Health Economics of Vaccine Development and Distribution: Lessons from the COVID-19 Pandemic

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ABSTRACT

The COVID-19 pandemic has had profound implications for the economics of vaccine development and distribution, revealing both achievements and disparities in global health systems. This narrative review examines the economic frameworks that shaped COVID-19 vaccine R&D, distribution logistics, and pricing strategies, with a focus on lessons for future pandemics. A thematic analysis of the literature was conducted, including peer-reviewed articles, government reports, and industry publications. Databases such as PubMed, Google Scholar, JSTOR, Scopus, and World Health Organization (WHO) archives were searched using terms like "COVID-19 vaccine economics," "vaccine distribution costs," and "pandemic preparedness." Inclusion criteria focused on studies examining economic models of vaccine development and distribution, while studies limited to clinical outcomes were excluded. Key findings highlight the critical role of public-private partnerships in accelerating vaccine development through shared financial risk, until now also revealing significant inequities in global access, exacerbated by pricing strategies that favored high-income countries. Logistical challenges, particularly cold chain storage and distribution, further delayed access in low- and middle-income countries. The review emphasizes the need for resilient global supply chains, innovative financing models, and equitable pricing frameworks to ensure fair vaccine access in future pandemics. Addressing these issues is essential for a more effective and fair global health response.

Keywords: COVID-19 vaccine economics, Public-private partnerships, Vaccine distribution logistics, Global vaccine equity, Innovative financing models

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Introduction

The COVID-19 pandemic was a significant test for healthcare systems around the world; a vaccine had to be developed, tested, and distributed quickly to meet this unprecedented challenge.[1] As fast as the scientific community was able to develop effective vaccines, the economic aspects of these processes exposed the advantages and disadvantages of global vaccine rollout strategies.[2,3] Examining the health economics of vaccine research and development, production, distribution logistics, and pricing, this review seeks to shed light on the factors supporting vaccine development and distribution during the COVID-19 pandemic. Insights obtained from these experiences teach us important lessons that can be applied to future pandemic responses and to optimize the financial frameworks that surround vaccine development and delivery.

This review focuses on the economic aspects in particular because, in addition to the science behind vaccine creation, it is crucial to understand the logistical, financial, and policy-related factors to ensure that vaccines are distributed fairly and efficiently. The goal is to outline the COVID-19 pandemic's innovative solutions and the economic challenges it faced so that future pandemics can be handled more efficiently and with more equitable vaccine access.

Rationale

Despite being a scientific victory, the rapid development and distribution of COVID-19 vaccines posed a significant economic challenge, necessitating joint efforts from governments, pharmaceutical companies, and international organizations.[4] Because of the pandemic, healthcare systems and economies had to rethink their approaches to vaccine development, which are normally more cautious and time-consuming. There was a tremendous strain on available funds, international supply chains, and distribution networks due to the combination of high demand, tight deadlines, and the critical requirement for mass vaccination.[5]

This review will shed light on the following by analyzing the economic strategies and results of the COVID-19 pandemic:

i. How do initiatives such as COVAX and other global collaborations, as well as public-private partnerships (PPPs) and government subsidies, speed up the process of developing vaccines?
ii. How do pricing strategies and market dynamics affect the availability of vaccines for all?
iii. Issues with logistics that developed while delivering vaccines to Lower Middle-Income countries (LMICs) and their effect on global health results.

This review is conducted to utilize the lessons learned during COVID-19 to enhance economic models for future vaccine development and distribution efforts. The goal is to ensure that global health emergencies are responded to more quickly, more effectively, and more fairly, all while keeping in mind the persistent threat of pandemics.

Background Information

Vaccine development is notably time-consuming and resource-intensive, typically spanning ten to fifteen years from the start of research to the release of the vaccine to the market.[6] Research at the fundamental level, preclinical trials, three stages of clinical trials, regulatory approval, production, and distribution are all part of the process. As we go through each stage,

we run the danger of losing a lot of money and having to plan for a long time. There has never been a vaccine that was created, tested, and authorized for emergency use in less than a year. The COVID-19 pandemic, on the other hand, changed vaccine development in fundamental ways.[7] The crisis demanded vaccines at an unprecedented scale and pace.

Before the pandemic, the world was not ready for such a large-scale health crisis. A lot of countries did not have the infrastructure, money, or long-term plans they needed to handle a pandemic on the scale of COVID-19. Outbreaks of SARS, MERS, and Ebola have shown how important it is to have strong pandemic plans, but not enough money has been spent on public health infrastructure and emergency response tools. Several interconnected factors led to the unpreparedness that occurred during the pandemic. First, many governments failed to adequately fund public health infrastructure, putting short-term financial worries ahead of healthcare system investments and pandemic preparedness. International cooperation on health emergencies was disjointed, with inadequate systems for sharing resources and collective action, exacerbating the underinvestment. Furthermore, there were major weaknesses in the worldwide medical supply chain, which made it unable to increase production of life-saving supplies like vaccines in the event of an emergency. The slow identification and reaction to new infectious diseases was exacerbated by many nations' inadequate monitoring systems. These shortcomings became apparent as the pandemic progressed, creating significant obstacles in the development and distribution of vaccines. Existing economic and logistical frameworks were exposed to their limits as the crisis demanded vaccines at an unprecedented scale and pace.

The COVID-19 vaccines were quickly put into use due to new economic strategies that sped up development and lowered financial risks.[8] Operation Warp Speed (OWS) in the US and other international programs like Gavi and Coalition for Epidemic Preparedness Innovations (CEPI) were vital in this regard.[9] Because of these investments, drug companies were able to increase production at the same time before full clinical efficacy was proven. This helped lower the financial risks of early-stage research and development. Using advanced market commitments (AMCs) was another important economic model. These made sure that vaccine makers would have buyers, which reduced risk and encouraged them to start investing in production early.[10] Global cooperation was also very important for distribution. For example, programs like COVAX work to make sure that everyone has the same access to vaccines.[11] Despite these efforts, there were still big differences in how vaccines were distributed because of problems with logistics and finance. At least in low- and middle-income countries, this was very true, as new events show how important it is to change economic policies in response to global health emergencies.

Scope

The main focus of this narrative review is on the economic side of making and spreading the COVID-19 vaccine. On top of that, the review will explore in detail the different ways that money has been used to speed up the development of vaccines, such as PPPs, venture capital investments, and government grants. It will also look at how pharmaceutical companies try to lower the risk of making vaccines by AMCs.

This review also examines the workings of the public and private sectors, along with governments and international groups. PPPs like OWS and COVAX are used as examples of how they helped make vaccine production increase to a larger level. We will judge how useful these partnerships are by how well they support equal access. This review also investigates problems that have come up with getting vaccines to LMICs around the world. These problems include limited transportation, the need for cold storage, and issues with the supply chain. However, various factors influence vaccine availability globally, particularly in low-income regions, including how companies determine their prices and the purpose of intellectual property rights and patents. In the end, we have provided suggestions to improve the financial systems that control the development and distribution of vaccines. These ideas will focus on improving international cooperation, making supply chains more resilient, and coming up with new ways to pay for vaccines so that everyone has equal access to them during future pandemics. By putting together the logistical and financial problems that came up during the rollout of the COVID-19 vaccine, this review aims to give policymakers, healthcare leaders, and international organisations useful information that they can use to improve global pandemic preparedness and vaccine economics in the future.

Methods

There was a structured but flexible way through which this narrative review found and put together relevant literature on the health economics of making and giving out vaccines during the COVID-19 pandemic.

Literature Search

A complete literature search was carried out across several databases to uncover a multitude of studies, reports, and data pertinent to the matter. These databases were used for the search: JSTOR, PubMed, Google Scholar, and the archives of the WHO. These sources were chosen to include academic papers that have been reviewed by other academics, government reports, trade magazines, and "grey literature." Key search terms like *"COVID-19 vaccine economics," "vaccine development cost," "vaccine distribution cost," "pandemic preparedness economics," "global vaccine distribution logistics," "equitable access to vaccines," and "health economics of vaccine production"* were used to make sure that the whole topic was covered. As needed, the search terms were changed, and Boolean operators (AND, OR) were used to narrow or broaden the search results.

Study Selection Criteria

After the search was completed, the following criteria were used to sort through the studies and pick the

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Table 1 | Inclusion and Exclusion Criteria for the Narrative Review on COVID-19 Vaccine Economics

Inclusion Criteria	Exclusion Criteria
Relevance to Vaccine Economics Articles focusing on the financial aspects of vaccine development, distribution, and access were prioritized.	**Non-Economic Studies** Articles focused purely on clinical aspects like efficacy or safety without addressing economic considerations were excluded.
COVID-19 Specific Studies Priority was given to articles and reports specifically addressing COVID-19 vaccine economics.	**Non-COVID-19 Studies** Non-COVID-19-related studies were excluded unless they provided a critical framework for vaccine economics in general.
Diverse Geographic Focus Studies covering both high-income countries (HICs) and LMICs for global coverage.	**Redundant Articles** Studies with overlapping data or conclusions from the same author groups were filtered out to avoid redundancy.
Case Studies and Reports Government reports case studies (e.g., OWS, COVAX), and industry white papers were included for practical insights.	

Table 2 | Key Thematic Areas of Focus in COVID-19 Vaccine Development, Distribution, and Economic Impact

Key Areas of Focus	Description
Economic Frameworks for Vaccine Development and R&D	Studies examining funding mechanisms, cost-benefit analysis, and PPPs used in the development of COVID-19 vaccines.
Manufacturing and Distribution Logistics	Literature focusing on logistical and supply chain challenges related to vaccine production and global distribution.
Pricing Strategies and Access	Articles discussing vaccine pricing models, affordability, and equity, particularly how pricing affected vaccine distribution to LMICs.
Global Health Policy and Governance	Sources examining the role of international organizations (e.g., WHO, Gavi) in coordinating vaccine distribution and ensuring equitable access worldwide.
Long-Term Economic Implications	Studies exploring the broader economic consequences of the COVID-19 vaccine rollout, including its impact on global health systems and future pandemic preparedness strategies.

ones that were most relevant for the review, which is explained in detail in Table 1.

Organizing the Literature

Once the relevant literature was found, it was put into groups based on themes to make the analysis more accurate. The literature was put together based on the following themes presented in Table 2.

Summarizing and Synthesizing the Literature

The literature was organized into thematic groups, and then the chosen studies were summed up to get the most important ideas. We examined each theme area to find the most important new ideas in the field. For example, the theme on economic framework explains how important it is for the government and businesses to work together, and the theme on manufacturing logistics explain about the problems that come up with keeping mRNA vaccines cold. The review also shows how different economic strategies affected each other along the pipeline of making and distributing vaccines. For example, studies on pricing were linked to problems with access in LMICs. Extractions of gaps in the literature occur during the synthesis process. For instance, comprehensive economic studies examining the long-term viability of the funding models employed during the pandemic are scarce. During future pandemics, there is a lack of research on ways to facilitate the delivery of vaccines to remote areas. Alternative funding mechanisms for future pandemics, such as pooled funds and vaccine bonds, were not adequately investigated. The review addresses these gaps, which are crucial for future research.

Literature Synthesis

The health economics of making and giving out vaccines during the COVID-19 pandemic include many economic, policy, and logistical problems that are all linked.[12] We have investigated previous research and organized it into main themes that show how the economics of vaccine research and development affect access and fairness, the role of PPPs, and the logistics of making and distributing vaccines around the world. This review examines closely the financial and operational parts of the global response to the pandemic by exploring case studies, reports, and peer-reviewed research. Putting these themes together not only explains the functioning of different vaccines but also teaches us important lessons about how to prepare for future pandemics. Using this all-encompassing theme, the review seeks to establish connections between the economic policies that were put in place and their effects on global equity and public health.

Thematic Structure

The literature review on the health economics of making and distributing vaccines during the COVID-19 pandemic is divided into thematic areas that explain important parts of the economic, logistical, and policy problems that came up during the global rollout of vaccines.

Theme 1 Economic Frameworks for Vaccine Research and Development (R&D)

The fast development of COVID-19 vaccines was made possible by unprecedented amounts of money from both the public and private sectors.[13] Traditional vaccine research and development is usually a long and expensive process. It takes more than ten years from the start of development to the product being approved for sale. But because of the COVID-19 pandemic, this time frame was cut down to less than a year for some vaccines.[14] This speeding up was made possible by large amounts of government funding, private investments, and new ways of handling finances that were meant to lower the risks that usually come with making vaccines.

Underinvestment in Pandemic Preparedness

One significant reason many countries were unprepared for the COVID-19 pandemic was the chronic underinvestment in pandemic preparedness and public health infrastructure. Despite numerous warnings from previous outbreaks such as SARS in 2003, H1N1 in 2009, MERS in 2012, and Ebola between 2014 and 2016, global health security remained underfunded and inadequately prioritized.

Factors Contributing to Underinvestment

Governments often face limited budgets and must balance various pressing needs such as education, defense, infrastructure, and healthcare. Pandemic preparedness, which requires significant investment in surveillance systems, healthcare infrastructure, stockpiling medical supplies, and funding R&D for vaccines and therapeutics, often falls low on the list of immediate priorities. The infrequency of pandemics can lead to complacency, with policymakers prioritizing short-term economic gains over long-term health security.

Investing in pandemic preparedness does not yield immediate visible benefits, making it less attractive to politicians seeking short-term achievements to showcase to their constituents. The benefits of such investments are only realized when a pandemic occurs, leading to a lack of sustained political commitment. International organizations like the WHO have limited authority and funding to enforce compliance with International Health Regulations (IHR). The absence of binding mechanisms to ensure countries invest adequately in preparedness contributes to global vulnerability. The private sector, including pharmaceutical companies, historically underinvests in vaccine development for emerging infectious diseases due to low expected returns on investment. Diseases that predominantly affect low-income countries may not promise lucrative markets, disincentivizing R&D efforts.

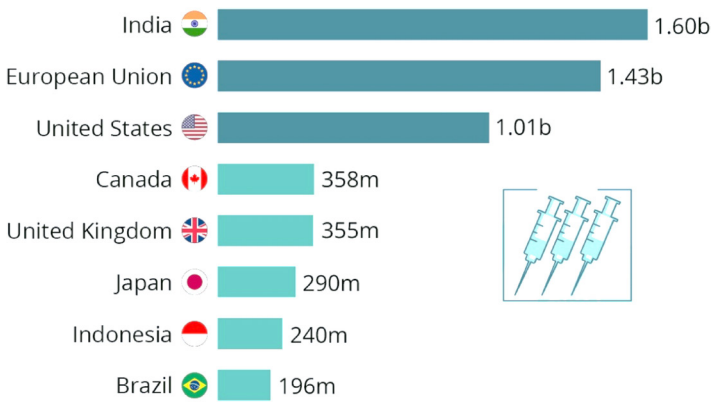

Fig 1 | Total number of vaccine doses secured by governments as of November 2020
Source: McCarthy N.[15]

Consequences of Underinvestment

Underfunded healthcare systems lack the capacity to handle surges in patient volumes, leading to overwhelmed hospitals, inadequate critical care facilities, and shortages of medical personnel during pandemics. Inadequate investment in disease surveillance hampers early detection of outbreaks, delaying response efforts and allowing pathogens to spread unchecked. Without strategic stockpiles of personal protective equipment (PPE), ventilators, and other essential supplies, countries faced severe shortages, endangering healthcare workers and patients alike.

Case Studies Highlighting Underinvestment

Despite being ranked highly on the Global Health Security Index, the U.S. faced significant challenges due to underfunded public health agencies, limited stockpiles, and fragmented healthcare infrastructure. Budget cuts to the Centers for Disease Control and Prevention (CDC) and public health programs weakened preparedness efforts. Many LMICs struggled with weak healthcare systems that lacked basic infrastructure, equipment, and trained personnel, exacerbating the pandemic's impact. Limited fiscal space further constrained their ability to respond effectively (Figure 1).

Duke University has been collecting and analyzing publicly available data to learn more about how each country buys the COVID-19 vaccine.[15] As of November 20, 2020, a total of 9.8 billion doses had been reserved. 3.8 billion doses have been given to HICs, and 828.8 million doses have been reserved or secured for middle-income countries. LMICs, on the other hand, get 1.75 billion doses.

Researchers at Duke University found that low-income countries did not report any direct procurement agreements. This means that these countries probably need to get their vaccines from the COVAX alliance. India is first on the list of countries that moved quickly to stockpile vaccines, with 1.6 billion doses secured. The US is second, with 1.01 billion doses secured, and the European Union has also been able to get 1.43 billion doses.

People from both the public and private sectors worked together during the pandemic as a key strategy. To lower the risk of vaccine research and development, governments, international groups, and drug companies worked together closely.[16] These partnerships made it possible for vaccine trials and production to

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be scaled up quickly by giving direct financial support and securing early-stage funding commitments. PPPs were very important for moving forward with clinical trials and getting manufacturing ready before vaccines got regulatory approval, which helped vaccine developers lower their financial risks.[17]

Case Study: OWS

OWS, which was led by the U.S. government, was one of the most important examples of a partnership between the government and the private sector during the pandemic.[18–20] The United States government put more than $10 billion into the program, which helped companies like Pfizer, Moderna, and Johnson & Johnson make vaccines.[21] OWS paid for the clinical trials, made sure that the infrastructure for making vaccines was set up, and that advance purchase agreements were made for millions of doses. By lowering the risk of research and development, OWS made vaccines much more available in the U.S. market. As the trial goes on, more people take part, so more information is gathered about safety and effectiveness. For example, phase 3 has more people than phase 2 presented in Figure 2. Even though the program was successful, it also raised concerns about the lack of price transparency and the possibility of vaccine manufacturers having a monopoly on the market (Table 3).[22]

These partnerships not only speed up the process of making vaccines but also set a new standard for future public health emergencies. When public and private organizations share risks and benefits, it can make vaccine ecosystems more responsive and effective.

Funding Mechanisms for Vaccine Development

The economic framework for COVID-19 vaccine development was characterized by an unprecedented infusion of public and private capital. Governments and organizations like the CEPI and Gavi played crucial roles in financing vaccine R&D and de-risking early-stage investments.[26] These funding mechanisms ensured that vaccine developers could scale up production even before receiving regulatory approvals (Table 4).

Table 3 | Key PPPs in COVID-19 Vaccine Development

Partnership	Key Players	Role	Impact
OWS	U.S. government, private companies	Funded clinical trials and manufacturing	Accelerated vaccine availability in the U.S.
CEPI[25]	Global governments, private sector	Provided funding for vaccine R&D	Facilitated global vaccine R&D, especially in LMICs

Table 4 | Key Funding Mechanisms for COVID-19 Vaccine Development

Funding Mechanism	Description	Examples
Government Grants	Direct government investment in vaccine R&D.	OWS, CEPI
PPPs	Collaboration between government, private sector, and academia.	Pfizer-BioNTech, Moderna
AMCs	Pre-purchase agreements ensure vaccine supply upon approval.	Gavi COVAX AMC
Venture Capital Investments	Private investment in biotech firms developing vaccines.	Moderna's IPO funding

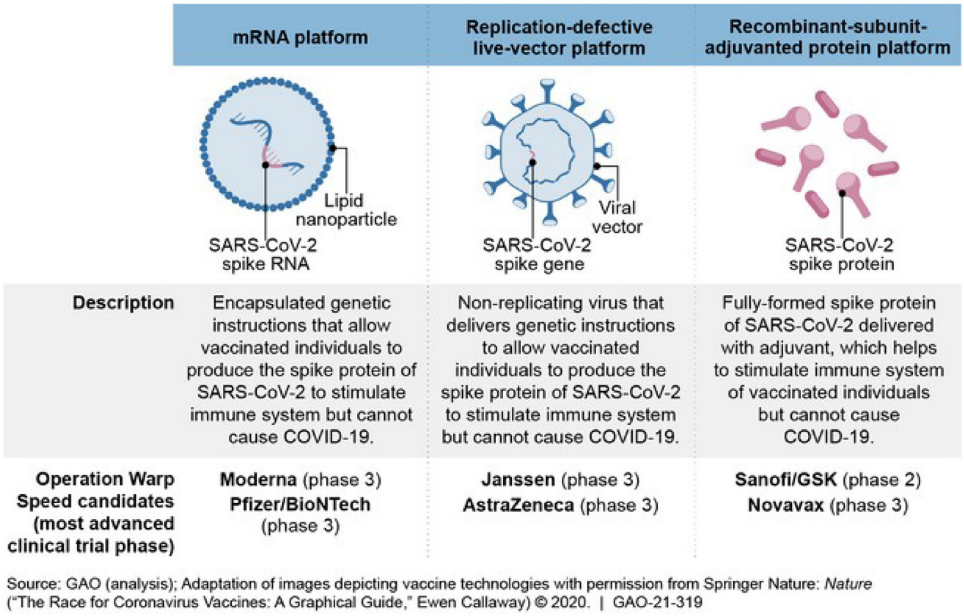

Fig 2 | Comparison of COVID-19 vaccine platforms and leading candidates under OWS

Source: Callaway E, Spencer N.[23]; U.S. Government Accountability Office. Operation Warp Speed: Accelerated COVID-19 Vaccine Development Status and Efforts to Address Manufacturing Challenges. GAO-21-319[24]

The COVID-19 pandemic showed how important it is for the government to get involved in vaccine research and development as early as possible. Public investments sped up the process of making vaccines, but there were doubts about making sure that prices were fair and that everyone got their share. In the event of future pandemics, governments and global organizations may need to come up with long-term ways to pay for things, like pooled funding or new ways to get money (like vaccine bonds), so that development can happen quickly while also being affordable and easy for everyone to get.

Theme 2 Public-Private Partnerships and Global Collaboration

Collaboration between governments, international groups, and private businesses around the world was a key factor in increasing the production and distribution of vaccines.[27,28] There were big differences in how easy it was for people in HICs and LMICs to get vaccines.

Global Collaboration vs. Vaccine Nationalism

There was an issue between international cooperation and vaccine nationalism in response to the distribution of vaccines around the world. Initiatives like COVAX, which was led by Gavi, the WHO, and CEPI, tried to make sure that everyone in the world had equal access to vaccines.[29] However, vaccine nationalism, in which wealthy countries got doses before others, got in the way of the program's goals. HICs, like the US, UK, and EU members, were able to get large amounts of vaccines early due to agreements to buy them ahead of time.[30] This meant that LMICs had to rely on late shipments from projects like COVAX, which had trouble with production and supply.

Figure 3 shows the global vaccination rates for different regions. It shows the percentages of fully and partially vaccinated people as a share of the total population. Latin America and the Asia-Pacific region have the highest vaccination rates, at 82%. This means that a large portion of their populations have been fully vaccinated. Even though these places have high rates, the U.S. and Canada are very close behind with 81% vaccination rates. Europe has also made a lot of progress; 70% of its people have been vaccinated, but it is still behind the Americas and the Asia-Pacific.

In the Middle East, on the other hand, only 58% of the population has been vaccinated, which means it

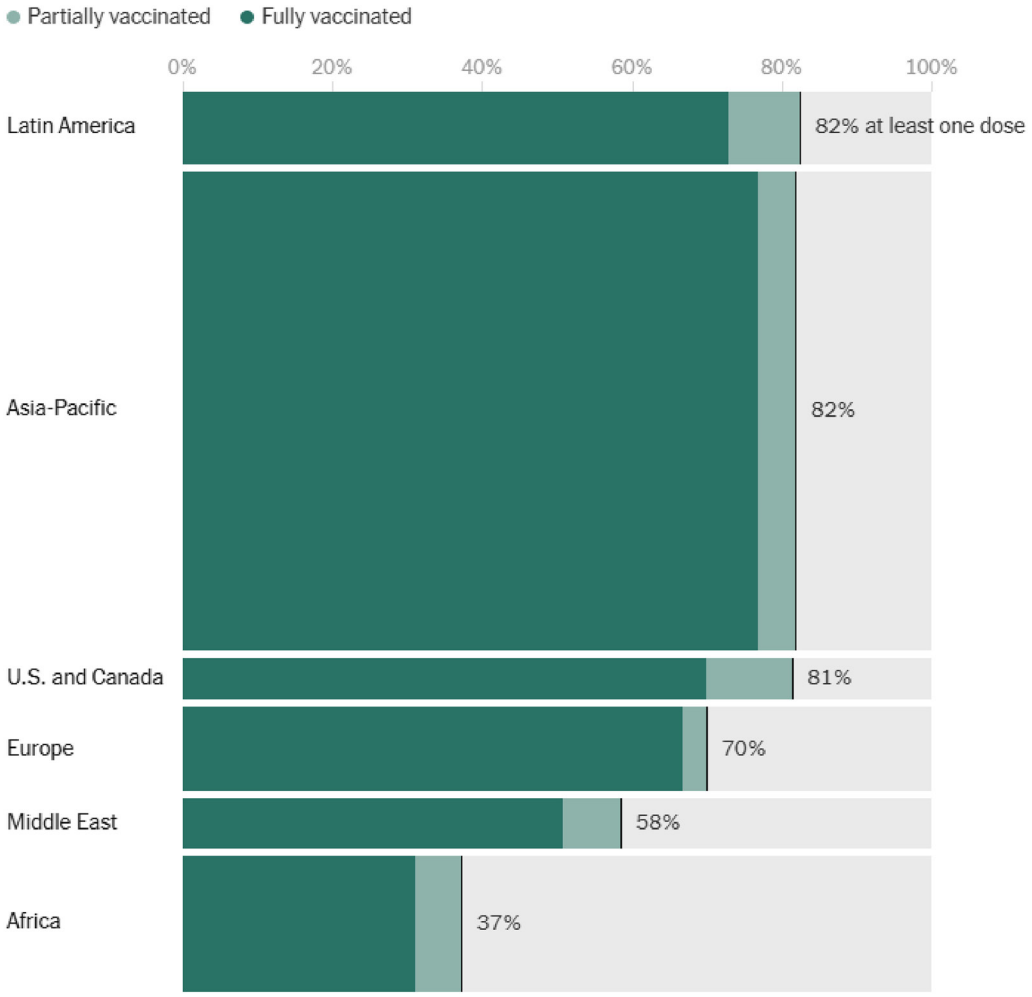

Fig 3 | Global COVID-19 vaccine distribution (percentage of population vaccinated by region)

Source: Holder J.[31]

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will be harder to reach a large population. Africa has the lowest vaccination rate, at 37%. This shows how different it is around the world to get vaccines and get them to people who need them. There are big differences in the levels of vaccination in different parts of the world. Generally, wealthier areas have higher rates, while places like Africa and the Middle East still have a long way to go before they are fully vaccinated. This difference shows that the global system for distributing vaccines isn't working well enough to make sure everyone has equal access. LMICs are the ones who have to deal with delayed shipments, higher costs, and other problems with logistics.

The differences in the rates of vaccine distribution between high-income areas like North America and Europe and low-income areas like Africa and Latin America show that global health governance needs to be changed.[32] If these changes are made, fair access could be given more weight than national interests. This would help create global supply chains that make sure everyone, no matter their income, has access to vaccines.

COVAX and the Role of Global Organizations

COVAX was created as a global effort to make sure that everyone could get the COVID-19 vaccines, especially people in low-income countries.[33] Even though COVAX had good intentions, it ran into several problems, such as not being able to get enough vaccine doses, having trouble getting vaccines to remote areas, and manufacturing taking longer than expected.[34] It is hard to rely on a single platform for fair vaccine distribution, especially when wealthy countries bid more than COVAX for early supplies because of vaccine nationalism.

The COVID-19 pandemic showed that we need stronger international systems that put international cooperation and fair access to vaccines at the top of the list.[35,36] It is time for global health organizations to rethink how they distribute vaccines. They should focus on making global supply chains more resilient and pushing for financing models that do not favor rich countries over poor ones. This is very important for getting ready for future pandemics. This thematic analysis shows how the economic strategies used during the COVID-19 pandemic were both new and, in some cases, unfair. PPPs and large financial investments helped make it possible for vaccines to be made and distributed quickly. However, differences in access to vaccines around the world slowed down these efforts. In the future, public health policies should include stressing the need for fair, collaborative, and financially stable ways to make and distribute vaccines.

Theme 3 Logistical Challenges in Manufacturing and Distribution

The creation of effective COVID-19 vaccines was a huge scientific accomplishment, but making and sending these vaccines all over the world proved to be very difficult. The sudden need to make billions of doses very quickly caused problems with both production and distribution, especially in places that did not have the right infrastructure.

Manufacturing Bottlenecks

One of the biggest problems during the pandemic was that the world did not have enough factories to make a lot of vaccines. Usually, the process of making vaccines is very well thought out. But during the pandemic, there was an unprecedented need for billions of doses, which overwhelmed the manufacturing infrastructure that was already in place.[37] Because of this higher demand, production was held up, and global supply chains were messed up. The newer mRNA vaccines had the most trouble getting made because they needed specialized production facilities and materials, like lipid nanoparticles.[38] As vaccine makers rushed to make more, these delays caused doses to be sent to fewer countries, especially low- and middle-income ones that were usually the last in the queue to get them.

Cold Chain Storage and Distribution

A good cold chain is a temperature-controlled system that keeps vaccines safe and is needed to store and handle vaccines properly.[39] When the vaccine is made, it is stored in a cold place. The cold chain then goes through transport and delivery and finally ends with proper storage at healthcare facilities until the vaccine is given.[40] If this chain is broken, the vaccine might not

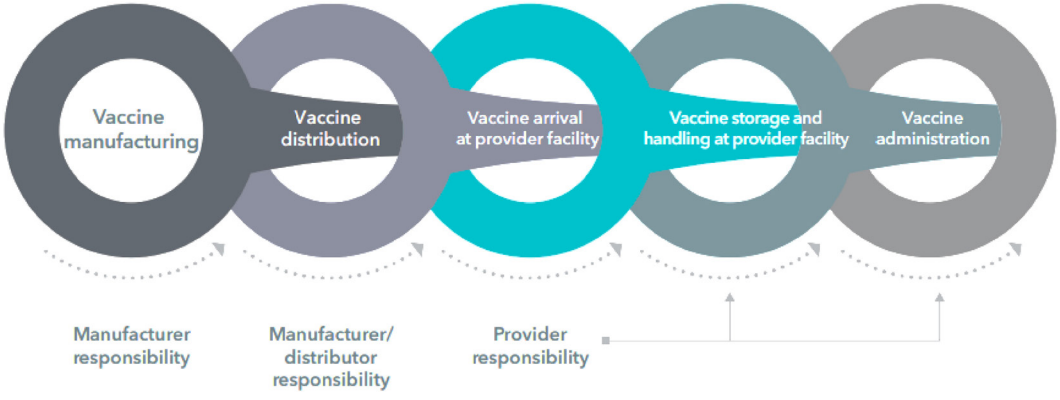

Fig 4 | Cold chain flowchart

Source: Centers for Disease Control and Prevention. Vaccine Storage and Handling Toolkit[43]

work as well. Keeping the right storage conditions from the time the vaccine is made until it is used is important since the effectiveness of the vaccine decreases each time it is exposed to the wrong conditions. This includes being too hot, too cold, or too bright at any point in the chain. It is impossible to get potency back once it has been lost. Any refrigerated vaccine can lose its effectiveness if it is exposed to bad conditions. Freezing temperatures (0°C or 32°F or below) can damage vaccines permanently, especially those that contain adjuvants (Figure 4).[41,42]

The need for cold chain storage and distribution was another big problem with logistics. This was especially true for mRNA vaccines like Pfizer-BioNTech and Moderna. Many other vaccines are kept in refrigerators at temperatures between 2 and 8°C, but the Pfizer-BioNTech vaccine had to be kept at −70°C, which is very cold.[44] This rule made things very hard for countries that do not have cold chain infrastructure, especially in LMICs. Keeping the vaccine safe at such low temperatures required expensive investments in special freezers and transportation systems that could keep everything very cold along the supply chain.[39] This meant that the Pfizer-BioNTech vaccines took longer to get to places where the infrastructure was not good enough.

The Moderna vaccine had to be stored at −20°C, which made it easier to get than the Pfizer-BioNTech vaccine. However, many LMICs still needed to buy cold storage equipment, which was expensive. But the AstraZeneca vaccine could be kept at 2–8°C, which made it work better with the cold chain systems that are already in place for regular vaccines in LMICs as depicted in Table 5. This logistical advantage made AstraZeneca an easier choice for many countries, but production delays and worries about side effects made it harder to get.

The table shows how different COVID-19 vaccines compare based on the company that makes them, the type of vaccine, the doses that are needed, and how they should be stored. Starting with the Oxford Uni-AstraZeneca vaccine uses a viral vector approach to boost the immune system presented in Figure 5. This method uses genetically modified viruses. This vaccine needs to be given twice, and it can be kept at 2–8°C for up to six months. This means it can be used in places with basic refrigeration systems. Next, the Moderna vaccine builds immunity with RNA technology. The Novavax vaccine, which is made of proteins, should also be kept between 2 and 8°C and should be given every two weeks, just like other vaccines. Last but not least, the Janssen vaccine is unique because it only needs one dose. This makes it easier for people who need it to get it. It works with viruses and can be stored between 2 and 8°C for up to three months.

Figure 6 shows the steps that need to be taken to get a new vaccine to people who need it and store it so that it can stay cold for a long time. To start, the vaccine is sent to the target country in dry ice packs that are made to hold up to 5,000 doses each. This prevents the vaccine from freezing while it's being sent. It will stay good for a long time because the country that gets the vaccine can keep it in a freezer farm at −70°C for up to six months. Third, use dry ice packs that haven't been opened to give the vaccine ten days to get to the places where people get vaccinated. For shipping and logistics purposes, this gives more time, but it doesn't change the quality of the vaccine. After it gets to the center, the vaccine can be kept in a regular fridge for up to five days as long as the temperature stays between 2 and 8°C. This window makes it possible to distribute and give the vaccine before its effectiveness is lost. These problems with logistics made it clear that the world needs to spend more money to improve the systems that are used to make vaccines and keep them cold.[49] This way, vaccines can be given out more quickly and fairly during future pandemics. It would be easier for LMICs to handle the distribution of vaccines that need to be stored in a complicated way if they spent money on strong cold chain systems and regional manufacturing hubs.

Theme 4 Pricing Strategies and Access to Vaccines

The way drug companies set their prices during the

Table 5 | Temperature for COVID-19 Vaccine Storage

Vaccine mfg.	ULT (−70°C)	Freezer (−25 to −15°C)	Fridge (2 to 8°C)	Room Temp. Punctured	Room Temp. Unpunctured
Pfizer 1.8 mL multi-dose 6 doses/vial Diluent mix on-site	**Until exp. date** Dry ice thermal shipper Replenish dry ice Day 1 & every 5 days	2 weeks	31 days	6 hours	6 hours
Moderna 5 mL multi-dose 11 & 15 dose/vial No diluent	N/A	Until exp. date	30 days	12 hours	12 hours
Johnson & Johnson 2.5 mL multi-dose 5 doses/vial No diluent	N/A	**2 years** (mfg. site only)	Until exp. date	6 hours	12 hours
• Vaccines cannot be returned to colder storage temperatures • Discard all doses if not used within expiry time					

Source: TruMed Systems.[45] How to protect COVID-19 vaccines with the correct vaccine storage temperatures COVID-19 immunization guidelines for Pfizer, Moderna, and Johnson & Johnson.

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Company	Type	Doses	Storage
Oxford Uni-AstraZeneca	Viral vector (genetically modified virus)	x2	2 to 8°C (6 months)
Moderna	RNA (part of virus genetic code)	x2	-25 to -15°C (7 months)
Pfizer-BioNTech	RNA	x2	-80 to -60°C (6 months)
Gamaleya (Sputnik V)	Viral vector	x2	-18.5°C (liquid form) 2 to 8°C (dry form)
Sinovac (CoronaVac)	Inactivated virus (weakened virus)	x2	2 to 8°C
Novavax	Protein-based	x2	2 to 8°C
Janssen	Viral vector	x1	2 to 8°C (3 months)

Fig 5 | Comparison of different vaccine storage and temperature requirements

Source: South Africa may swap or sell AstraZeneca's Covid-19 vaccine[46]; Khan SA, Siddiqui NI.[47]

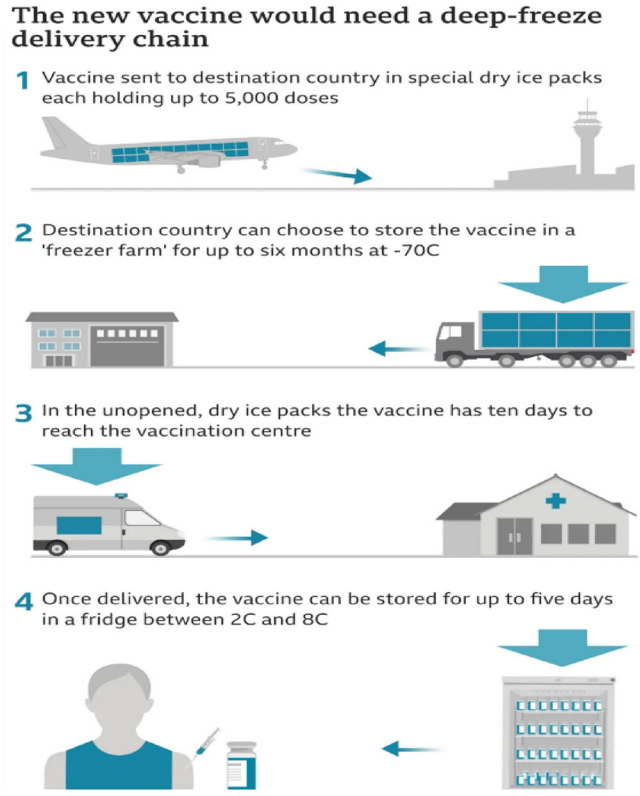

Fig 6 | Deep freeze vaccine delivery chain

Source: Kleinman Z.[48]

COVID-19 pandemic had a huge effect on how easy it was for people around the world to get vaccines. Different companies used different pricing models, which affected how much vaccines cost and where they could be found, especially in low- and middle-income countries.

Vaccine Pricing Models

Different drug companies set the prices of their vaccines in different ways. Some, like AstraZeneca, said they would sell their vaccines for as little as they cost during the pandemic.[50] This promise was specially made to make sure that people in LMICs could get vaccines since high prices could have made it impossible for many individuals to get vaccinated. AstraZeneca's cost-based pricing strategy was better because it put public health ahead of making money. The COVAX initiative also made the vaccine available at fairly low prices, especially in poorer countries.

Figure 7 shows that different companies that make COVID-19 vaccines charge different amounts for their products. It compares the prices per dose of these vaccines. The most expensive vaccine is made by Moderna. Each dose costs between $25 and $37. There is a similar range in price for Sinovac, which is between $13.6 and $29.75. The cost of one dose from Sanofi/GSK is $10.65 to $21, and the cost of one dose from Pfizer/BioNTech is $18.34 to $19. Prices for Oxford-AstraZeneca range from $4 to $8.1 per dose, which is a lot less than other companies.

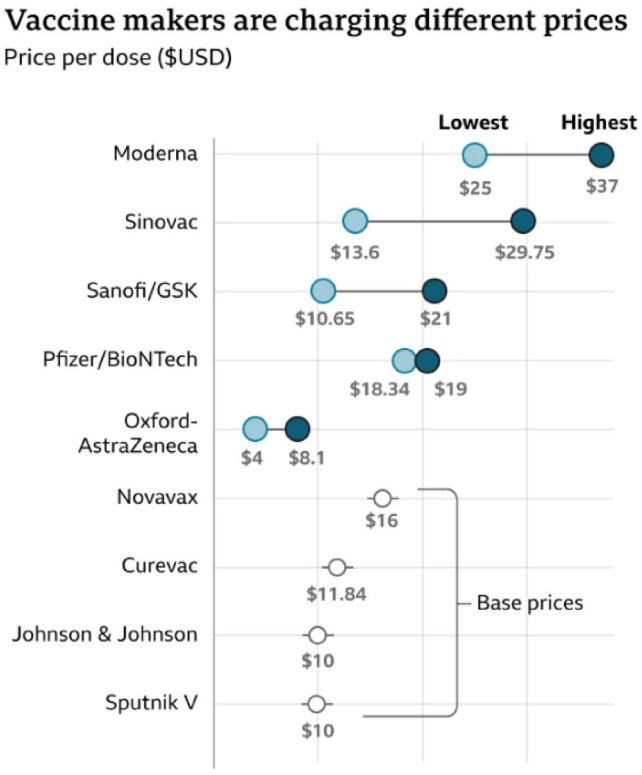

Fig 7 | Price per dose of COVID-19 vaccine $US

Source: Espiner T. [51]; Unicef, US Government Contracts, WHO

Some vaccines, like Novavax, Curevac, Johnson & Johnson, and Sputnik V, have prices that are more narrow and, on average, less expensive. Newovax costs $16, Curevac costs $11.84, and both Johnson & Johnson and Sputnik V cost $10 per dose. Price differences could be caused by differences in how goods are made, how they are distributed, or trade agreements.

Equitable Access

One of the most controversial parts of the global response to the pandemic was how different it was for rich countries and LMICs to get vaccines.[52] HICs, like the US, UK, and EU members, bought most of the vaccine doses early on by making deals with drug companies to buy them in advance. These deals would often lock in supplies before vaccines had even been approved by the government. This way, countries with more money would be the first to get doses when they were made. This behavior, called *"vaccine nationalism,"* made global inequality worse by making LMICs rely on programs like COVAX that send vaccines later than planned.[53]

Figure 8 shows how much the prices of different vaccines are different on the UNICEF/GAVI market compared to the public market in the US. The price of a Hepatitis B (HepB) dose in the UNICEF/GAVI market is only $0.18, while it costs $9.63 in the US public market. If you want to buy the Tetravalent vaccine (DTP3-HepB), each dose costs $0.69 in the UNICEF/GAVI market but $21.50 in the US public market. In the case of the Pentavalent vaccine (DTP3-HepB-Hib), the UNICEF/GAVI market price is $2.49, which is a lot less than the $30.58 price tag in the US public market. The price difference for the Pneumococcal conjugate vaccine is also very big. In the UNICEF/GAVI market, it costs $3.50 per dose, but in the US public market, it costs $95.10 per dose. Another difference is that the Rotavirus vaccine costs $2.50 per dose on the UNICEF/GAVI market, but $88.50 per dose on the US public market. This graph shows the big difference in the prices of vaccines between these two markets. Vaccines are always much cheaper in the UNICEF/GAVI market than in the US public market.

COVAX Initiative

Developed by Gavi, the WHO, and CEPI, the COVAX initiative was created to make sure that everyone could get the COVID-19 vaccines they needed, especially those in low- and middle- income countries.[55] COVAX wanted to spread vaccines fairly among the countries that were taking part by pooling their resources and negotiating lower prices for them. Even so, COVAX had a few problems at the beginning of the pandemic, despite its best efforts. Challenges in getting enough doses to meet global demand, especially from HICs, were caused by vaccine nationalism, production bottlenecks, and problems in the supply chain.

Figure 9 shows how much money different countries have given to COVAX (COVID-19 Vaccines Global Access) to help distribute vaccines around the world, especially to low- and middle-income countries. The

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United States gives the most, with $2 billion. Germany comes in second, with $1 billion. The European Union gave $489 million, and the United Kingdom gave $735 million more. Japan will then give $200 million, and Canada has promised $181 million. Saudi Arabia and Norway have each given $153 million and $141 million, which are both large amounts of money. The U.S. has promised to support COVAX with an even bigger amount: $4 billion. The contributions show how important it is for richer countries to pay for sending vaccines to poorer areas, which helps protect global health and stop pandemics.

Need for Future Pricing Models

The problems with pricing and distributing vaccines during the COVID-19 pandemic show how important it is to have future pricing models for vaccines that make them affordable and easy for everyone to get. For future pandemics, the global response to vaccine prices will need to be better coordinated, making sure that public health comes before making money. Vaccines are priced differently depending on how much a country can pay. Systems like tiered pricing could be expanded to give LMICs stronger guarantees of access. Vaccine nationalism might get in the way of efforts to immunize everyone in the world. To stop this, global health organizations might need to play a bigger role in setting prices and making sure there are enough vaccines for everyone.

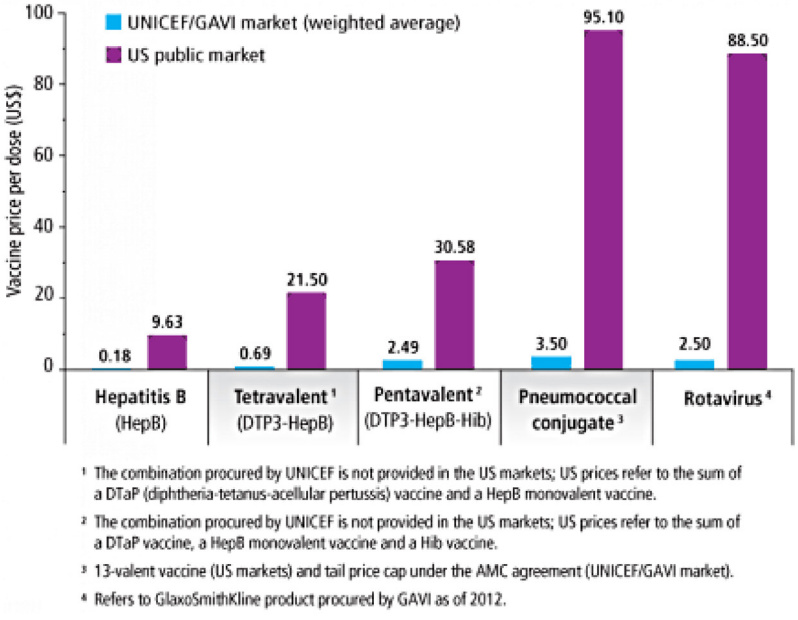

Fig 8 | Comparison of vaccine prices between UNICEF/GAVI market and US public market for various vaccines

Source: UNICEF Supply Division.[54]

Theme 5 Lessons for Future Pandemic Preparedness

During the pandemic, there were problems with money and transportation. These have shown the areas where the world's health infrastructure, governance, and funding are lacking. The main lessons learnt in this section are used to make global governance better, supply chains stronger, and money for research and development of vaccines so that we are better ready for future health crises. One important thing we learnt from the COVID-19 pandemic is that global supply chains need to be more reliable and able to grow as needed. Existing supply chains were put under a lot of stress by the sudden and widespread demand for vaccines, which showed that there were major problems with production and distribution. The inability to quickly scale up manufacturing, particularly in LMICs, slowed down the global response to the pandemic and exacerbated inequities in vaccine access.

End-to-end supply chain and logistics systems that make sure vaccines are stored, distributed, handled, and managed well are essential for immunization programs to work and are explored in detail in Figure 10. These systems are made to keep the temperature very stable throughout the cold chain and use logistics management information systems to make them more reliable and effective. The main goal is to make sure that high-quality vaccines are always available from the manufacturer to service delivery points. Even though routine immunization programs have been successful, there is pressure on national vaccine supply chains. They have to change with the times as new vaccines

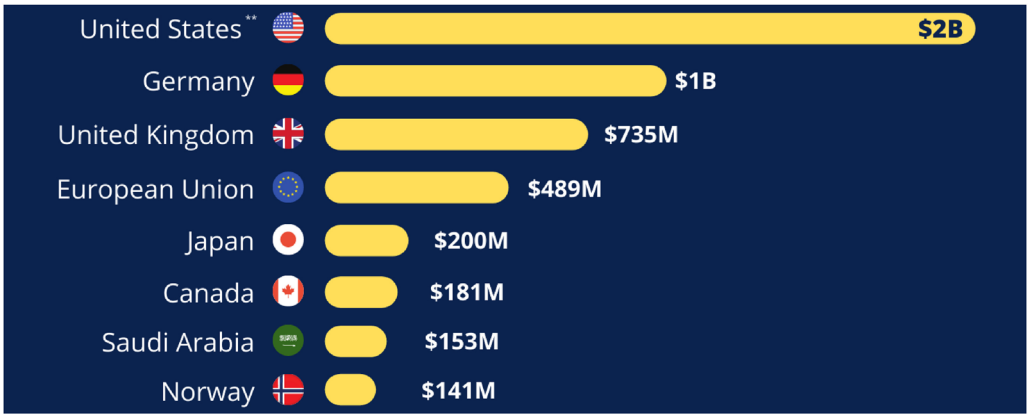

Fig 9 | Monetary donations by country for COVAX

Source: McCarthy N.[56]

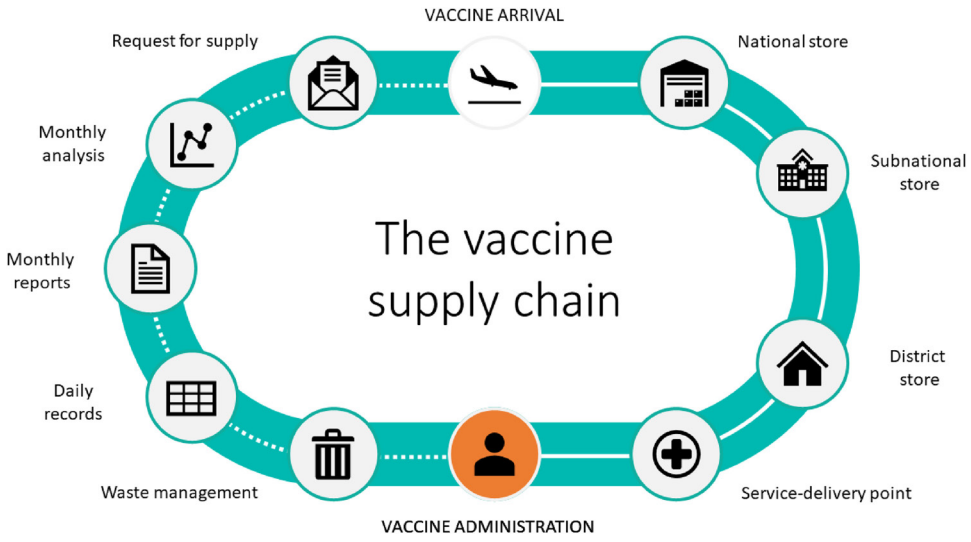

Fig 10 | The vaccine supply chain

Source: World Health Organization. Essential Programme on Immunization[56]

come out, delivery methods change and cold chain equipment gets better.

The Immunization Agenda 2030 (IA2030) is a big plan for vaccines and immunizations around the world from 2021 to 2030. A big part of this is to make supply chains robust so that there are always enough high-quality vaccines in the right amount, at the right time, in the right place, and stored properly.[57,58] IA2030 wants to improve primary healthcare by connecting the supply chains for vaccines and other health supplies.

Figure 10 shows the vaccine supply chain, from the request for supply to the administration of the vaccine to individuals. The chain starts with the request for supply and ends with the administration of the vaccine. As part of the process, daily records, waste management, monthly reports, and analyses are all part of regular monitoring and management steps that make sure the cold chain stays intact and vaccines stay effective. Vaccines are made by one company and used by another. This system helps make sure that they are available and work at every point in the supply chain.

Investing in Regional Manufacturing Hubs

One important step forward is to invest money into regional hubs for making vaccines, especially in LMICs.[59] Many of the vaccines used in the COVID-19 pandemic were made in HICs, which caused delays in getting vaccines to LMICs. By spreading out the production of vaccines and setting up regional hubs, future pandemics can be dealt with more quickly and locally.[60] Investing in these hubs will not only make sure that vaccines can be made closer to the people who need them, but it will also create jobs, help technology spread, and improve the health infrastructure around the world. Having manufacturing capabilities in LMICs will also help these areas build cold chain infrastructure, train skilled workers, and improve their ability to make vaccines in an emergency.

Resilient Cold Chain Systems

A strong cold chain is very important, especially in LMICs, and the pandemic made that clear.[49] Antibodies like those made by Pfizer and BioNTech need to be kept very cold, at −70°C. If there are any more pandemics, it will be very important for LMICs to spend money on better cold chain systems, training, and more advanced refrigeration technologies. Building a strong cold chain system that can handle different types of vaccines will help get vaccines to more people faster during health emergencies.

Innovative Financing Models and Global Vaccine Bonds

Another important thing we learnt from the pandemic is to come up with new ways to pay for vaccine development that do not put too much financial stress on governments or private companies.[8] Traditional ways of funding things, like public sector funding or private investment, were not enough to make sure that everyone had equal access to COVID-19 vaccines. Creating global vaccine bonds is a promising way to pay for vaccines in the future. It would be possible for governments, international groups, and private investors to pool their money through these bonds and put it into a global fund for vaccine research, development, and production.[61] In times of health emergencies, this fund could be used to pay right away for the work needed to make vaccines and get them to people who need them.

Pooled Funding Mechanisms

People from different groups can put money into a common fund that helps with making and researching vaccines.[62] The WHO, Gavi, or the CEPI could be in charge of these systems of global health.

When people pool their money, the risks of losing money are spread out among many people. The system will not have to rely as much on market-based models that put making money ahead of people's

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health. Pooled mechanisms can bring in money from several different sources to keep vaccine development going even in low-return markets.[63] The rules for fair distribution of pooled funds can also make sure that low-income countries get vaccines first and are not left behind by market forces.

PPPs

The COVID-19 vaccine was made faster with the help of PPPs like OWS. However, these partnerships can be used in the future to make things more affordable and fair. For better partnerships in the future, there is a need to make sure that PPPs have clear rules for fair pricing and access for everyone around the world. This will help stop vaccine nationalism and monopolistic practices. Governments, international groups, and private companies must work together to make financing deals that balance making money with meeting public health needs.

Global Governance Reforms and Preventing Vaccine Nationalism

The COVID-19 pandemic also showed that the global governance systems that control the distribution of vaccines are not as strong as they should be. Even though programs like COVAX tried to make things more fair, the international response was disorganized, and richer countries beat out LMICs for early vaccine supplies. During the COVID-19 pandemic, one of the biggest problems was vaccine nationalism, which is when richer countries put their people ahead of fairness for everyone else.[64]

Global Distribution Frameworks

As a possible solution, global distribution frameworks could be set up so that vaccines and other important medical supplies are given out based on clear criteria like the number of diseases, the size of the population, and the vulnerability of the population. By setting up ways to give priority to vulnerable groups, regardless of how wealthy their country is, global health governance can make sure that everyone has equal access during pandemics. Also, we need to think about intellectual property (IP) again in terms of how vaccines are made.[65] IP rules made it hard for LMICs to make vaccines locally during the pandemic, even though the technology was out there. If IP laws are changed to allow temporary exemptions during global health emergencies, vaccines could be made faster and for more people.[66] Such changes would allow LMICs to make generic versions of vaccines without being limited by patent laws. This would make sure that a few companies or countries cannot regulate the supply of vaccines.

Long-Term Implications for Health Economics and Policy

The COVID-19 pandemic has taught us a lot about health policy and economics that will last for a long time. First, it is clear that putting money into health infrastructure, especially in LMICs, is not only the right thing to do but also the smart thing. If there is not a global response to health emergencies, the economy will continue to be severely and widely affected. Not only will strengthening health systems and supply chains save lives, but also lessen the damage that future pandemics do to the economy. Also, the pandemic has shown the importance of having economic policies that are adaptable and quick to respond to crises. To make sure that vaccines and other important supplies get to the people who need them most quickly, governments and international organizations must be ready to act quickly with finances, changes to the way things are run, and help with logistics. The world will be better prepared for the next pandemic if these lessons are used to shape future global health policies. Finally, what we learnt from the COVID-19 pandemic should be used to make future efforts to be ready even better. To make sure that vaccines are made and distributed more quickly, fairly, and effectively during future pandemics, it is important to strengthen global supply chains, look into new ways to finance them, and change the way governments work.

Critical Analysis and Discussion

This theme-based review of the literature shows some important economic strategies that helped the COVID-19 vaccine rollout. It was clear that access was very different around the world, especially between high- and low- and middle-income countries, even with these successes. This part explores closely the economic factors that made it possible for vaccines to be made quickly. It also discusses the issues and unfairness in vaccine distribution.

The COVID-19 Pandemic Exposed Significant Gaps in Global Pandemic Preparedness

The COVID-19 pandemic exposed weakness of global health systems, which is why many countries were not ready to respond effectively. It was caused by a number of interconnected issues, such as not investing enough in public health infrastructure, poor global coordination, economic differences, and weak spots in the supply chain.

Many countries were not ready for a pandemic like COVID-19 because they had not been investing enough in their public health infrastructure for a long time. Even though outbreaks like SARS in 2003, H1N1 in 2009, MERS in 2012, and Ebola from 2014 to 2016 sent warnings, governments often did not put pandemic preparedness at the top of their list of priorities because they had competing economic interests and thought such events were unlikely to happen.

There were limited funds and many requests for resources, so governments often put short-term investments in infrastructure, defense, and economic growth ahead of long-term investments in health security. Public health systems, programs that track diseases, and emergency preparedness plans often did not have enough money. Investing in pandemic preparedness does not show results right away, which makes it less politically appealing than projects with clear results right away.

Policymakers became indolent because there have not been any major pandemics in recent years. People had a false sense of security because they thought that modern medicine could quickly treat infectious diseases. As a result, plans for being ready for a pandemic stayed out of date, and response capabilities were rarely tested through simulations or drills. Health care systems did not have enough hospital beds, intensive care units, medical staff, and basic tools like ventilators and PPE because they were not investing enough. This lack of resources made it harder to handle the sudden rise in COVID-19 cases, which overloaded hospitals and raised death rates.

Responses to the pandemic were disorganized and poorly coordinated because there were no good global governance systems in place. IHR were not being followed properly, and there wasn't a way to make sure that resources were shared fairly during a pandemic. The 2005 revision of the IHR was meant to improve global health security by requiring countries to build up core surveillance and response capabilities. But following IHR is optional, and many countries did not fully take the steps that were needed. There weren't enough ways to hold people accountable to make sure they followed through.

As the world's top health authority, the WHO had problems because it did not have enough finances and was under a lot of political pressure. Member states did not want to give up power or share data in a clear way, which made it harder for the organization to coordinate a global response. In addition, the WHO's advisory role did not include enforcement power, which made it less useful for putting together a unified global strategy. During the pandemic, many countries took nationalistic stances, putting their own needs ahead of working together. Limits on the export of vaccines and medical supplies made it harder for countries to work together. The lack of unity made it harder to share resources, information, and the best ways to do things, which made the global health crisis worse.

The ability of countries to respond to the pandemic was greatly affected by differences in their economies. LMICs had a hard time because they didn't have enough money to put a lot of effort into making vaccines, get supplies through advance purchase agreements, or take other comprehensive public health measures. HICs tend to spend more per person on health care, which leads to better infrastructure, technology, and human resources. LMICs, on the other hand, tend to spend less of their GDP on healthcare, which makes their health systems weaker. This difference made it harder to test, track down, and treat COVID-19 cases properly.

Rich countries got most of the vaccine doses by investing a lot of money and making deals with drug companies ahead of time. Unfortunately, this "vaccine nationalism" made access unfair, with LMICs getting vaccines much later or in smaller amounts than other places. Not being able to get vaccines quickly made the pandemic last longer in these areas. A lot of money is needed to carry out public health measures like lockdowns, mass testing, and social support programs. LMICs had a hard time keeping up long-term interventions without letting them hurt their economies. There weren't enough financial safety nets for vulnerable groups, so containment strategies didn't work as well as they could have. Around the world, supply chains were not strong or flexible enough to handle sudden rises in demand for medical supplies and vaccines. Dependence on a few manufacturing hubs made countries vulnerable to problems, which caused shortages of important goods at crucial times.

Many important medical supplies and medicines are made in just a few countries, like China and India. When these countries had outbreaks or put limits on exports, it messed up supplies around the world. There were severe shortages because many countries did not have the ability to make their own PPE, ventilators, or testing kits. Just-in-time inventory management was often used by healthcare systems and suppliers to cut costs by keeping small amounts of supplies on hand. During the pandemic, when demand went through the roof and supply chains got messed up, this approach didn't work. The lack of reserves made it harder to respond right away.

Transportation restrictions, closed borders, and fewer international flights made it harder for goods to move. Shipping and customs clearance delays made it even harder to get essential supplies on time. LMICs had a lot of problems because their infrastructure and transportation systems weren't very good. Vaccines are made using complicated supply chains that need specific raw materials and parts from many countries. Anything that goes wrong in the chain can stop production. The pandemic showed that supply chains need to be more flexible and resilient to keep things running.

Many countries were not ready for the COVID-19 pandemic because they had not invested enough in public health infrastructure, there was not enough global coordination, there were economic differences, and there were weaknesses in the supply chain. Taking care of these problems is necessary to improve global pandemic preparedness and make sure that future responses will work better.

Synthesis of Findings

COVID-19 vaccines could be made so quickly because of PPPs, which had never been seen before. They sped up research, clinical trials, and manufacturing. Many governments, international groups, and private businesses worked together and shared their resources to make the process of making vaccines go faster. More than $10 billion in government funds were given to help develop, make, and distribute vaccines at unheard-of speeds in the US through OWS.[67] Additionally, worldwide plans like CEPI made it easier for early vaccine research, especially in LMICs.[68] There were concerns about the costs, the agreements for distribution, and the fact that richer countries got early vaccine supplies because they bid more.

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Since mRNA vaccines like Moderna and Pfizer-BioNTech need to be kept at Ultra-cold storage (−70°C for Pfizer-BioNTech), this was needed for these vaccines, which was a big problem for many countries, especially LMICs that did not have the right infrastructure.[69] Many LMICs had to wait longer to get these vaccines because they needed specialized tools, reliable electricity, and advanced transportation systems. Vaccines like AstraZeneca were easier to get to people because they could be kept at normal fridge temperatures. However, their production was often delayed because of problems in the supply chain and limits on exports.[70] These problems with logistics showed the world's uneven health infrastructure.

Vaccine pricing strategies made it even harder for some people to get vaccines around the world. Some, like AstraZeneca, promised to sell their vaccines at cost during the pandemic, while others, like Moderna, raised prices even after getting a lot of money from the government for research and development.[71] Because mRNA vaccines are expensive and drug companies have advance purchase agreements with HICs, these countries were able to get most of the doses early on, leaving low- and middle-income countries with limited access. This behavior, which is sometimes called "vaccine nationalism," led to big differences in the number of people getting vaccinated around the world.[72] The COVAX initiative, which wanted to make sure everyone had equal access to vaccines, had a hard time getting doses early in the pandemic because of competition from countries with more money and problems with production. Many LMICs had to wait longer for vaccines to be sent out, which not only made the pandemic last longer but also made health disparities worse around the world.

These results show that the release of the COVID-19 vaccine was a big step forward for science and the economy, but it was also a big problem for health systems around the world. The growing gap in vaccine access between HICs and LMICs was caused by using pricing models based on the market, not distributing vaccines equally, and the fact that it was hard to make and send more vaccines all over the world.[73] To make things better in the future, we will need more fair ways to pay for things, stricter rules for global governance, and more money to improve health infrastructure. This way, we can avoid repeating the same unfair patterns in how we respond to pandemics.

Gaps in Knowledge

Long-term economic studies of how COVID-19 vaccine pricing plans will impact public health are one of the most important gaps that need to be filled. This is especially true in LMICs. Pricing plans that were used during the pandemic were only meant to work for a short time. To get the medicine to people in HICs quickly, they often let the market decide who could get it. However, these models have not been fully tested to see how they will affect long-term global public health equity, healthcare budgets, and people in LMICs' ability to get vaccines.

Some vaccines, like mRNA vaccines, were very expensive, and some countries had to pay ahead of time to get them. This meant that there were two levels of access. LMICs had to wait longer and pay more to get doses, while rich countries could get them faster. Since some countries had trouble getting vaccines, it is important to think about how pricing strategies for vaccines affected not only the number of people who got vaccinated right away but also death rates, the length of the pandemic in different parts of the world, and the overall economic recovery of those countries.[74] There needs to be more research on how these pricing strategies have changed long-term gaps in immunity, the strength of healthcare systems, and the ability of countries with lower incomes to recover from the pandemic.

Worldwide supply chains had major flaws during the COVID-19 pandemic. These flaws were mostly found in how vaccines are made, stored, and sent out. Many LMICs did not have the right infrastructure, so it took longer for vaccines like Moderna and Pfizer-BioNTech to get there and be used there.[75] There needs to be less centralization and more resilience in the global supply chain so that it can grow quickly in times of emergency.

Also, there needs to be more study on how to use cutting-edge technologies in supply chain management, such as blockchain, AI, and data analytics. With these technologies, it would be possible to keep track of vaccine doses in real time, figure out the best ways to get them to people, and guess when supplies will run out. This would make things run more smoothly and cut down on wait times. On the other hand, these technologies should only be used after a full analysis of their possible pros, cons, and issues.

Theoretical Contributions

The COVID-19 pandemic has shed light on new ways to think about the economics of making and distributing vaccines. Key to these theoretical advances is the understanding that global cooperation is an important part of vaccine economics and that we urgently need inclusive financing models that make sure everyone, no matter their income, has equal access to vaccines.

Global Cooperation is a Key Part of the Economics of Vaccines

In the past, vaccine development was mostly influenced by national interests and market-based incentives. This is because drug companies focus on making money in lucrative markets, and governments put their own citizens' health needs first. The COVID-19 pandemic, on the other hand, showed how important global interdependence is for handling health crises and how everyone needs to work together to stop them. The fast spread of the virus across borders showed how nationalistic views, which are sometimes called "vaccine nationalism," can make the pandemic last longer by not immunizing large parts of the world's population. This allows the virus to keep changing and spreading.

This knowledge has led to the creation of new theories that put global public goods at the center of strategies for dealing with pandemics. Vaccines are now

more often seen as global public goods. This means that all countries benefit from making and giving them out, regardless of who pays for or makes them. This is why the pandemic has changed the conversation from being about nationalism and the market to being about how everyone can benefit and share responsibility. The economic theory of public goods was first used to explain things like keeping the environment safe or making sure the country is safe.[76] Now it is being used to explain how to make vaccines. To stop pandemics, we need finances from everywhere and equal access to new medicines for everyone.[77]

This change has big theoretical effects on how vaccines will be paid for and given out in the future. For example, COVID-19 vaccines were made available equally to both high-income and low-income countries as part of COVAX, one of the first large-scale efforts to put the ideas of global cooperation in vaccine distribution into practice.[78] Even though COVAX had some problems, it was an important step towards making the financial and operational systems for distributing vaccines more fair around the world. In the future, vaccine economics models will need to improve the ways that global resources are distributed so that vaccines and other health interventions reach the people who need them the most, rather than just being given out based on a country's wealth or political power.

Models of Inclusive Financing for Fair Access

Another important theoretical contribution of the pandemic is the realization of the need for financing models that work better for everyone. The problems with the economy that came up during the rollout of the COVID-19 vaccine showed how flawed traditional ways of funding things are that depend on market-based solutions and money from the federal government. These models often make inequality worse because vaccines can be bought early by richer countries through advance purchase agreements.

Because of this, the pandemic has led to the creation of new funding systems that are meant to lower the risk of making vaccines and ensure fair distribution from the start. More theoretical models stress the importance of pooled funding systems that spread financial risk among many parties, such as governments, international organizations, and private investors. In the old way of doing things, countries or companies take on most of the risk when they research, develop, and make vaccines. This method is different. People can get more vaccines made when they pool their money, like in the CEPI program. Vaccine bonds are a new way to get money to fund the research, development, and distribution of vaccines. Long-term funding for global health initiatives could come from this model. New ideas focus on tiered pricing, also known as differential pricing, where vaccines are sold for less in poorer countries and more in richer countries.[79] This method is fair and takes into account the fact that different areas have different economic situations. This makes global health financing more in line with the bigger goals of fair resource distribution and social justice.

Changing the Incentives for Innovation and IP

Along with these changes in funding, the pandemic has also caused people to think about what role IP rights should play in how much vaccines cost. During the COVID-19 crisis, there was a lot of discussion about whether or not IP waivers should be used to allow LMICs to make generic versions of vaccines without being stopped by patents. The traditional way of making vaccines gives the company that comes up with the idea full rights to control production and pricing. This system encourages new ideas, but it can also make it hard to get medical care during global health crises.

Hybrid models that balance the need for innovation incentives with the need for global access are now being explored in theory. Some people have suggested that during pandemics, temporary IP waivers or mandatory licensing should be put in place to allow more companies to make vaccines without impacting the long-term incentives for innovation. These models show that intellectual property rules should be able to change during global emergencies so that more people can get access to important medical innovations.

Implications

The pandemic taught us that we need policies and practices that put global fairness at the top of our list when it comes to making vaccines, getting them to people who need them, and setting prices. Because of these real-world effects, governments, international organizations, and drug companies need to work together to make sure that future pandemics are dealt with in a way that is fair, effective, and open to everyone, no matter their income. Another useful step could be to set up vaccine stocks just for LMICs, which would be managed by international groups like the WHO. These stockpiles would make sure that vaccines are ready to go in case of a pandemic, so there wouldn't be any delays like there were during COVID-19. Regional distribution centers could be set up to quickly store and send vaccines to places that aren't usually served by global supply chains.

From now on, governments, international groups, and drug companies need to work together to create pricing models that make sure all countries can afford them. One practical solution is to use tiered pricing, also known as differential pricing, to change the price of vaccines based on the income level or ability to pay each country. Also, pricing models could include LMICs' advance purchase commitments, which are paid for by international groups like Gavi or the Global Fund, and help them get doses at a price they can afford before they are made.

Future PPPs should make it clear that they support global access and require drug companies to provide vaccines to LMICs at prices that people can afford. PPPs could also be used to build regional manufacturing hubs. In these cases, governments and private companies would invest in the infrastructure needed to make vaccines in LMICs. PPPs can help make sure that everyone in the world has equal access to vaccines

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by making sure that LMICs are involved in the early stages of vaccine research and production.

IP rights became a contentious issue during the COVID-19 pandemic, especially since LMICs had a hard time getting vaccine technologies made in HICs. When pharmaceutical companies get exclusive rights under the old IP system, they often have a monopoly on vaccine production, which means that only people who can afford it can get it. A useful way to make sure that more people can get vaccine technologies is through voluntary IP-sharing programs like the WHO's COVID-19 Technology Access Pool (C-TAP). Drug companies are asked to share their IP and production know-how as part of C-TAP. This will make it easier for LMICs to make vaccines, tests, and treatments.

A lot of the delays in giving vaccines to people were caused by logistics issues, like not having enough cold chain storage, transportation issues, or healthcare workers. Groups and countries around the world need to spend money on strong health systems that can handle the difficult task of giving out vaccines during a pandemic. The COVID-19 pandemic has shown how important it is to have rules that make sure everyone can get vaccines. To make pricing models that work for everyone, pharmaceutical companies, governments, and international groups need to work together. They also need to improve PPPs, change how intellectual property is handled, and spend money to build up global health infrastructure.

Conclusion

This review examines in depth the important economic factors that had an impact on the production and distribution of COVID-19 vaccines. Vaccines are being made at record-breaking speeds, mostly because of large-scale PPPs. This shows how important it is for governments, drug companies, and international groups to work together. PPPs can speed up the production of vaccines by dividing up financial risks and putting money into early-stage R&D. However, problems getting vaccines to people who needed them and unequal access to them made these partnerships less effective.

One of the most significant lessons that was learnt is how important it is to have strong global supply chains that can quickly boost production if there is another one. The issues brought up by the need for a cold chain, production delays, and transportation limits showed how bad the world's health infrastructure is right now, mainly in low- and middle-income countries. It was clear during the COVID-19 pandemic that market-driven pricing strategies didn't work when it came to vaccine access. HICs had better access than LMICs. In the future, strategies for getting vaccines to all countries, especially those with limited funds, must focus on fair pricing models like tiered or differential pricing to make sure that all countries can afford them. Even though the COVAX initiative had good intentions, it had a hard time because of vaccine nationalism and a lack of supplies. In the future, global health policies should pay more attention to making sure that fair access is built into the ways that vaccines are distributed, both financially and operationally.

In the end, the health economics of vaccines must put global equity first to make sure that everyone can benefit from quickly developing vaccines during future pandemics. For the global health system to be more resilient and fair, it needs to have more investments in global health infrastructure, better global governance, and financing models that include everyone. If these economic issues are fixed, the world will be better prepared to handle future public health emergencies. This will stop huge differences in who can get and give out vaccines like there were during the COVID-19 pandemic.

Limitations

This review works at every aspect of economics that affects the creation and distribution of COVID-19 vaccines. However, it is limited by the fact that the pandemic is changing quickly and there was not enough data available at the time of writing. New variants, more vaccines, and changing geopolitical factors are always shaping the global response, which means that vaccine distribution, pricing, and access are always changing. So, this review might not include the newest information or the full extent of the pandemic's financial effects.

Another problem is that it only examines economic factors. These are important for understanding how vaccines are made and distributed, but they are only one part of a bigger, more complicated system that also includes public health, social, and ethical issues. There are some things that this review doesn't go into great detail about when it comes to the bigger public health effects of vaccine rollouts, like the long-term effects on healthcare systems, vaccine hesitancy, and the social determinants of health. In the future, researchers could look into these areas in more depth and look at how economic strategies affect health and social outcomes more completely.

To sum up, this review brings up some important economic issues that need to be thought about when making and distributing vaccines, but it is by no means complete. Because of how quickly the pandemic is changing things, the focus on economic factors, and the use of publicly available data, more research is needed to fully understand the public health, social, and moral aspects of the vaccine rollout. This review wants to lay the groundwork for future studies that can continue to look into the complicated topics of vaccine economics and global health preparedness by pointing out these problems.

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