines before the $20^{th}$ century was Louis Pasteur and his rabies vaccine. Louis Pasteur is a French microbiologist, chemist, and unity of the founders of microbiology, who is often referred to as the "father of microbiology". He developed the rabies vaccine at the end of the 19th century and made a profound contribution to the development of modern vaccinology. In the course of his research, Pasteur discovered that rabies is caused by a pathogen called the rabies virus, which is mainly found in the spittle of dogs and other animals. By vaccinating rabbits with the rabies virus and subsequently using the attenuated or inactivated virus, Pasteur and his team successfully developed a vaccine that could prevent rabies. After years of exploration, experimentation, and improvement Pasteur's rabies vaccine became widely used in the 1890s. His research has made great contributions to the development of modern vaccinology, the prevention of infectious diseases in animals and humans, and the field of microbiology. His findings led to a deeper understanding of microbiology and provided a footing for the future treatment and prevention of other diseases.

Since the 20th century, the development of vaccines has entered the fast lane, and many basic vaccines that are now widely available around the world have been developed. In the 1930s, Pearl Kendrick and Grace Eldering studied pertussis, and then they developed and conducted the first successful large-scale study of a vaccine for the disease[3]. In 1938, Roosevelt established the National Polio Foundation to treat polio patients and promote the development of vaccines. With the support of the foundation, Dr. Jonas Salk spent nearly 9 years successfully developing the first successful polio vaccine in 1952, which began mass vaccination in 1955. Albert Sabin developed the oral version of the "Sabin Vaccine" (OPV) using the attenuated poliovirus, and clinical trials of this vaccine began in

[3] Shapiro-Shapin, C.G. (2010) 'Pearl Kendrick, Grace Eldering, and the Pertussis Vaccine', Emerging Infectious Diseases, 16(8), pp. 1273–1278. Available at: https://doi.org/10.3201/eid1608.100288.

1957 and were licensed in August 1961. These two vaccines nearly wiped out polio, marking another major milestone in the development of vaccines in the 20th century and laying an important foundation for polio eradication in most parts of the world today. In 1963, John Franklin Enders, winner of the 1954 Nobel Prize in Physiology or Medicine, and his colleagues successfully developed a measles vaccine using the Edmonston-B strain and were approved for marketing. In 1968, American scientist Maurice Hilleman at Merck & Co. and colleagues improved the vaccine, making it the main measles vaccine in use in the United States since 1968.

Entering the 21$^{st}$ century, with the rapid development of technology, and the development of human vaccines developed fast as well, more vaccines have been developed to protect people from more communicable diseases. In 2006, The American company Merck & Co. developed a vaccine for HPV, the quadrivalent vaccine Gardasil® (Merck), also known in Europe as Silgard, which protects against HPV types 6, 11, 16, and 18, preventing human papillomavirus infection. In 2020, COVID-19 was menacing, and the speed of vaccine development and promotion has also developed by leaps and bounds, which is the fastest vaccine research and development speed in human history.

Vaccines are usually classified according to their mechanism and composition. There are several types of vaccines, including inactivated vaccines; live-attenuated vaccines; messenger RNA (mRNA) vaccines; subunit, recombinant, polysaccharide, and conjugate vaccines; toxoid vaccines; and viral vector vaccines. However, this classification focus on the technology of Vaccine production and it doesn’t help much when it comes to the analysis of the social economic impact of vaccines. According to the World Health Organization (WHO) Model List of Essential Medicines, there are 12 kinds of vaccines are recommended for all. They are BCG vaccine, Diphtheria vaccine, Haemophilus influenzae type b vaccine, Hepatitis B vaccine, Human papilloma virus (HPV) vaccine, Measles vaccine, Pertussis vaccine, Pneumococcal vaccine, Poliomyelitis vaccine, Rotavirus vaccine, Rubella vaccine, and Tetanus vaccine. 3 kinds (Japanese encephalitis vaccine; Tick-borne encephalitis vaccine; and Yellow fever vaccine) are recommended for certain regions and 6 (Cholera vaccine; Dengue vaccine; Hepatitis A vaccine; Meningococcal meningitis vaccine; Rabies vaccine; and Typhoid vaccine) for some high-risk populations, and another 3 (Influenza vaccine (seasonal); Mumps vaccine; and Varicella vaccine) for immunization programs with certain characteristics. However, what is tragic is that normally, the poorer a country is, the poorer its healthcare system will be, which lead to a poorer living environment and healthcare service, thus more kind of vaccines are recommended to be vaccinated the local population, while due to its poor economy, fewer kinds of vaccines are affordable. This dilemma is hard for many developing countries to walk out of by itself. This thesis is trying to find out a way to give some advice to ease and solve this dilemma by analyzing and discussing the relevant data and then giving some possible policy suggestions.

# Chapter 1: Access to Vaccines

## 1.1 Production of Vaccines

Vaccine production has become one of the most popular topics worldwide, especially after the Covid-19 pandemic. Global vaccine production is mainly involved by many different manufacturers and institutions, including pharmaceutical giants such as Pfizer, Moderna, and AstraZeneca, as well as governments and research institutions. However, for many reasons, not every country has the capability to conduct research and development of vaccines. First, insufficient technical and scientific levels, developing and producing vaccines requires a high level of scientific, technical, and medical knowledge, and not all countries have these capacities and resources. Second, lack of funding and equipment, producing vaccines requires a lot of money and high-tech manufacturing equipment, which is a huge challenge for some poor and developing countries. In addition, lack of talent is also a big problem. Developing and producing vaccines requires a large number of researchers and professionals, and some countries may lack such talent. Last but not least, intellectual property restrictions: Some vaccine manufacturers hold patents and intellectual property rights, which prevent other countries from producing the same vaccines, limiting the scale and speed of global vaccine production. For these reasons, most production of vaccines is concentrated in some of the more developed countries, while the other countries, especially the least developed countries which actually need more kinds of vaccines, due to the poor healthcare system, have to import them. This undoubtedly further increases the cost of vaccination in those countries.

Taking the coronavirus pandemic as an example, as the pandemic rages, although governments and vaccine manufacturers have been constantly striving to produce sufficient quantities of vaccines to protect people around the world from the coronavirus, by May 2022, over two years after the breakout of the pandemic, there are only 11 vaccines（Pfizer/BioNTech, AstraZeneca-SK Bio, Astra Zeneca-Serum Institute of India, Astra Zeneca EU, Janssen, Moderna, Sinopharm, Sinovac: CoronaVac, Novavax: NVX-CoV2373, Bharat Biotech: Covaxin, CanSino Biologics Inc.: Convidecia）are validated by the WHO and listed on the Emergency Use Listing (EUL).

Among them, 5 of the world's biomedical giants, Pfizer, AstraZeneca, Johnson & Johnson, Moderna, and Sinovac developed and produced the most widely used vaccines. Pfizer Inc., a US-based pharmaceutical company, and BioNTech, a German biotechnology company, collaborated to develop and manufacture the Pfizer-BioNTech COVID-19 vaccine. Pfizer is also known for producing vaccines for other diseases such as pneumonia, meningitis, and influenza. AstraZeneca is a British-Swedish multinational pharmaceutical company that has developed a COVID-19 vaccine in collaboration with the University of Oxford. It also manufactures vaccines for other diseases such as measles, mumps, and rubella. Johnson & Johnson is an American multinational corporation that produces a COVID-19 vaccine that requires only one dose. The company also manufactures vaccines for other diseases such as hepatitis B, HPV, and tuberculosis. Moderna is an American biotechnology company that has developed a COVID-19 vaccine using mRNA technology. The company also manufactures vaccines for other diseases such as cytomegalovirus and influenza. Sinovac is a Chinese biopharmaceutical company that produces vaccines for diseases such as COVID-19, hepatitis A and B, and influenza. The company's COVID-19 vaccine, CoronaVac, has been authorized for emergency use by the World Health Organization. These companies and institutions are all from the northern hemisphere, and most are located in developed countries. China and India are the only developing countries, which have their vaccines certified.

Although these manufacturers and institutions have committed to producing billions of doses globally to meet the needs of different countries and regions, however, global vaccine production still faces some challenges and obstacles. Some countries are unable to produce sufficient quantities of vaccines because of insufficient production capacity, while others face slow vaccination rates. To address these issues, global efforts are being taken to accelerate vaccine production and distribution. Some countries are investing in increasing vaccine production capacity, while others are rolling out vaccination to speed up vaccination. At the same time, organizations such as the World Health Organization are pushing for equitable global vaccine distribution to ensure that all countries have access to enough vaccines to respond to outbreaks.

## 1.2 Universal Access to Vaccines

The global burden of infectious diseases and global vaccine access are important issues facing the world today. Infectious diseases refer to diseases caused by pathogens, such as AIDS, tuberculosis, malaria, influenza, etc. These diseases pose a serious threat to global health and have a huge impact on economies and societies. Global vaccine access is one of the key measures to reduce and control the burden of infectious diseases. The World Health Organization (WHO) estimates that vaccines prevent between 2 and 3 million deaths each year. According to the WHO World Health Statistics Yearbook 2021, more than 160 million people fall ill with tuberculosis, 220 million people become infected with the hepatitis B virus, 410 million people are infected with the interferon virus each year, and more than 1 million people die globally each year from AIDS. In addition, influenza kills up to 650,000 people worldwide each year. Additionally, there are also ongoing efforts to develop new vaccines for diseases such as malaria, tuberculosis, and HIV, which could have a significant impact on global health if successful.

In general, there are mainly four kinds of ways for people to get a vaccination. The first kind of vaccines are recommended and paid by the state, and usually, most people are obliged to be vaccinated. They are usually basic vaccines, such as the Poliomyelitis vaccine in most countries, as well as covid-19 vaccines during the pandemic. The second type is at the individual's own expense, these vaccines vary from country to country, for example in Australia HPV vaccines are paid by the state, while in China individuals have to pay the fee by themselves. Some self-pay vaccines are sometimes covered by commercial insurance, which becomes the third kind. These cases are usually more common in Anglo-Saxon states. While in some cases, there is also another source, donations by the international community. It is more common in underdeveloped countries. The donators are usually international organizations, such as the UN, WHO, NGOs, and charitable foundations, such as Bill & Melinda Gates Foundation.

In terms of vaccine access, despite the increase in global vaccination coverage, some problems remain. According to WHO, the most widely used vaccines globally are for diseases such as polio, measles, tetanus, hepatitis B, and diphtheria. By 2021, about 190 countries and territories around the world are implementing vaccination programs, but vaccination coverage varies greatly across countries and regions. According to the United Nations Children's Fund (UNICEF), about 90% of children worldwide received basic vaccines in 2021, Despite progress, there are still some challenges to achieving universal vaccination coverage. There are still many children who do not receive the necessary vaccines. In addition, many countries and regions still face problems such as vaccine supply shortages and uneven distribution such as lack of infrastructure, and other factors in some remote rural areas. The Global Vaccine Action Plan 2021-2030, published by the World Health Organization, aims to increase global vaccination coverage, especially in low- and middle-income countries. According to Forbes magazine, COVID-19 vaccination coverage is also uneven globally, with countries such as the United States and Israel had higher vaccination coverage than other countries by the end of 2021.

The reality is that the access to vaccines is unevenly distributed around the globe and showing significant regional differences.

# Chapter 2: Methods

This thesis mainly adopts the following research methods: retrieval; comparative research; as well as data calculation.

## 2.1 Retrieval

First of all, retrieval, the information, and data in this thesis are obtained from reliable international organizations or official national websites. For example, the WHO official website is one of the main sources, and much of the data in this study comes from there.

## 2.2 Comparative research

In addition, comparative research is a very important research method in this study. In this thesis, countries and vaccines are divided into three groups separately.

### 2.2.1 Countries

Firstly, according to different economic development stages, countries are mainly divided into three groups. “Developed countries” are those countries defined as advanced economies by the International Monetary Fund (IMF), for example, the United States of America, the United Kingdom, Canada, Australia, and most EU countries such as France, Germany and Italy. “Least developed countries” are those countries on the United Nation’s *List of Least Developed Countries*, which is viewed by the Committee for Development Policy (CDP), a subsidiary body of the Economic and Social Council of the UN every three years. The 46 countries currently on the list of LDCs include Afghanistan, Angola, Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Djibouti, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Kiribati, Lao People’s Dem. Republic, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Myanmar, Nepal, Niger, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, Solomon Islands, Somalia, South Sudan, Sudan, Timor-Leste, Togo, Tuvalu, Uganda, United Republic of Tanzania, Yemen, and Zambia. Finally, the rest are the "developing countries" such as Brazil, China, India, South Africa, Russia, Mexico, Viet Nam, the Philippines and so on.

Secondly, according to different vaccination policies for the same vaccines, countries can also be divided into three groups, namely covered by national healthcare service, which means individuals don't have to pay for the vaccine fees; paid by individuals themselves; and donated by the international community. The human papillomavirus (HPV) vaccine can be a good example. In Italy, it is free for females who are under 26 years old and have the national healthcare card (Tessera Sanitaria), to access by appointment (and in Roma in 2022, the waiting time was approximately 1-2 months). While in Australia, since 2013, HPV vaccines are also free for boys to get a vaccination. However, in China, individuals usually have to not only spend over 2000 RMB (around 270 euros) per dose and have to wait for about 1.5 years. What is worse is that in Africa, only 14 of the continent's 54 countries have national HPV vaccination programs. These different policies are implemented in different countries for the HPV vaccines leading to the various costs for individuals to access the HPV vaccines. As a result, HPV vaccination rates vary widely worldwide.

In addition, cultural differences are also a very likely factor due to the different geographical locations of countries and their histories and cultures. Therefore, countries will also be classified according to their geographical location and dominant culture, and this article will mainly compare the following 3 cultural categories that account for the largest population of the world, namely countries with Confucian culture in East Asia, such as China, Japan, and Korea; Western countries such as the United States and the United Kingdom; Muslim cultural countries such as Pakistan, Iran, Afghanistan, etc.

### 2.2.2 Vaccines

All of the vaccines used for comparison in this article are from the vaccines section of the World Health Group's Essential Medicines List. However, smallpox and its vaccine will be used as a successful example, in order to demonstrate the socioeconomic effect of vaccines. Then we will both see some vaccines which have a relatively high global vaccination rate, such as Polio & Poliomyelitis vaccines; tuberculosis & BCG; Measles vaccine; Pertussis vaccine; Rubella vaccine; Tetanus vaccine; Mumps vaccine, etc. and the vaccines whose vaccination rates vary significantly among countries, for example, Human papillomavirus (HPV) vaccine and Varicella vaccine.

### 2.2.3 Socioeconomic cost

In terms of the socioeconomic cost, three kinds of loss will be calculated. The first is the treatment cost which includes direct cost and indirect cost. The direct cost, which is easy to understand is namely the medical expenditure to treat that disease. While the indirect cost includes lost wages and looking after free. The second is the fees that each dose of vaccine costs. The third is the economic loss due to death.

We all know that the cost of a disease may include so many aspects, here I just take these three costs as example.

## 2.3 Data calculation

### 2.3.1 Hypothetic

Although for many reasons, the reality is far from the case, this study will assume that everyone can and should take the vaccines; and if the vaccines are effective for this individual then he or she will not get the specific disease.

Although the course of the disease and the treatment options will vary from person to person, this study only calculates the standard course of disease and treatment costs for most people and does not consider complications and their treatment costs.

In order to estimate the home care and escort costs, in this study, it is assumed that if one person gets sick, a member of his or her quits his or her work to take care of the patient.

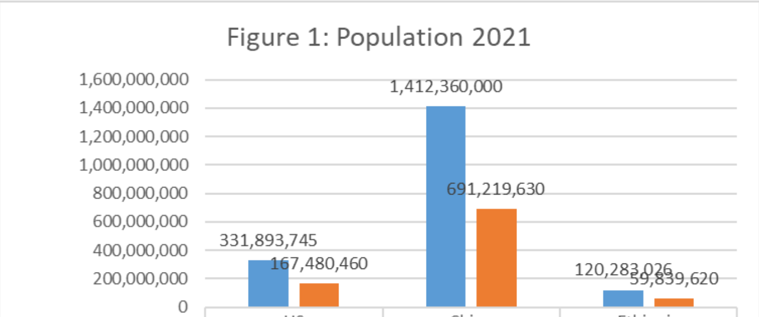
Finally, the calculation will be without regard to those administrative expenses, publicity, education expense, etc.

# Chapter 3: Data and analysis

It is important to understand the definition of the relevant data used in this thesis and to clarify the sources and reasons to use the exact data here. This part will first explain the definition and standard of the data used in the following analysis, as well as the specific calculation method, and then analyze them.

## 3.1 Economic indicators

There are serval economic indicators will be used in this study. They are population; female population; Gross domestic product (GDP); GDP per capita; average wage and Gross national income (GNI). In order to better compare the impact of different vaccines on countries at different stages of economic development, this study will select one country from each of the three kinds of countries at different stages of economic development as a representative for the comparative study. Among the developed countries, the United States would be chosen as a representative, while China would be chosen as a representative of developing countries and, finally, the representative of the least developed countries would be Ethiopia. What needs to be mentioned is that expect average income[4], all the other data comes from World Bank[5], and monetary values are in constant 2015 US dollars. Here are the data for each of the three countries.




| | US | China | Ethiopia |
|---|---|---|---|
| Total Population | 331,893,745 | 1,412,360,000 | 120,283,026 |
| Female population | 167,480,460 | 691,219,630 | 59,839,620 |

Figure 1 Population 2021

[4] The data on average income comes from https://www.worlddata.info/average-income.php and they are downloaded on May 16th, 2023.

[5] https://data.worldbank.org/ Data downloaded on May 16th, 2023

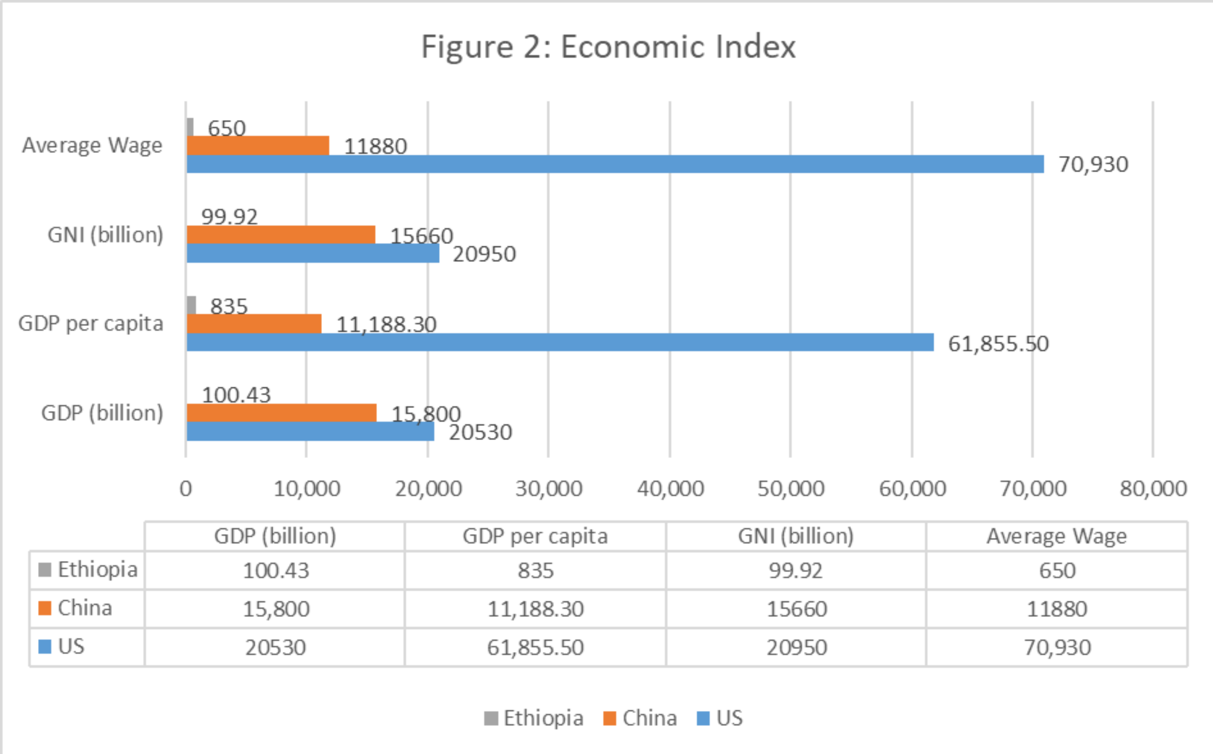



Figure 2 Economic Index

## 3.2 Vaccine efficacy and Effectiveness

The efficacy of vaccines is measured by controlled clinical trials and is based on the number of people who have an effective result, such as infection or producing antibodies and etc., compared with how many people who got the placebo but developed the same result. After the experiment was completed, the number of people who fell ill in each group was compared to calculate whether the vaccine had a relative effect on the subjects' disease, so that the vaccine efficacy, that is, the extent to which the vaccine reduced the risk of disease. If the vaccine is highly effective, the number of people in the vaccinated group will be much smaller than in the placebo group. While vaccine effectiveness is a measure of how well a vaccine works in the real world. Although clinical trials cover a wide range of people, covering a wide range of ages, including men and women, different ethnic groups, and people with known conditions, clinical trials do not perfectly reflect results for all populations. The efficacy observed in clinical trials applies to the specific results obtained in clinical trials, while effectiveness is to observe the protective effect of a vaccine on the entire community. Real-world effectiveness may differ from what trials measure because we cannot accurately predict the effectiveness of vaccines in a more diverse and diverse population than clinical trials in real-world settings that are closer to reality. However, the effectiveness of vaccines is very difficult to measure and count, so usually the efficacy of vaccines is more widely used in practice. For example, all COVID-19 vaccines approved for emergency use listed by WHO have passed randomized clinical trials that have been tested for quality, safety, and 50% or more efficacy to be approved. Once approved, it is continuously monitored for safety and effectiveness. Therefore, in this thesis vaccine efficacy will be used to replace vaccine effectiveness in data calculations.

Table 1 shows the vaccine efficacy of relevant diseases and vaccines. What needs to be noticed is that there are debates on the vaccine efficacy of Tdap on Pertussis, but according to the WHO position paper on Pertussis[6], for decades, it is very successful to prevent whooping cough through immunize infants and young children worldwide with qualified pertussis vaccines, and immunization of infants and young children with at least 90% coverage of 3 doses of Tdap remains the norm important immunization procedures are prioritized within the perimeter. So in this study, Tdap is still considered effective to prevent pertussis.

Another thing that needs to be noticed is the Human papillomavirus (HPV) vaccine. Human papillomavirus (HPV) is the name of a very common group of viruses, with more than 100 different types. Most of the time, most of them don't affect most people, but some types can cause genital warts or cancer. HPV affects the skin but usually does not cause any symptoms. Most people with it don't even realize it and don't have any problems, but sometimes the virus causes painless growths or bumps around the vagina, or anus.[7] Studies have shown that the Human papillomavirus (HPV) vaccine has a different degree of effective prevention against severe diseases, and it is estimated that HPV vaccines may prevent 70% of cervical cancer, 80% of anal cancer, 60% of vaginal cancer, 40% of vulvar cancer, and more than 90% efficacy in preventing HPV-positive oropharyngeal cancers, but in this study will only calculate with representations of cervical cancer.

In addition, as mentioned before, there are serval different vaccines for Covid-19, and they have different mechanisms of action therefore different efficacy and prices. In this study, the Moderna mRNA-1273 vaccine against COVID-19 will be used as an example to make the calculation.

[6] WHO Weekly Epidemiological Record. No.4, 2005, pp. 31-39

[7] https://www.nhs.uk/conditions/human-papilloma-virus-hpv/ Data checked on May 16th, 2023.

| Disease | Vaccine | Vaccine efficacy |
|---|---|---|
| Polio | Poliomyelitis vaccine | 95%[8] |
| Tuberculosis | BCG | 80%[9] |
| Measles | MMR | 97%[10] |
| Mumps | | |
| Rubella | | |
| Diphtheria | Tdap | 98.40%[11] |
| Pertussis | | about 80%[12] |
| Tetanus | | about 100%[13] |
| Cervical cancer | HPV vaccine | 70%/[14] |
| Varicella | Varicella vaccine | 95%[15] |
| Covid-19 | Covid-19 vaccine | 93%[16] |

Table 1 Vaccine Efficacy

## 3.3 Course of disease

The course of a disease, also known as the natural history of a disease, refers to the development of the disease in patients, including the sequence and speed of the stages and forms they go through.

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8 Atkinson W, Hamborsky J, McIntyre L, Wolfe S, eds. (2008) & Kash et al., 2015 & Committee on Infectious Diseases, 1997 & The Immunological Basis for Immunization Series Module 6: Poliomyelitis

9 WHO Weekly Epidemiological Record. No.4, 2004, pp. 27-38 & Fine et al.

10 WHO Weekly Epidemiological Record. No.7, 2006, pp. 51-60 & Measles vaccines: WHO position paper, April 2017 – Recommendations & Prevention of Varicella: Recommendations for Use of Varicella Vaccines in Children, Including a Recommendation for a Routine 2-Dose Varicella Immunization Schedule

11 WHO Weekly Epidemiological Record. No.3, 2006, pp. 24-32

12 WHO Weekly Epidemiological Record. No.4, 2005, pp. 31-39 & Cherry, 2013 & Shapiro-Shapin, 2010

13 WHO Weekly Epidemiological Record. No.20, 2006, pp. 198-208

14 Takes, R.P. et al. (2015) 'HPV vaccination to prevent oropharyngeal carcinoma: What can be learned from anogenital vaccination programs?', Oral Oncology, 51(12), pp. 1057–1060. Available at: https://doi.org/10.1016/j.oraloncology.2015.10.011.

15 WHO Weekly Epidemiological Record. No.32, 7 August 1998, pp. 241-248 & Committee on Infectious Diseases, 2007

16 Interim recommendations for use of the Moderna mRNA-1273 vaccine against COVID-19. WHO reference number: WHO/2019-nCoV/vaccines/SAGE_recommendation/mRNA-1273/2022.1

## Polio

The course of polio can vary from individual to individual, but in general, it can be divided into incubation period, onset period, and recovery period. The incubation period is usually 3 to 21 days, but it is about 7 to 10 days in most cases. Onset usually lasts from days to weeks but can be longer. At this stage, the virus invades the central nervous system, causing the typical symptoms of polio, including muscle weakness, muscle atrophy, and inflammation of the spinal cord and brainstem. The recovery period can range from weeks to years, but in general, it will last around 8 months. At this stage, patients may recover gradually, but some people may be left with neurological complications.[17]

## Tuberculosis

The course of tuberculosis is a long-term process, and the key to treatment is to adhere to the full course of anti-tuberculosis drug treatment in accordance with the WHO's *Guidelines for the Diagnosis, Treatment, Prevention, and Control of Tuberculosis* to ensure that the pathogen is completely eliminated and to avoid worsening or recurrence. In general, there are 3 stages in the course of tuberculosis. After infection with Mycobacterium tuberculosis, many people enter the latent infection phase. At this stage, the immune system can control the growth of bacteria, and the patient has no obvious symptoms. The course of active tuberculosis can last from weeks to months, at this stage, patients may experience symptoms such as cough, sputum production, low-grade fever, etc. Once tuberculosis is diagnosed, treatment usually includes long-term chemotherapy with anti-tuberculosis drugs. The standard treatment regimen is usually 6 months, but for some conditions, such as multidrug-resistant TB infection, the treatment period may be longer.[18]

### Measles

Measles is a highly contagious disease that generally lasts about 1 to 2 weeks, but the exact course may vary from individual to individual. The incubation period is usually 7 to 14 days, during which the patient has no obvious symptoms, but the virus has entered the body and started spreading.

[17] https://en.wikipedia.org/wiki/Polio checked on May 16th 2023.
[18] https://www.cdc.gov/tb/topic/treatment/tbdisease.htm checked on May 16th 2023.

The first symptoms of measles usually last 2 to 4 days. At this stage, people may present with symptoms of respiratory infections such as fever, cough, runny nose, and sore throat. The rash is one of the most typical features of measles and usually occurs on the 3rd to 7th day after the onset of fever. During the rash phase, a red maculopapular rash appears all over the body. The rash phase usually lasts about 5 to 7 days.[19]

## Mumps

The course of Mumps varies from individual to individual. Some people may have mild symptoms and recover faster, while others may have a longer duration and more severe symptoms. In general, the incubation period is usually 14 to 25 days but can be extended to 35 days, during which the patient has no obvious symptoms, but the virus has entered the body and started spreading. The first symptoms of mumps usually last 1 to 3 days. At this stage, patients may experience fever, headache, muscle pain, and loss of appetite. In addition, the patient's parotid glands may be swollen and painful. The recovery period for mumps is usually around 7 to 10 days after the swelling of the parotid gland begins, during which the patient's parotid gland swelling gradually decreases, and the general symptoms gradually relieve.[20]

## Rubella

Rubella is a highly contagious disease that usually lasts 1 to 2 weeks. The incubation period is usually 14 to 21 days. At this stage, the patient has no obvious symptoms, but the virus has entered the body and started spreading. The first symptoms of rubella usually last 1 to 5 days. The patient may present with mild fever, cough, runny nose, sore throat, and, swollen lymph nodes. Rash is one of the most typical features of rubella and usually occurs 1 to 5 days after the onset of initial symptoms. During the rash phase, a reddish maculopapular rash appears all over the body, first appearing on the face and then quickly spreading to other parts of the body. These rashes may last for about 3 to 5 days and gradually subside.[21]

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[19] https://www.cdc.gov/measles/hcp/index.html checked on May 16th 2023 & https://www.who.int/news-room/fact-sheets/detail/measles checked on May 16th 2023

[20] https://www.cdc.gov/mumps/hcp.html checked on May 16th 2023

[21] https://www.cdc.gov/rubella/hcp.html checked on May 16th, 2023.

## Diphtheria

Diphtheria is a serious condition that can lead to serious complications, including difficulty breathing, heart problems, and neurological damage. In general, the course of diphtheria can be divided into the following 4 stages. The incubation period is usually 2 to 5 days but can be extended to 2 weeks. At this stage, the patient has no obvious symptoms, but the pathogenic bacteria of the disease have entered the body and begun to multiply. The initial symptoms of diphtheria usually last 1 to 2 days. At this stage, patients may present with fever, sore throat, and there may be superficial ulceration in the larynx. During the progression of diphtheria, a grayish-white membrane forms in the larynx, which is a typical symptom of diphtheria. This membrane may coat the throat and laryngotracheal, blocking air passage and making breathing difficult. The membrane formation phase usually lasts 1 to 2 weeks. After the membrane formation period, the patient enters the recovery phase. At this stage, the membrane gradually subsides, the larynx heals, and the symptoms gradually relieve.[22]

## Pertussis

Pertussis is a highly contagious disease that can have serious effects in infants and people with weakened immune systems. In general, the first symptoms of whooping cough usually last 1 to 2 weeks, during which patients may experience symptoms similar to the common cold. This stage is called the "epidemic phase" and people can infect other people. The cough period is its characteristic symptom and usually lasts 4 to 6 weeks, sometimes even longer. At this stage, people develop severe, intense paroxysmal coughs that last from seconds to minutes and may cause difficulty breathing. After the cough period, the patient enters the convalescent phase. At this stage, the cough gradually decreases, and the symptoms are relieved.[23]

## Tetanus

Tetanus is a serious disease that can lead to serious complications and even death. In general, the course of tetanus can be divided into the following 4 stages. The incubation period is usually 3 to

[22] https://www.cdc.gov/diphtheria/index.html checked on May 16th, 2023.
[23] https://www.cdc.gov/pertussis/ checked on May 16th, 2023

21 days but can be extended to several months. At this stage, the patient has no obvious symptoms, but the toxins produced by tetanus have entered the body and begun to affect the nervous system.
The first symptoms of tetanus usually last 1 to 3 days. Patients may experience muscle pain and stiffness, mainly affecting the neck and jaw muscles, and these symptoms may gradually worsen and spread to other muscle groups. At the peak period of tetanus, symptoms reach their most severe degree. Patients may experience severe muscle stiffness and spasticity, and these spasms can cause breathing difficulties, choking, and heart problems. With proper treatment, the symptoms of tetanus will gradually resolve. The recovery period can take weeks or months for the muscles to fully recover.[24]

## Varicella

The course of varicella, which is also known as chickenpox, is usually 1 to 2 weeks. In general, the incubation period is usually 10 to 21 days. At this stage, the patient has no obvious symptoms, but the chickenpox virus has entered the body and begun to multiply. The first symptoms of chickenpox usually last 1 to 2 days. At this stage, patients may present with systemic symptoms such as fever, fatigue, headache, and loss of appetite. The blistering phase of chickenpox is a typical symptom and usually lasts 5 to 10 days, during which patients develop red pimples and blisters, which initially appear on the trunk and face and then quickly spread to other parts of the body. After the blister phase ends, the blisters of chickenpox gradually dry out and crust. These scabs usually take 1 to 2 weeks to dry and fall off completely.[25]

## Cervical cancer

Cervical cancer, as a type of cancer, cannot be completely cured once the disease is infected. However, in clinical practice, achieving a 5-year survival after treatment can be called a clinical cure. Before stage II, cervical cancer has a 5-year survival rate of more than 80%.

[24] https://www.cdc.gov/tetanus/index.html checked on May 16th, 2023.
[25] https://www.cdc.gov/chickenpox/about/index.html checked on May 16th, 2023.

# COVID-19

The course of COVID-19 varies according to individual differences and disease severity. Some patients may experience asymptomatic infection, while others may experience severe respiratory symptoms and complications. In general, it can be divided into the following stages:

Incubation period: The incubation period is usually 2 to 14 days, but most people have an incubation period of 5 to 6 days, during which the patient has no obvious symptoms, but the virus has entered the body and began to multiply. About a week after infection, most patients experience mild symptoms such as fever, cough, sore throat, fatigue, and muscle pain. Symptoms at this stage usually last from days to weeks. Some patients may have symptoms that gradually worsen after the first week with moderate symptoms such as dyspnea, shortness of breath, chest tightness, and persistent cough. These symptoms may take longer to ease, usually several weeks. After symptom relief, the patient enters a recovery phase. Most patients with mild and moderate symptoms recover completely within a few weeks.[26]

# Table 2 Course of diseases

Table 2 summarizes the course of these diseases. In the calculation, due to individual differences and the fact that some severe cases may have a longer course of the disease, resulting in higher treatment costs, the upper limit of the general course of the disease will be used as the basis for the calculation.

| Disease | Vaccine | course of disease |
|---|---|---|
| Polio | Poliomyelitis vaccine | 8 months |
| Tuberculosis | BCG | 4-9 months |
| Measles | MMR | 1-2 weeks |
| Mumps | | 5-10 days |
| Rubella | | 1-2 weeks |
| Diphtheria | Tdap | 1-2 weeks |

[26] https://www.who.int/publications/i/item/clinical-management-of-covid-19 checked on May 16th, 2023.

| | | |
|---|---|---|
| Pertussis | | 2-3 months |
| Tetanus | | 3-4 weeks |
| Cervical cancer | HPV vaccine | around 5 years |
| Varicella | Varicella vaccine | 1-2weeks |
| Covid-19 | Covid-19 vaccine | 10-14 days |

Table 2 Course of diseases.

## 3.4 Cost of Vaccines

The cost of vaccines varies from one to another, but in general, most of them cost less than 10 US dollars per person. The data on the price per dose of these vaccines mainly comes from the official websites of the CDC of the United States. However, since the United States is not a region with a high incidence of polio and tuberculosis, there is no relevant updated data on the Poliomyelitis vaccine and the BCG vaccine. The price of these two vaccines comes from *the International Medical Products Price Guide 2015.* The cost per vaccine per person is equal to the cost per vaccine per dose, times the doses that the vast majority of individuals require to form immunity. Table 3 shows the cost of these vaccines in detail.

Actually, cost of vaccines should include the expenditure of transportation, distribution, nurse education and so many things. But for convenience of calculations, this study is represented by the price of vaccines.

| Disease | Vaccine | Cost per dose | Doses | Cost per person |
|---|---|---|---|---|
| Polio | Poliomyelitis vaccine | 0.2153 | 3 | 0.6459 |
| Tuberculosis | BCG | 0.1847 | 1 | 0.1847 |
| Measles | MMR | 2.27125 | 2 | 4.5425 |
| Mumps | | | | |
| Rubella | | | | |
| Diphtheria | Tdap | 1.86775 | 3 | 5.60325 |

| | | | | |
|---|---|---|---|---|
| Pertussis | | | | |
| Tetanus | | | | |
| Cervical cancer | HPV vaccine | 163.81 | 3 | 491.43 |
| Varicella | Varicella vaccine | 13.167 | 2 | 26.334 |
| Covid-19 | Covid-19 vaccine | 25.5 | 2 | 51 |

Table 3 Cost of Vaccines (in constant 2015 US dollars)[27]

## 3.5 Treatment Cost

The expensive treatment costs, which also include rehabilitation costs are one of the main causes of the disease burden, especially, when the disease can not be completely cured or result in lifelong disability in the patient. Among all the diseases studied in this thesis, polio, and cervical cancer are two of them. This means, once the patient is ill, he or she will suffer from the disability caused by polio or the immunocompromised due to cancer chemoradiotherapy all the rest of his or her life and thus loses his or her ability to work. In this case, the treatment cost may also be lifelong, but in this study, only the average treatment costs following the standard treatment regimen that is recommended by the CDC or National Health Service (NHS) of the United Kingdom will be considered, otherwise, the cost will become uncountable. The following are the standard treatment regimen for the diseases covered by the study.

### Polio

There's currently no cure for polio. Treatment focuses on supporting bodily functions and reducing the risk of long-term problems while the body fights off the infection. This can include bed rest in the hospital, taking painkillers, breathing support, and regular stretches or exercises to prevent problems with the muscles and joints. If the patient is left with long-term problems as a result of a polio infection, ongoing treatment, and support are needed. This may include physiotherapy to help with any movement problems, devices such as splints and braces to support weak limbs or joints,

[27] The data on the Poliomyelitis vaccine and BCG vaccine comes from *the International Medical Products Price Guide 2015* and the other data comes from the CDC of the United States at the following link: https://www.cdc.gov/vaccines/programs/vfc/awardees/vaccine-management/price-list/index.html

occupational therapy to help you adapt to any difficulties, and possibly surgery to correct any deformities.[28]

## Tuberculosis

The 6- to 9-month RIPE Tuberculosis treatment regimens[29].

Through joint use of Rifampin (RIF), Isoniazid (INH), Pyrazinamide (PZA), and Ethambutol (EMB), the treatment has an intensive phase of 2 months, followed by a continuation phase of either 4 or 7 months (total of 6 to 9 months for treatment). In the first 8 weeks, patients take all 4 medicines 7 days/week for 56 doses, and then in the following 18 weeks, take only INH and RIF 7 days/week for 126 doses, in a total of 182 doses.

## Measles

There is no specific antiviral therapy for measles. Medical care is supportive and helps relieve symptoms and address complications such as bacterial infections. Severe measles cases among children, such as those who are hospitalized, should be treated with vitamin A. Vitamin A should be administered immediately on diagnosis and repeated the next day. The recommended age-specific daily doses are 50,000 IU for infants younger than 6 months of age; 100,000 IU for infants 6–11 months of age and 200,000 IU for children 12 months of age and older.[30]

## Mumps

There are currently no medications to treat the mumps virus, but the infection should pass within one or two weeks. Treatment for mumps is focused on relieving symptoms until the immune system of the patient's body fights off the infection. The treatment used to relieve symptoms includes: getting plenty of bed rest and fluids; using painkillers, such as ibuprofen and paracetamol; applying a warm or cool compress to the swollen glands to help relieve pain; drinking plenty of fluids, but avoiding acidic drinks such as fruit juice as these can irritate your parotid glands, and water is usually the best fluid to drink; eating foods that don't require a lot of chewing, such as soup, mashed potatoes, and

[28] https://www.nhsinform.scot/illnesses-and-conditions/infections-and-poisoning/polio/ checked on May 16th, 2023.
[29] https://www.cdc.gov/tb/topic/treatment/tbdisease.htm checked on May 16th, 2023.
[30] https://www.cdc.gov/measles/hcp/index.html checked on May 16th, 2023.

scrambled eggs.[31]

## Rubella

There's no specific treatment for rubella. The condition is usually mild and improves without treatment within 7 to 10 days. Treat symptoms mainly includes controlling fever, relieving pain, and treating cold-like symptoms. If necessary, paracetamol or ibuprofen can be used to reduce a high temperature (fever) and treat any aches or pains.[32]

## Diphtheria

Diphtheria treatment involves using diphtheria antitoxin to stop the bacteria toxin from damaging the body, which is very important for respiratory diphtheria infections, but it is rarely used for diphtheria skin infections and using antibiotics to kill and get rid of the bacteria. This is important for diphtheria infections in the respiratory system and on the skin and other parts of the body (e.g., eyes, blood).[33]

## Pertussis

Doctors generally treat whooping cough with antibiotics. There are several antibiotics available to treat whooping cough. Macrolides erythromycin, clarithromycin, and azithromycin are preferred for the treatment of pertussis in persons 1 month of age and older. Ideally, treat pertussis during the first 1 to 2 weeks before coughing paroxysms occurs.[34]

## Tetanus

Tetanus is a medical emergency requiring evaluation and cares in the hospital. Immediate treatment is to take a medicine called human tetanus immune globulin (TIG) and to have aggressive

[31] https://www.nhsinform.scot/illnesses-and-conditions/infections-and-poisoning/mumps#treating-mumps checked on May 16th, 2023.
[32] https://www.nhs.uk/conditions/rubella/ checked on May 16th, 2023.
[33] https://www.cdc.gov/diphtheria/about/diagnosis-treatment.html checked on May 16th, 2023.
[34] https://www.cdc.gov/pertussis/clinical/treatment.html checked on May 16th, 2023.

wound care, as well as take drugs to control muscle spasms, antibiotics, and tetanus vaccination. Depending on how serious the infection is, a machine may be required to help someone with tetanus breathe.[35]

## Cervical cancer

Cervical cancer is treated in several ways. It depends on the kind of cervical cancer and how far it has spread. Treatments include surgery, chemotherapy, and radiation therapy. In the surgery, doctors remove cancer tissue in an operation. Then in chemotherapy, special medicines are used to shrink or kill the cancer. The drugs can be pills that the patient takes directly, or medicines given in veins, or sometimes both. While in radiation, high-energy rays are used to kill the cancer.[36]

## Varicella

There is no cure for chickenpox, and the virus usually clears up by itself without any treatment. However, there are ways of easing the itch and discomfort including taking a mild painkiller, such as paracetamol; keeping hydrated to avoid dehydration, and avoiding anything that may make the mouth sore as well; stop the scratching to avoid future scarring. Stronger treatments include antiviral medicine and immunoglobulin treatment. Ideally, acyclovir needs to be started within 24 hours of the rash appearing. It does not cure chickenpox, but it makes the symptoms less severe. The patient normally needs to take the medicine in tablets 5 times a day for 7 days. Immunoglobulin is a solution of antibodies that is taken from healthy donors. Varicella-zoster immunoglobulin (VZIG) contains antibodies to the chickenpox virus. Immunoglobulin treatment is given by injection. It is not used to treat chickenpox, but to protect people who are at high risk of developing a severe chickenpox infection.[37]

[35] https://www.cdc.gov/tetanus/about/diagnosis-treatment.html checked on May 16th, 2023.
[36] https://www.cdc.gov/cancer/cervical/basic_info/diagnosis_treatment.htm checked on May 16th, 2023.
[37] https://www.nhsinform.scot/illnesses-and-conditions/infections-and-poisoning/chickenpox/#treating-chickenpox checked on May 16th, 2023.

## Covid-19

Antiviral treatments target specific parts of the virus to stop it from multiplying in the body, helping to prevent severe illness and death. The following table from the CDC of the United States of America shows the detailed treatment plans for different people.

| Treatment | Who | When | How |
|---|---|---|---|
| Nirmatrelvir with Ritonavir (Paxlovid) *Antiviral* | Adults; children ages 12 years and older | Start as soon as possible; must begin within 5 days of when symptoms start | Taken at home by mouth (orally) |
| Remdesivir (Veklury) *Antiviral* | Adults and children | Start as soon as possible; must begin within 7 days of when symptoms start | Intravenous (IV) infusions at a healthcare facility for 3 consecutive days |
| Molnupiravir (Lagevrio) *Antiviral* | Adults | Start as soon as possible; must begin within 5 days of when symptoms | Taken at home by mouth (orally) |

Table 4 Antiviral treatments for Covid-19[38]

# Treatment cost per patient

According to the standardized treatment regimen mentioned above, we can derive the direct cost of drug therapy required to treat these diseases, as shown in Table 5. Most of the prices of the drugs are based on the *2015 International Medical Products Price Guide*, except the price of Paxlovid, because it is a new drug for Covid-19.

[38] https://www.cdc.gov/coronavirus/2019-ncov/your-health/treatments-for-severe-illness.html checked on May 16th, 2023.

| Table 5 Direct Treatment cost per patient (constant 2015 US$) | |
|---|---|
| **Disease** | **Direct Treatment cost per patient to cure** |
| Polio | 4227.953623 |
| Tuberculosis | 852.138 |
| Measles | 26.3382 |
| Mumps | 18.332 |
| Rubella | 25.6648 |
| Diphtheria | 646.3688 |
| Pertussis | 185.391 |
| Tetanus | 392.5012 |
| Cervical cancer | 177725.1698 |
| Varicella | 1818.4523 |
| Covid-19 | 530 |

Table 5 Direct Treatment cost per patient (constant 2015 US$)

In addition to the direct treatment cost, which includes drug costs and the cost of one surgery for cervical cancer, as well as the cost of other necessary treatments, there are also indirect treatment costs (i.e. treatment cost per patient = direct treatment cost per patient + indirect treatment cost per patient). The indirect treatment cost includes many other necessary expenditures to treat the diseases, such as the cost of seeing a doctor, the cost of examination in order to diagnose, nutrition, rehabilitation and etc. However, this part of treatment costs can vary from country to country and are hard to calculate. In order to calculate this part of the costs, the following estimates were made in this study. Since the human capital in developed countries is much higher than that in developing countries and least developed countries, this study uses two times the direct treatment cost to replace the indirect treatment cost in developed countries, namely the United States, and 1.5 times in developing countries, namely China and 1 time in the least developed countries. So the treatments costs of these diseases are:

| Treatment cost per patient (constant 2015 US$) | | | |
|---|---|---|---|
| **Disease** | **United States** | **China** | **Ethiopia** |
| Polio | 12683.86087 | 10569.88406 | 8455.907246 |
| Tuberculosis | 2556.414 | 2130.345 | 1704.276 |
| Measles | 79.0146 | 65.8455 | 52.6764 |

| | | | |
|---|---|---|---|
| Mumps | 54.996 | 45.83 | 36.664 |
| Rubella | 76.9944 | 64.162 | 51.3296 |
| Diphtheria | 1939.1064 | 1615.922 | 1292.7376 |
| Pertussis | 556.173 | 463.4775 | 370.782 |
| Tetanus | 1177.5036 | 981.253 | 785.0024 |
| Cervical cancer | 533175.5094 | 444312.9245 | 355450.3396 |
| Varicella | 5455.3569 | 4546.13075 | 3636.9046 |
| Covid-19 | 1590 | 1325 | 1060 |

Table 6 Treatment cost per patient (constant 2015 US$)

## 3.6 Treatment cost and GDP loss

### 3.6.1 Treatment cost

Based on the efficacy rate of the vaccine, the treatment cost per patient in all three countries, and the assumptions mentioned above, the treatment cost reduction can be calculated in this way:

vaccine efficacy * population = numbers of cases reduction

number of cases reduction * treatment cost per patient = treatment cost reduction

When calculate the numbers of reduction about Cervical cancer, I use the female population.

| **Treatment cost reduction (in constant 2015 US dollars) in 2021 － the United States** | | | |
|---|---|---|---|
| Female population | 167480460 | Total Population: | 331893745 |
| **Disease** | **Treatment cost per patient** | **Number of cases reduction because of vaccine** | **Treatment cost reduction** |
| Polio | 12683.86087 | 315299057.8 | 3.99921E+12 |
| Tuberculosis | 2556.414 | 265514996 | 6.78766E+11 |
| Measles | 79.0146 | 321936932.7 | 25437717959 |
| Mumps | 54.996 | 321936932.7 | 17705243548 |
| Rubella | 76.9944 | 321936932.7 | 24787340967 |
| Diphtheria | 1939.1064 | 326583445.1 | 6.3328E+11 |

| | | | |
|---|---|---|---|
| Pertussis | 556.173 | 265514996 | 1.47672E+11 |
| Tetanus | 1177.5036 | 331893745 | 3.90806E+11 |
| Cervical cancer | 533175.5094 | 150732414 | 8.03668E+13 |
| Varicella | 5455.3569 | 315299057.8 | 1.72007E+12 |
| Covid-19 | 1590 | 308661182.9 | 490771280731.50 |

Table 7 Treatment cost reduction (in constant 2015 US dollars) in 2021 – the United States

| **Treatment cost reduction (in constant 2015 US dollars) in 2021 － China** | | | |
|---|---|---|---|
| Female population: | 691219630 | Total Population: | 1412360000 |
| **Disease** | **Treatment cost per patient** | **Number of cases reduction because of vaccine** | **Treatment cost reduction** |
| Polio | 10569.88406 | 1341742000 | 1.41821E+13 |
| Tuberculosis | 2130.345 | 1129888000 | 2.40705E+12 |
| Measles | 65.8455 | 1369989200 | 90207623869 |
| Mumps | 45.83 | 1369989200 | 62786605036 |
| Rubella | 64.162 | 1369989200 | 87901247050 |
| Diphtheria | 1615.922 | 1389762240 | 2.24575E+12 |
| Pertussis | 463.4775 | 1129888000 | 5.23678E+11 |
| Tetanus | 981.253 | 1412360000 | 1.38588E+12 |
| Cervical cancer | 444312.9245 | 622097667 | 276406033753905.00 |
| Varicella | 4546.13075 | 1341742000 | 6.09973E+12 |
| Covid-19 | 1325 | 1313494800 | 1740380610000.00 |

Table 8 Treatment cost reduction (in constant 2015 US dollars) in 2021 – China

| **Treatment cost reduction (in constant 2015 US dollars) in 2021 － Ethiopia** | | | |
|---|---|---|---|
| Female population | 59839620 | Population: | 120283026 |
| **Disease** | **Treatment cost per patient** | **Number of cases reduction because of vaccine** | **Treatment cost reduction** |
| Polio | 8455.907246 | 114268874.7 | 9.66247E+11 |
| Tuberculosis | 1704.276 | 96226420.8 | 1.63996E+11 |
| Measles | 52.6764 | 116674535.2 | 6145994487 |
| Mumps | 36.664 | 116674535.2 | 4277755159 |
| Rubella | 51.3296 | 116674535.2 | 5988857223 |
| Diphtheria | 1292.7376 | 118358497.6 | 1.53006E+11 |
| Pertussis | 370.782 | 96226420.8 | 35679024757 |
| Tetanus | 785.0024 | 120283026 | 94422464089 |
| Cervical cancer | 355450.3396 | 53855658 | 1.9143E+13 |
| Varicella | 3636.9046 | 114268874.7 | 4.15585E+11 |
| Covid-19 | 1060 | 111863214.2 | 1.18575E+11 |

Table 9 Treatment cost reduction (in constant 2015 US dollars) in 2021 – Ethiopia

## 3.6.2 GDP loss

In the same way, based on the efficacy rate of the vaccine, the GDP per capita in all three countries, and the assumptions mentioned above, the direct and indirect GDP loss reduction can be calculated, through the following formulas:

indirect GDP loss reduction = the part of GDP loss reduction due to home care

number of cases reduction because of vaccine* course of diseases (days) / 365 * GDP per capita = direct GDP loss reduction

total GDP loss = direct GDP loss + indirect GDP loss

| United States | | | | GDP per capita: | 61855.5 |
|---|---|---|---|---|---|
| **Disease** | **Number of cases reduction because of vaccine** | **Course of disease** | **Direct GDP loss reduction** | **Indirect GDP loss reduction** | **GDP loss reduction** |
| Polio | 315299057.8 | 240 | 12823877830129.40 | 12823877830129.40 | 25647755660258.80 |
| Tuberculosis | 265514996 | 270 | 12148936891701.50 | 12148936891701.50 | 24297873783403.10 |
| Measles | 321936932.7 | 14 | 763808161987.53 | 763808161987.53 | 1527616323975.06 |
| Mumps | 321936932.7 | 10 | 545577258562.52 | 545577258562.52 | 1091154517125.05 |
| Rubella | 321936932.7 | 14 | 763808161987.53 | 763808161987.53 | 1527616323975.06 |
| Diphtheria | 326583445.1 | 14 | 774832197315.19 | 774832197315.19 | 1549664394630.37 |
| Pertussis | 265514996 | 90 | 4049645630567.18 | 4049645630567.18 | 8099291261134.36 |
| Tetanus | 331893745 | 28 | 1574862189665.01 | 1574862189665.01 | 3149724379330.03 |
| Cervical cancer | 150732414 | 365 | 9323628834177.00 | 9323628834177.00 | 18647257668354.00 |
| Varicella | 315299057.8 | 14 | 748059540090.88 | 748059540090.88 | 1496119080181.76 |
| Covid-19 | 308661182.9 | 14 | 732310918194.23 | 732310918194.23 | 1464621836388.46 |

Table 10 GDP loss reduction (in constant 2015 US dollars) in 2021 – the United States

| China | | | | GDP per capita: | 11,188.30 |
|---|---|---|---|---|---|
| **Disease** | **Number of cases reduction because of vaccine** | **Course of disease** | **Direct GDP loss reduction** | **Indirect GDP loss reduction** | **GDP loss reduction** |
| Polio | 1341742000 | 240 | 9870780505380.82 | 9870780505380.82 | 19741561010761.60 |
| Tuberculosis | 1129888000 | 270 | 9351265741939.73 | 9351265741939.73 | 18702531483879.50 |
| Measles | 1369989200 | 14 | 587917540627.51 | 587917540627.51 | 1175835081255.01 |
| Mumps | 1369989200 | 10 | 419941100448.22 | 419941100448.22 | 839882200896.44 |
| Rubella | 1369989200 | 14 | 587917540627.51 | 587917540627.51 | 1175835081255.01 |
| Diphtheria | 1389762240 | 14 | 596402948430.38 | 596402948430.38 | 1192805896860.76 |
| Pertussis | 1129888000 | 90 | 3117088580646.58 | 3117088580646.58 | 6234177161293.15 |
| Tetanus | 1412360000 | 28 | 1212201114695.89 | 1212201114695.89 | 2424402229391.78 |
| Cervical cancer | 622097667 | 365 | 6960215327696.10 | 6960215327696.10 | 13920430655392.20 |
| Varicella | 1341742000 | 14 | 575795529480.55 | 575795529480.55 | 1151591058961.10 |
| Covid-19 | 1313494800 | 14 | 563673518333.59 | 563673518333.59 | 1127347036667.18 |

Table 11 GDP loss reduction (in constant 2015 US dollars) in 2021 – China

| Ethiopia | | | | GDP per capita: | 835 |
|---|---|---|---|---|---|
| **Disease** | **Number of cases reduction because of vaccine** | **Course of disease** | **Direct GDP loss reduction** | **Indirect GDP loss reduction** | **GDP loss reduction** |
| Polio | 114268874.7 | 240 | 62738308191.45 | 62738308191.45 | 125476616382.90 |
| Tuberculosis | 96226420.8 | 270 | 59436291970.85 | 59436291970.85 | 118872583941.70 |
| Measles | 116674535.2 | 14 | 3736781689.65 | 3736781689.65 | 7473563379.30 |
| Mumps | 116674535.2 | 10 | 2669129778.32 | 2669129778.32 | 5338259556.64 |
| Rubella | 116674535.2 | 14 | 3736781689.65 | 3736781689.65 | 7473563379.30 |
| Diphtheria | 118358497.6 | 14 | 3790714621.25 | 3790714621.25 | 7581429242.50 |
| Pertussis | 96226420.8 | 90 | 19812097323.62 | 19812097323.62 | 39624194647.23 |
| Tetanus | 120283026 | 28 | 7704704514.74 | 7704704514.74 | 15409409029.48 |
| Cervical cancer | 53855658 | 365 | 44969474430.00 | 44969474430.00 | 89938948860.00 |
| Varicella | 114268874.7 | 14 | 3659734644.50 | 3659734644.50 | 7319469289.00 |
| Covid-19 | 111863214.2 | 14 | 3582687599.35 | 3582687599.35 | 7165375198.71 |

Table 12 GDP loss reduction (in constant 2015 US dollars) in 2021 – Ethiopia

### 3.6.3 Savings

According to the above table, it can be seen that both the cost of treatment and the loss of GDP due to disease are very large, so it is very important to form herd immunity to eliminate the disease. But to achieve universal immunity, as many people as possible must be vaccinated, ideally for everyone except those who cannot be vaccinated for physical reasons such as ingredient allergies or immune deficiencies. The total population of each country is so large, even if the cost of one dose of vaccine is low, the cost of vaccinating everyone will be very high. This is because vaccine cost in one country = vaccine cost per person * population who should be vaccinated. The table below calculates the cost of vaccinating all people and the cost-effectiveness between the cost of vaccination and treatment cost reduction and GPD loss reduction. Regarding the specific number of people who should be vaccinated, the calculation method is as follows:

- ✧ Vaccinate all surviving newborns born in each country between the start year of the corresponding incidence rate in the past and January 1, 2022, in all three countries (i.e. Crude birth rate minus neonatal mortality) with the Poliomyelitis vaccine, BCG, MMR, Tdap vaccine;
- ✧ Due to the different ranges of people allowed to be vaccinated with the Human papillomavirus (HPV) vaccine in various countries around the world, some countries only allow the female to be vaccinated, and some countries only allow adolescents to be vaccinated, for the convenience of statistics, the number of vaccinated people is replaced by the number of women in each country in 2021
- ✧ According to the WHO Position Paper on Varicella[39], chickenpox is an acute, highly contagious viral disease that spreads worldwide. Although the varicella vaccine is 95% effective and has a long duration of effective protection, the prevalence increases significantly if the number of vaccinated people does not reach at least 80% of the total population (ideally maintaining a high level of 85%-90% vaccination rate). As a result, countries, especially developing and least developed countries, rarely have nationwide vaccination against chickenpox, such as China, which has incorporated varicella vaccine into childhood immunization schedules in developed regions such as Shanghai. Therefore, in this study, the varicella vaccine will take the total

[39] Weekly Epidemiological Record. No.32, 7 August 1998, pp. 241-248

population of each country in 2021 as the total number of people who should be vaccinated, just like the Covid-19 vaccine.

In summary, the social economic savings = GDP loss reduction + treatment cost reduction - vaccine cost. The tables below illustrate the cost-benefit data between the cost of vaccination and treatment cost reduction and GPD loss reduction for countries in detail.

| **Cost and Savings - United States** | | | | | |
|---|---|---|---|---|---|
| **Disease** | **Vaccine** | **Vaccine cost** | **Treatment cost reduction** | **GDP loss reduction** | **Savings** |
| Polio | Poliomyelitis vaccine | 106116555.4 | 3999209380806.01 | 25647755660258.80 | 29646858924509.40 |
| Tuberculosis | BCG | 16148666.2 | 678766252984.34 | 24297873783403.10 | 24976623887721.20 |
| Measles | MMR | 323916165 | 25437717958.57 | 1527616323975.06 | 1552946069878.62 |
| Mumps | | | 17705243548.02 | 1091154517125.05 | 1108751788618.06 |
| Rubella | | | 24787340967.23 | 1527616323975.06 | 1552295692887.28 |
| Diphtheria | Tdap | 920572207.8 | 633280048488.68 | 1549664394630.37 | 2182637585716.47 |
| Pertussis | | | 147672271870.31 | 8099291261134.36 | 8246656675602.08 |
| Tetanus | | | 390806079554.98 | 3149724379330.03 | 3540223601482.43 |
| Cervical cancer | Human papilloma virus (HPV) vaccine | 82304922458 | 80366831618852.40 | 18647257668354.00 | 98931784364748.60 |

| | | | | | |
|---|---|---|---|---|---|
| Varicella | Varicella vaccine | 8740089881 | 1720068890259.96 | 1496119080181.76 | 3207447880560.89 |
| Covid-19 | Covid-19 vaccine | 183654893.4 | 490771280731.50 | 1464621836388.46 | 1955209462226.52 |

Table 13 Cost and Savings - United States

| Cost and Savings - China | | | | | |
|---|---|---|---|---|---|
| **Disease** | **Vaccine** | **Vaccine cost** | **Treatment cost reduction** | **GDP loss reduction** | **Savings** |
| Polio | Poliomyelitis vaccine | 500459448.4 | 14182057375710.10 | 19741561010761.60 | 33923117927023.40 |
| Tuberculosis | BCG | 65629672.44 | 2407051251360.00 | 18702531483879.50 | 21109517105567.00 |
| Measles | MMR | 1314749901 | 90207623868.60 | 1175835081255.01 | 1265604455156.71 |
| Mumps | | | 62786605036.00 | 839882200896.44 | 902230555965.54 |
| Rubella | | | 87901247050.40 | 1175835081255.01 | 1263298078338.51 |
| Diphtheria | Tdap | 4341538015 | 2245747378385.28 | 1192805896860.76 | 3437106095907.64 |
| Pertussis | | | 523677665520.00 | 6234177161293.15 | 6756407647474.75 |
| Tetanus | | | 1385882487080.00 | 2424402229391.78 | 3808837537133.38 |
| Cervical cancer | Human papilloma virus (HPV) vaccine | 3.39686E+11 | 276406033753905.00 | 13920430655392.20 | 289986778348001.00 |

| | | | | | |
|---|---|---|---|---|---|
| Varicella | Varicella vaccine | 37193088240 | 6099734564766.50 | 1151591058961.10 | 7214132535487.60 |
| Covid-19 | Covid-19 vaccine | 611066458 | 1740380610000.00 | 1127347036667.18 | 2867116580209.16 |

Table 14 Cost and Savings – China

| **Cost and Savings - Ethiopia** | | | | | |
|---|---|---|---|---|---|
| **Disease** | **Vaccine** | **Vaccine cost** | **Treatment cost reduction** | **GDP loss reduction** | **Savings** |
| Polio | Poliomyelitis vaccine | 74504122.19 | 966247005611.05 | 125476616382.90 | 1091649117871.77 |
| Tuberculosis | BCG | 13097075.9 | 163996379535.34 | 118872583941.70 | 282855866401.14 |
| Measles | MMR | 269290301.5 | 6145994487.06 | 7473563379.30 | 13529794432.52 |
| Mumps | | | 4277755159.31 | 5338259556.64 | 9526251282.11 |
| Rubella | | | 5988857223.03 | 7473563379.30 | 13372657168.49 |
| Diphtheria | Tdap | 646331046.1 | 153006480106.35 | 7581429242.50 | 160372465666.83 |
| Pertussis | | | 35679024757.07 | 39624194647.23 | 75087775722.28 |
| Tetanus | | | 94422464089.26 | 15409409029.48 | 109616429436.72 |
| Cervical cancer | Human papilloma virus (HPV) vaccine | 29406985439 | 19143011925793.70 | 89938948860.00 | 19203543889214.20 |

| | | | | | |
|---|---|---|---|---|---|
| Varicella | Varicella vaccine | 3167533207 | 415584996033.25 | 7319469289.00 | 419736932115.57 |
| Covid-19 | Covid-19 vaccine | 190627650.8 | 118575007030.80 | 7165375198.71 | 125549754578.69 |

Table 15 Cost and Savings – Ethiopia

# 3.7 Incidence Rate and Vaccine immunization coverage

## 3.7.1 Incidence rate

The incidence rate is the proportion of occurrence of a given medical condition in a population within a specified period of time, which can be used to determine the risk of morbidity. In the case of a known incidence of a disease, we can calculate the number of cases in a country over a certain period of time from the total population, and we can also calculate the incidence when the number of cases is known. The incidence data for the United States[40] and China[41] now are the 2021 data released by the respective national CDC (The incidence rate of cervical cancer[42] is both 2019 data.), while the incidence data in the past in all three countries and the incidence data in Ethiopia now comes from the WHO or World Bank. The data of incidence rates in the past of different diseases are from different years, for many reasons, for example, the time of detection, outbreak, and attention of diseases, the invention of vaccines, and the timing of mass vaccination are all different. Here is the period in which data of incidence rates in the past of different diseases used in this study come from.

- Tuberculosis 2000s
- Measles 2005s 、Mumps 2005s 、Rubella 2005s
- Poliomyelitis 1980s
- Diphtheria 1980s、Pertussis 1980s、Total tetanus 1980s (China 1995s)

40 https://wonder.cdc.gov/nndss/nndss_weekly_tables_menu.asp?comingfrom=202201&savedmode=&mmwr_year=2021&mmwr_week=52 checked on May 16th, 2023.

41 http://www.nhc.gov.cn/jkj/s3578/202204/4fd88a291d914abf8f7a91f6333567e1.shtml checked on May 16th, 2023.

42 United States cervical cancer data comes from https://gis.cdc.gov/Cancer/USCS/#/Trends/ checked on May 16th, 2023.

For all the diseases, the incidence rates are the average data of 5 years available in that period of time. This is done in order to obtain more truthful and accurate general data for that era, and to avoid bias in the data due to the concentrated outbreak of the disease in a particular year.

However, due to the lack of cervical cancer and varicella incidence data in Ethiopia now, Ethiopia's two data are replaced by the incidence of East Africa in its region. All the data related to Covid-19 comes from WHO[43]. Once we have the incidence rate and the number of cases, we can calculate how much the incidence rate has decreased. The unit of incidence rate is per 100,000 population.

| Incidence Rate (per 100,000 people) - United States | | | |
|---|---|---|---|
| **Disease** | **Incidence rate in the past** | **Incidence rate 2021** | **Incidence rate Reduced** |
| Polio | 0.003879418 | 0 | 0.003879418 |
| Tuberculosis | 6.12 | 1.958156819 | 4.161843181 |
| Measles | 0.022743236 | 0.001506506 | 0.02123673 |
| Mumps | 0.656618023 | 0.047304296 | 0.609313726 |
| Rubella | 0.004013858 | 0.000903904 | 0.003109955 |
| Diphtheria | 0.001385053 | 0 | 0.001385053 |
| Pertussis | 0.828369865 | 0.48479371 | 0.343576155 |
| Tetanus | 0.036294943 | 0.006026025 | 0.030268918 |

Table 16 Incidence Rate – the United States

| Incidence Rate (per 100,000 people) - China | | | |
|---|---|---|---|
| **Disease** | **Incidence rate in the past** | **Incidence rate 2021** | **Incidence rate Reduced** |
| Polio | 0.594649502 | 0 | 0.594649502 |
| Tuberculosis | 100.4 | 45.3651 | 55.0349 |
| Measles | 8.152769274 | 0.0392 | 8.113569274 |
| Mumps | 20.65949493 | 8.5088 | 12.15069493 |

[43] https://covid19.who.int/ checked on May 16th, 2023.

| | | | |
|---|---|---|---|
| Rubella | 4.278946233 | 0.0596 | 4.219346233 |
| Diphtheria | 0.705846192 | 0 | 0.705846192 |
| Pertussis | 41.79913822 | 0.6817 | 41.11743822 |
| Tetanus | 0.275907816 | 0.0019 | 0.274007816 |

Table 17 Incidence Rate – China

| Incidence Rate (per 100,000 people) - Ethiopia | | | |
|---|---|---|---|
| **Disease** | **Incidence rate in the past** | **Incidence rate 2021** | **Incidence rate Reduced** |
| Polio | 0.38682464 | 0.008313725 | 0.378510915 |
| Tuberculosis | 391.4 | 119 | 272.4 |
| Measles | 1.660822871 | 16.2 | -14.53917713 |
| Mumps | No data | 63 | |
| Rubella | 0.232964338 | 0.9 | -0.667035662 |
| Diphtheria | 1.07810583 | 37 | -35.92189417 |
| Pertussis | 36.89682516 | 0 | 36.89682516 |
| Tetanus | 2.860616394 | 0.3 | 2.560616394 |

Table 18 Incidence Rate – Ethiopia

### 3.7.2 Vaccine immunization coverage

So how much of that is the role of vaccines? To answer this question, we must first understand how the vaccine works on morbidity. After vaccination, individuals develop immunity to this specific disease, but in reality, because vaccines are not effective for everyone, and there are some people who cannot be vaccinated for various physical reasons, they need others to form herd immunity to be protected. The table below shows how vaccination rates have changed across countries in the last 15 to 40 years.

| Disease | Vaccine | China in the past | China 2021 | Ethiopia in the past | Ethiopia 2021 | United States in the past | United States 2021 |
|---|---|---|---|---|---|---|---|
| Polio | Poliomyelitis vaccine | 80% in 1982 | 99.36% | 3% in 1980 | 68% | 95% in 1980 | 92.70% |
| Tuberculosis | BCG | 34% in 1983 | 99.68% | 5% in 1980 | 68% | No data | No data |
| Measles<br>Mumps<br>Rubella | MMR | 86% in 2005 | 99.43% | No data | No data | 93% in 2004 | 91.60% |
| Diphtheria<br>Pertussis<br>Tetanus | Tdap | 58% in 1983 | 99.19% | 3% in 1981 | 71% | 96% in 1980 | 93% |

Table 19 Vaccine immunization coverage[44]

### 3.7.3 Savings

From the data above, we can see that, except in Ethiopia, the vaccine coverage of all the vaccines increases or maintains at a relevant high level, while the incidence rate of all the diseases has decreased after 15 to 40 years. This is the long-term impact of vaccines, while the decline in the incidence rate is another reflection of the socio-economic benefits of vaccines, which is also quite a lot. Through the following formulas, the reduced incidence due to vaccines and the socio-economic benefits they bring can be obtained. See detailed data in the tables below.

number of case reduced = incidence rate reduced/100000 * population * vaccine efficacy

savings = number of case reduced * (treatment cost per patient +GDP loss per patient)

[44] Data comes from WHO official website on https://immunizationdata.who.int/ checked on May 16th, 2023.

| Disease | Number of case reduced | Savings |
|---|---|---|
| Polio | 7978.662119 | 201726627.7 |
| Tuberculosis | 621832.7309 | 11617637749 |
| Measles | 111155.0228 | 102721251.9 |
| Mumps | 166463.2083 | 109680532.9 |
| Rubella | 57804.58771 | 53321411.17 |
| Diphtheria | 9809.583849 | 24270897.35 |
| Pertussis | 571434.6304 | 3417747843 |
| Tetanus | 3808.057155 | 10273430.27 |

Table 20 Savings - incidence rate – China

| Disease | Number of case reduction | Savings |
|---|---|---|
| Polio | 12.87554467 | 1210662.745 |
| Tuberculosis | 13812.89719 | 1299360738 |
| Measles | 70.48337841 | 340018.4466 |
| Mumps | 2022.274146 | 6965396.628 |
| Rubella | 10.32174477 | 49772.21556 |
| Diphtheria | 4.596904279 | 30726.56254 |
| Pertussis | 1140.307768 | 35418250.27 |
| Tetanus | 100.4606451 | 1071680.257 |

Table 21 Savings - incidence rate – United States

| Disease | Number of case reduction | Savings |
|---|---|---|
| Polio | 455.2843827 | 4349782.18 |
| Tuberculosis | 327650.9628 | 963168820.64 |
| Measles | -17488.16221 | -2041414.06 |
| Mumps | No data | No data |
| Rubella | -802.3306784 | -92576.44 |
| Diphtheria | -43207.9413 | -58624206.14 |
| Pertussis | 44380.6178 | 34730621.50 |
| Tetanus | 3079.986884 | 2812372.95 |

Table 22 Savings - incidence rate – Ethiopia

From the above table, we can know that even in developed countries like the United States, where the incidence itself is low, the incidence rate decreases by only 1/100000, which can also bring huge social and economic benefits.

While the opposite has happened in Ethiopia, where the increase in incidence has imposed a significant socio-economic burden on Ethiopia over the years. This is because the relationship between incidence rate and vaccine immunization coverage is not simply a linear function. As vaccination rates increase, the incidence of some diseases increases, but when vaccination rates reach higher coverage and general immunity develops, the incidence decreases sharply. From Table 19, we can know that the vaccine coverage of all the diseases is around 70%, which may not be high enough to form herd immunity.

## 3.8 Results and policy suggestions

From the above data and analysis, we can conclude that:

First, vaccines have positive social fund benefits for countries at all levels of development, so we should promote vaccination. With the process of economic development and globalization, the flow of people in various countries in the world is getting closer and closer, so now the formation of universal immunity is not only each country's own business, in time some relatively developed countries have formed herd immunity, but also should continue to maintain a high level of vaccination rate to prevent the outbreak of infectious diseases due to imported cases.

Secondly, for developing countries, after ensuring the coverage of traditional basic vaccines, it should be timely according to the WHO list of essential drugs, and the actual incidence of the country, such as when the incidence reaches a certain level of disease corresponding to the vaccine priority, as far as possible, all the vaccines recommended on the list, especially the newly developed vaccines in recent years, such as HPV vaccine (despite its high price, its socio-economic benefits are enormous as well. This can be seen from the data and analysis above.) into the national immunization plan. For relatively expensive vaccines like HPV vaccines, the state can work with commercial insurance companies to add vaccine-related provisions to health insurance, and the state and commercial insurance companies jointly pay for the vaccine. Taking the HPV vaccine as an example, for insurance companies, although the price of the HPV vaccine is relatively high, there are many types of diseases that can be prevented and their treatment costs are also very high, so paying part of the cost of vaccination for the insured can attract more people to insure, and actually reduce the probability and cost of its compensation.

It should be noted here that the representative of developing countries selected in this study is China, and China is a developing country with a relatively high level of development among developing countries, and some developing countries may still not ensure the coverage of traditional basic vaccines, and these countries should give priority to ensuring the coverage of traditional basic vaccines, keep up with the pace of other countries, and assume their responsibilities in the process of world disease elimination.

Finally, for the LDCs, national health spending should be increased and more spent on vaccines. However, even so, it may still be difficult for the least affected countries to achieve high vaccination rates on their own, limited by their level of development, but as part of the world, if a disease is to be eliminated as a threat to all mankind, it must also be eliminated in the least affected countries. Therefore, developed countries should assume international social responsibility of developed countries and work with international organizations to provide health assistance to the least reached countries. Helping them eliminate multiple infectious diseases can not only help them achieve economic development but also promote the process of global eradication of infectious diseases.

What needs to be noticed is that many international organizations and private foundations now donate drugs to treat diseases when they provide assistance to the least accessible countries. Part of that is due to the push of big pharmaceutical companies to profit from it. However, in fact, it can be concluded from this study that the use of vaccines to prevent infectious diseases is far more economically beneficial than treating infectious diseases after they occur. This is especially true from a humanitarian point of view, whether it is the death caused by infectious diseases or the sequelae left by infectious diseases such as polio, which may last a lifetime, no economic benefit can be measured. Therefore, when providing health assistance to underdeveloped areas, the donation of vaccines should be preferred over the donation of medicines.

# Chapter 4: Other Factors Affecting Vaccination Rate: Some Case Studies

From the data and structure above, we can see that vaccines have a huge positive socio-economic impact. As mentioned before, in addition to the degree of economic development, there are also many other factors that could affect the vaccination rate. In this part, these factors will be analyzed through case studies and possible recommendations will be drawn to increase global vaccination coverage and thereby reduce the global burden of communicable diseases.

## 4.1 Religion

When vaccines came out, there were people who opposed them for religious reasons. At that time, some Christians believed that if God wanted a person to die because of smallpox, it was a sin for people to save him from death by vaccinating him from death, against God's will.[45] There are few such arguments in the church today, but there are still others who oppose vaccination for various religious reasons, and ethical dilemmas arise when there are too many unvaccinated children to invalidate herd immunity and affect others.[46] In the 1960s, some vaccines (such as the rubella vaccine) were cultured from embryonic tissue from therapeutic abortions, so there was a moral risk to anti-abortion religious believers to take these vaccines. The Vatican Curia expressed concern about the origin of embryonic cells from which the rubella vaccine is made and said that for vaccines originating from embryonic cells, Catholics have “a grave responsibility to use alternative vaccines and to make a conscientious objection” but concluded that it is acceptable for Catholics to use the existing vaccines until an alternative becomes available.[47]

There are also concerns among Muslims about the composition of vaccines. While gelatin can be extracted from many animals, Jewish and Islamic scholars have determined that vaccinations

[45] Bazin H. The ethics of vaccine usage in society: lessons from the past. Endeavor. 2001 Sep;25(3):104-8. doi: 10.1016/s0160-9327(00)01376-4. PMID: 11725304.

[46] May T, Silverman RD. Free-riding, fairness and the rights of minority groups in exemption from mandatory childhood vaccination. Hum Vaccin. 2005 Jan-Feb;1(1):12-5. doi: 10.4161/hv.1.1.1425. Epub 2005 Jan 6. PMID: 17038833.

[47] https://zh.wikipedia.org/zh-hans/%E7%96%AB%E8%8B%97%E7%8C%B6%E8%B1%AB#cite_ref-Vatican_142-0 checked on May 16th, 2023.

containing gelatin are acceptable because it is cooked rather than consumed as food. However, in 2015 and 2020, the possible use of pig-based gelatin in vaccines raised religious concerns among Muslim and Orthodox Jews about the halal or kosher status of several vaccines against COVID-19. The Muslim Council of Britain opposed the use of the intranasal flu vaccine in 2019 because of the gelatin in the vaccine and considered such vaccines non-halal.[48]

Many governments allow parents of children not to vaccinate their children because of religious reasons, and some parents are reluctant to vaccinate their children because of other factors, but in order to get permission from the government, falsely claim that they will not be vaccinated because of religious reasons. Before 2019, there were only three states in the United States, Mississippi, West Virginia, and California, which were not allowed to not be vaccinated because of religious factors, but due to religious beliefs and vaccine skeptics refusing to vaccinate, the United States had the worst measles outbreak in more than 20 years, and on June 13, 2019, New York State also prohibited parents from preventing their children from completing the vaccinations necessary for school on the grounds of religious belief, and Maine abolished this exemption in early 2019. However, there are still 45 states that allow not to be vaccinated because of religion.[49]

While freedom of belief should be protected, people around the world are now facing the threat to the life of communicable diseases and the enormous socio-economic costs they can cause, so all parties should act more aggressively to protect people's lives. For example, local Christian churches can inform believers of the conclusion by the Vatican Curia that "it is acceptable for Catholics to use existing vaccines when alternative vaccines are not yet available", dispel some people's concerns due to information asymmetry, and give them the right to make their own choices after understanding the whole picture. More importantly, vaccine manufacturers should also take corporate social responsibility, accelerate research, and find and provide alternative vaccines, so that more people can use vaccines with confidence and do not have to be in a dilemma.

## 4.2 Culture and biases

If the worries from religions are reasonable concerns, then some rumors widely spread in some

[48] Priyanka Deladia (November 9, 2014). "Pork gelatine flu spray concerns". BBC. https://www.bbc.com/news/health-30118984
[49] http://www.xinhuanet.com/world/2019-06/15/c_1210159750.htm checked on May 16th, 2023.

cultures are terrible biases. There has been a misconception in Pakistan that the polio vaccine contains banned ingredients that can cause impotence and infertility in boys, leading some parents not to allow their children to be vaccinated. This belief is most prevalent in Khyber Pakhtunkhwa and Federally Administered Tribal Areas. There have also been attacks on polio vaccination teams, hampering international efforts to eradicate polio in Pakistan and globally.[50]

For the widespread prejudice against vaccines in some cultures, strengthening popular science education and eliminating prejudice will be a more effective method. Eliminate prejudice as much as possible by making people truly understand how vaccines work, and what they do, and realize the enormous benefits that vaccines can have on individuals, families, countries, and the world, and that failure to vaccinate can not only have a serious socio-economic impact but may even lead to unnecessary deaths. In this regard, international organizations such as the United Nations and the World Health Organization can send personnel to train local healthcare professionals in the aid, and at the same time put appropriate pressure on local politics and laws to eliminate prejudice and promote vaccination as one of the conditions for receiving assistance, so as to avoid local governments choosing not to pay attention to this issue.

## 4.3 Global Cooperation

The Covid-19 pandemic is a global pandemic of coronavirus disease 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The disease was first reported in Wuhan, Hubei Province, People's Republic of China in late 2019, followed by cases reported in many countries around the world in early 2020, gradually turning into a global pandemic. As of 18th May 2023, more than 766,440,032 confirmed cases have been reported globally, including more than 6,932,578 deaths, with a case fatality rate of about 2.09%[51], making it one of the largest epidemics in human history. At present, the WHO has not studied the source of the disease, and it is preliminarily judged that the virus comes from wild animals. Current research suggests that SARS-CoV-2 may have entered human society and began to spread as early as October-November 2019, and the first known case of infection occurred in Wuhan on December 1st, 2019. On January 23rd, 2020, the Wuhan New

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50 http://news.bbc.co.uk/2/hi/south_asia/6299325.stm checked on May 16th, 2023.
51 https://ourworldindata.org/coronavirus checked on May 16th, 2023.

Coronary Pneumonia Epidemic Prevention and Control Headquarters announced the adoption of lockdown measures in epidemic areas, which is the first time in modern public health history that a large city with a population of 10 million has been adopted lockdown measures[52]. On 29th February, WHO raised the global risk level of the outbreak to "very high". On 11th March, there were large numbers of cases in countries in Europe and the Middle East, and WHO declared the outbreak a "global pandemic". Since then, Europe and South America have been declared the epicenter of the pandemic. On 5th October, WHO said that according to "the most accurate estimates", about 10% of the world's population may have been infected with the virus. As of 21st May 2021, according to WHO estimates, the true death toll could be 2-3 times higher than officially reported, with at least 6 million to 8 million people.

The incubation period between the infection pathogen and the onset of symptoms is an average of 5 to 6 days, ranging from 1 to 14 days in general, and up to 24 days in some cases; Even infected people who do not have a fever, show no signs of infection, or have only mild signs of infection can transmit the virus to others, and patients who do not show symptoms make screening ineffective; If a patient with mild disease appears, its symptoms are similar to the influenza epidemic in the same period, which is easy to lead to misjudgment by patients, families, and the government. At the same time, although the probability is quite low, the disease has also been found to be transmitted through environmental factors such as close contact with the surface of contaminated items by people, and the time is quite short. It is more difficult to control than outbreaks of Middle East respiratory syndrome (MERS) or severe acute respiratory syndrome (SARS). In fact, the outbreak took only a quarter of the time to cause ten times the number of confirmed cases of SARS. The pathogen of coronavirus disease 2019 has also mutated at least twice, and its infectivity has increased dramatically. At present, there are still knowledge gaps in the research of viruses, including key factors such as virus source and virus origin are still uncertain. Prevention and treatment of coronavirus disease 2019 is not fully understood. Supportive therapy is currently the main treatment, it is known that remdesivir or Pax Loved and Monapiravir can be used in patients with mild disease, and with the approval of the above broad-spectrum antiviral drugs from 2021, the investment of new oral drugs can also reduce the probability of death due to weight turnover; Severe disease can be treated with corticosteroids such as

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[52] Wuhan lockdown 'unprecedented', shows commitment to contain virus: WHO representative in China https://www.reuters.com/article/us-china-health-who-idUSKBN1ZM1G9 checked on May 16th, 2023.

dexamethasone. Social distancing, wearing masks, and keeping surfaces clean can effectively prevent the spread of COVID 2019. At the height of the outbreak, at least 57 COVID-2019 preventive vaccines were in trial around the world, six of which were available for emergency use. In August 2021, the U.S. Food and Drug Administration officially approved the first fully authorized vaccine, the Pfizer-BioNTech 2019 coronavirus disease vaccine in cooperation with BNT of Germany. As of May 2023, 13.38 billion doses of the COVID-19 vaccine have been administered globally, 70% of the world's population has received at least one dose of the COVID-19 vaccine and 29.9% of people in low-income countries have received at least one dose.[53], with Israel and other countries being one of the first countries to lift the epidemic due to the early vaccination rate. In 2022, the Omicron variant became the main epidemic strain, and its case record was low in the severe disease rate, coupled with the launch of emerging drugs, antigen rapid screening, and next-generation vaccines, although the new crown epidemic has not disappeared, under the gradual control of the impact, the global new crown epidemic prevention has entered the final stage. On 5th May 2023, WHO Director-General Tedros Adhanom Ghebreyesus announced at a press conference that the COVID-19 outbreak no longer constitutes a Public Health Emergency of International Concern (PHEIC).

The pandemic caused severe global social and economic disruption, was seen as the worst crisis humanity has faced since World War II, and plunged the global economy into its biggest recession since the Great Depression of the 1930s. In the early days of the crisis, there were also problems of insufficient supply of medical and people's livelihood supplies around the world due to panic consumption, the spread of fake news, and racial or geographical discrimination against different ethnic groups. Many educational institutions and public areas were partially or completely closed, and many events were canceled or postponed. The spread of the epidemic has had a huge impact on global aviation, tourism, entertainment, sports, oil markets, financial markets, etc., and will continue for many years after the economic reopening.

Vaccines have played a vital role in the global COVID-19 pandemic, and without them, the pandemic may not have ended today, with more lives lost and greater socio-economic losses. In such a global public health emergency event, the cooperation of all the countries around the world is essential. Developed countries have more advanced science and technology, so they can cooperate

[53] https://ourworldindata.org/covid-vaccinations checked on May 16th, 2023.

with large pharmaceutical companies to develop efficient vaccines as soon as possible. While developing countries such as China and India as the world's factories, can be responsible for the production of vaccines. Countries with their own responsibilities and a clear division of labor can greatly improve the whole process of vaccine development to vaccination so that low-income countries and least-developed countries that lack science, technology, and production capacity can have more people vaccinated and thus eliminate the adverse effects of the pandemic faster.

In addition to cooperation at the national level, just as big countries should have the responsibility of big countries, large pharmaceutical companies should also assume their social responsibilities. After the successful development of the COVID-19 vaccine, WTO member states and large pharmaceutical companies engaged in fierce negotiations on the issue of intellectual property exemption for the new crown vaccine, and finally reached a difficult agreement[54]. But in fact, in the face of the threat to the life of all mankind caused by the virus, interests should give way to life, and large pharmaceutical companies should assume their social responsibilities. Giving up part of the economic benefits and assuming its social responsibilities is not necessarily a loss for enterprises. Companies should be aware that, in addition to shareholders, customers, and in this pandemic, even people around the world, are important stakeholders, so their interests should also be taken into consideration. Merck & Co., also a large pharmaceutical company, can be a good example.

In the late 1980s and early 1990s, Merck & Co. developed a drug to treat river blindness, a disease that is common in developing countries. However, the disease primarily affected people in poverty-stricken areas, and Merck & Co. faced a limited market for the drug in these regions. Roy Vagelos, the CEO of Merck & Co., believed that the company had a social responsibility to help those in need, regardless of their ability to pay. He decided to donate the drug to treat river blindness for as long as it was needed, which meant that the company would not make a profit on the drug in these regions. From a strategic point of view, this decision can be justified as a way to enhance the company's reputation, increase access to healthcare in developing countries, and potentially create long-term business opportunities. By demonstrating a commitment to social responsibility, Merck & Co. could strengthen its relationships with customers, employees, and other stakeholders, leading to increased loyalty and market share. From an ethical point of view, this decision can also be justified.

[54] https://international.caixin.com/2022-06-18/101900679.html checked on May 16th, 2023.

Merck & Co. recognized its social responsibility to help those in need, particularly in regions where access to healthcare was limited. The decision to donate the drug for free demonstrated a commitment to ethical principles such as compassion, fairness, and respect for human dignity. Additionally, Merck & Co. recognized the potential harm that could result from withholding life-saving medication from those who need it, which further supports the ethical justification for the decision. Overall, the decision to donate the drug to treat river blindness for free can be justified both from a strategic and ethical point of view. By balancing social responsibility with financial performance, Merck & Co. was able to create a positive impact on society while also ensuring long-term success for the company.

Therefore, companies should take social responsibility in public health crises, which is both an ethical consideration and a demonstration of sustainable business.

# Conclusion

This study compared data from different countries at different levels of development over nearly 40 years and demonstrated that vaccines have positive economic benefits for countries at all stages of development. After that, some policy recommendations were made, based on the current vaccination coverage situation in various countries, that is, developed countries should continue to maintain high vaccination coverage to prevent possible outbreaks. Developing countries should, in accordance with their actual incidence patterns, maximize existing vaccination rates while incorporating more basic vaccines into their national immunization schedules. For LDCs, more health spending should be spent on vaccines. And the international community should prioritize vaccine assistance when providing health assistance to least developed countries. In addition, there are also other factors, such as religion, culture, bias, and global cooperation, that will also affect the vaccination within countries. Based on their actual conditions, countries can promote cooperation with large pharmaceutical companies internally, accelerate research and development and popularization of science, increase the vaccination rate of their citizens as much as possible, as well as cooperate closely with other countries abroad, take their respective responsibilities, and make efforts to comprehensively eliminate infectious diseases.

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