The Global Economic Recovery From COVID-19 Vaccinations

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The analysis examines the COVID-19 pandemic's economy-wide global effects, assessing the impact on gross domestic product (GDP) through reduced labor supply and productivity in diverse sectors. Utilizing a Computable General Equilibrium model from the Global Trade Analysis Project database, the results highlight the pronounced influence on Light and Heavy manufacturing due to disrupted global supply chains. The vaccination's effectiveness in economic recovery is emphasized, indicating increased labor participation and productivity. The study underscores vaccine disparities among developing nations, affecting global economic resurgence. Overall, it stresses the interconnectedness of COVID-19's impact on national GDP, the manufacturing sectors, and the crucial role of vaccination in driving economic activity and global recovery.

Keywords: computable general equilibrium (CGE) model, COVID-19 pandemic, vaccine inequity

INTRODUCTION

In this paper we studied the economic impact of the COVID-19 pandemic both at the level of the aggregate gross domestic product and the level of industrial sectors in individual countries. We employed the Computable General Equilibrium (CGE) model based on the Global Trade Analysis Project (GTAP) database for this analysis. We first provided a brief overview of the COVID-19 global pandemic to highlight our research question dealt with in this paper.

COVID-19 Impacts on the Global Economy

Since the COVID-19 outbreak began in early 2020, the growth of global GDP declined by approximately 4%, with the highest drops in Argentina (9.9%), Italy (8.9%), India (8.0%), Columbia (6.8%), Thailand (6.1%), and the United States (US) (3.5%), while China and Vietnam experienced a slight increase of 2.3% and 2.91%, respectively (The World Bank Data, 2022). These two economies registered positive economic growth because they took early actions, ranging from border closures and face coverings, massive testing, lockdowns, contact tracing, and compulsory quarantines based on possible exposure rather than symptoms only. These preventative actions minimized both asymptomatic and pre-symptomatic transmission. Millions of jobs and businesses have been impacted by the economic catastrophe that followed the global health crisis. According to the latest report of the International Labor Organization (2021), in comparison to the fourth quarter of 2019, 8.8% of worldwide working hours were lost in 2020, equating to roughly 255 million full-time jobs. Working-hour losses were especially significant in Latin America, the Caribbean, Southern Europe, and Asia. Working-hour losses in 2020 were almost four times higher than in 2009 during the global financial crisis. Consequently, worldwide labor income (before considering income support measures) was expected to have decreased by 8.3%, amounting to $3.7 trillion, or 4.4 percent of global GDP. Workers in the Americas lost the most money (10.3%), while those in Asia and the Pacific lost the least (6.6%).

According to Baldwin and Di Munro (2020), the pandemic has influenced the economies of the Group of Seven (G7) nations, including Canada, France, Germany, Italy, Japan, the United Kingdom (UK), and the US. These countries contributed to about 60% of the world's supply and demand, 65% of the world's production, and 41% of the world's exports. Hence, these economies were affected severely by the pandemic. The rest of the world seemed to follow the same pattern. McKibbin and Fernando (2020) employed Dynamic Stochastic General Equilibrium and CGE modeling to demonstrate seven pandemic scenarios. The first three scenarios were conducted under the assumption that only China was affected by COVID-19 in different severity levels, while the rest focused on the global economies. Their findings showed a decline in GDP development across economies worldwide under all scenarios. It was determined that if the consequences of COVID-19 were similar to the Spanish flu, the global GDP would drop between -4.8 and -6.7 % (McKibbin & Fernando, 2020; McKibbin & Sidorenko, 2006). Additionally, Fernandes (2020) determined that the drop in GDP growth was about 3-5% in a mild scenario depending on the region, with an increase of around 2-2.5% of worldwide GDP development for each additional month of lockdown. It became evident that border closures led by the widespread pandemic affected numerous economies detrimentally. A study by Baldwin and Tomiura (2020) discussed the widespread COVID-19 effect of a demand shock and a supply shock that can significantly decrease aggregate trade streams. Beck (2020) focused on finance and banking risks created by the widespread debate. The impact of the pandemic on financial institutions would depend on three elements: the extent of the pandemic's financial impacts worldwide, the financial and monetary policy reactions to the shocks, and regulatory reactions addressing possible bank fragility. Moreover, Wren-Lewis (2020) indicated that the COVID-19 pandemic decreased economic development, resulting from the declined labor force, higher manufacturing cost, higher temporary inflation, and reduced social consumption.

COVID-19 Vaccine Development

Ever since COVID-19 was initially discovered in December of 2019, vaccines have offered hope for better limiting the effects of the pandemic, which had infected over 629 million people and killed over 6.5 million as of November 2, 2022 (Worldometers, 2022). Several vaccines were distributed across the world. By August 2021, about 28% of the world population had received at least one dose of a COVID-19 vaccine, while 14.6% were fully vaccinated. About 4.14 billion doses have been delivered, with 37.72 million doses presently delivered worldwide (Our World in data, 2021). However, the global equitable access to COVID-19 vaccines has not been addressed. Even in the leading region, North America, only around 15 doses were administered per 100 individuals, while Asia and the Pacific are behind in administering vaccines, with less than two doses administered per 100 individuals, led by India, Indonesia, China, and Singapore (Our World in data, 2021). Furthermore, about 1.1% of individuals have received at least one dose in low-income economies. Vaccination coverage in Indonesia (5.5%), Thailand (4.74%), and Vietnam (0.29%) were behind schedule (Our World in data, 2021). COVAX has increased vaccine attainment for low and low-to-middle income nations, whereas high-income countries have gained enough doses to incorporate 185% of their populations. The COVAX program was expected to provide 2.3 billion vaccine doses in 2021 (Gavi, 2021). The distribution of vaccinations was notably challenging in Asia and the Pacific's economies, with the first challenge involving the vaccine's storage and distribution requirement in ultra-low temperature freezers. In addition, existing immunization systems in developing regions were not prepared for new vaccines, which necessitated new guidance involving allocating massive vaccination programs for adults and the elderly. Next, limited vaccine supply, transportation, logistics infrastructure, adequate medical professionals, and public vaccine hesitancy were the factors that affected the successful vaccination strategy implementation (Park et al., 2021). As a result, effective national vaccination policies and strategies have been challenging in these countries.

Vaccinations developed by Pfizer/BioNTech, Oxford/AstraZeneca, and Moderna have been approved for early or emergency use in about 85–149 countries. In contrast, other approved vaccines were only available in a few nations. Currently, 19 economies in the area had approved at least one of these vaccinations, but the number of national approvals for accessible vaccines is projected to rise. To assure global equitable access to COVID-19 vaccines, COVAX, the vaccine's pillar under the Access to COVID-19 Tools Accelerator, the worldwide collaboration platform developed by the World Health Organization (WHO) and partners to resolve the pandemic, was introduced. Through the COVAX platform, the global economy was shielded from a monthly loss of US$ 375 billion to the world economy. As of November 7, 2022, about 68.2% of the world population has received at least one dose of a COVID-19 vaccine, and 12.91 billion doses have been delivered, with 2.01 million doses presently managed every day worldwide (Our World in Data, 2022). Several nations were making an effort to manufacture their vaccinations. China has manufactured two vaccines approved outside of its original country. India was developing its vaccine, called Covaxin, which is approved for limited emergency usage in the country and might help the country meet its own vaccine need. Vietnam's vaccine, Nanocovax, was presently in Phase ½ trial results. Another vaccine was set to begin Phase 1 testing in February, and the other two vaccines were in the development stage (Thuy and Tuan, 2021).

Vaccine Inequity

Mathieu et al. (2021) stated that approximately 85% of worldwide vaccine doses were administered in high and upper-middle-income countries, with 75% in only ten countries, including the US, the UK, Germany, and France. As of February 21, 2022, most of the estimated 10.57 billion COVID-19 vaccine doses had been administered in a small number of nations. COVID-19 vaccines remain out of reach for much of the world, particularly those in low- and middle-income countries. Only 11.4% of people in low-income nations have received at least one dose (Our World in Data, 2022). While international initiatives like COVAX and other vaccine donation programs aim to advance global vaccine access, it was predicted that some countries and regions will not achieve significant vaccination levels until 2023. Globally, inequity in vaccine access can be explained by rich countries' accumulation of vaccines, resulting in the poorest countries suffering considerable damage from the pandemic due to a lack of vaccine access (Asundi et al., 2021). The economic cost of vaccine inequity has also affected the global economy. If the vulnerable nations did not utilize the vaccine, the world would lose $153 billion in GDP annually (Hafner et al., 2020). The need for global vaccine coverage was becoming more pressing since new transmissible variants can cause increasing cases in almost all countries, even countries with a young population. In the case of Brazil and India, where new variants have appeared, the infection rate was higher in younger generations compared to the initial virus (The Wall Street Journal, 2021), emphasizing the critical need for vaccinations.

This paper endeavors to quantify COVID-19's potential impact on the global economy under four different vaccination scenarios. The objective of the paper is to analyze the (1) economywide impact of the COVID-19 pandemic on the global economy, (2) evaluate the effectiveness of COVID-19 vaccinations towards economic recovery, and (3) address vaccine inequity among developing countries with high COVID-19 infection rates by utilizing a CGE model based on the GTAP database. The model comprehends the economic interactions due to COVID-19 infections and vaccination rates based on inter-regional and inter-industry relationships. This paper outlines the global economic framework and scenarios in section 2, with section 3 presenting the results and discussion of scenarios simulated in the model. Section 4 concludes the research by summarizing the essential findings and limitations.

METHODOLOGY

Modelling Framework

CGE models have been broadly utilized in health policy analyses involving pandemic applications, such as influenza (Smith et al., 2011; Keogh-Brown, 2020). CGE models are adaptable and can be employed to evaluate both direct and indirect health effects on labor supply and consumption impacts on industries. CGE models produce market equilibrium results accounting for interactions of various economic agents such as consumers, producers, and government in the economy. A producer firm maximizes profits in each sector in each region and pays income to the regional household. The firm sells the final products by incorporating the endowments with the intermediates to the private households, government, and trade commodities in an open economy. Consumers budget their income between household consumption and savings. The government collects taxes and subsidies from the firms. Foreign companies collaborate with domestic agents on imports and exports. The model considers equilibrium in all markets simultaneously, taking into account the interdependence of various sectors in the economy. The interaction of the different agents depends on economic theory. CGE models are top-down models that can seize inter-industry and inter-regional linkages through input-output tables and macroeconomic flows.

Laborde et al. (2021) incorporated IFPRI's global CGE model, the MIRAGRODEP model, and the epidemiological models to analyze the impacts of COVID-19 on economic growth, especially in poverty and food insecurity. The POVANA model was also employed to determine the effects of COVID-19 at the household level. In this paper, health impacts, labor mobility limitations, business closures, and logistic factors were converted into MIRAGRODEP's model to determine the impacts on the overall growth of the economy, including employment, trade, and poverty. Their results indicated that the COVID-19 pandemic caused an increase in the number of people in poverty by approximately 150 million individuals, equivalent to about 20% of present poverty levels.

In the current model, we adapted the GTAP database and evaluated the global impacts of COVID-19 and the impact of vaccinations on economic recovery from the incessant pandemic. We developed a framework with an aggregated GTAP database comprising of 22 regions and 14 sectors and assumed perfect competition in all sectors. Health impacts, disruption of labor mobility due to restriction policy, and reduction in labor force participation, served as elements underlying the socioeconomic impacts of COVID-19, were also incorporated into the CGE model to simulate the impacts on the development of the economy, consumption, international trade, and welfare endogenously. Moreover, the health consequences of the pandemic on labor productivity and supply were associated with the results of the epidemiological models. As presented in **Figure 1**, the overall study approach included utilizing epidemiological models based on COVID-19 infections and vaccination rates and translating them into global economic shocks.

For the present analysis, working day loss was assumed to be 15 days (3 weeks absence from work). We assumed further that labor loss is the same as machinery loss. A capital loss was the same as a productivity loss since it was assumed that one laborer used one machine. Manufacturers had minimal capacity to transform the use of capital and labor relations in one year. National governments took numerous critical economic responses regarding fiscal measures, monetary instruments, and foreign exchange operations. One of the critical government policy responses was employing macroeconomic stabilization policies. Primarily, they categorized payroll program support to maintain jobs, cash transfers and distribution of essential goods, reduction in the advance payment of the corporate tax, deferment or installment payments of tax debts without generating late payment interest for businesses, and market liquidity support through numerous market instruments. Besides, we used the actual vaccination rate as the base case to compare with the rate of 75% and 100% complete vaccination.

Since this study aims to determine the impacts of COVID-19 on the global economy during 2020 and 2021, we updated the database from the base year 2014 to 2019 by using historical data on macroeconomic variables, such as growth rates in GDP, population, and labor force across all the regions in the model.

Scenario Development

The impacts of COVID-19 on the global economy have been considered from different perspectives, such as health costs (Keogh-Brown et al., 2020), food security (Laborde et al., 2021), global trade (Vidya and Prabheesh 2020), and unemployment (Bauer and Weber, 2020) The influence of the virus on labor supply and productivity has received little consideration in the literature to date. Therefore, all the shocks were designed for these two factors. The model comprehended the economic interactions of COVID-19 infection and vaccination rates based on inter-regional and inter-industry relationships. We formulated four scenarios as listed below.

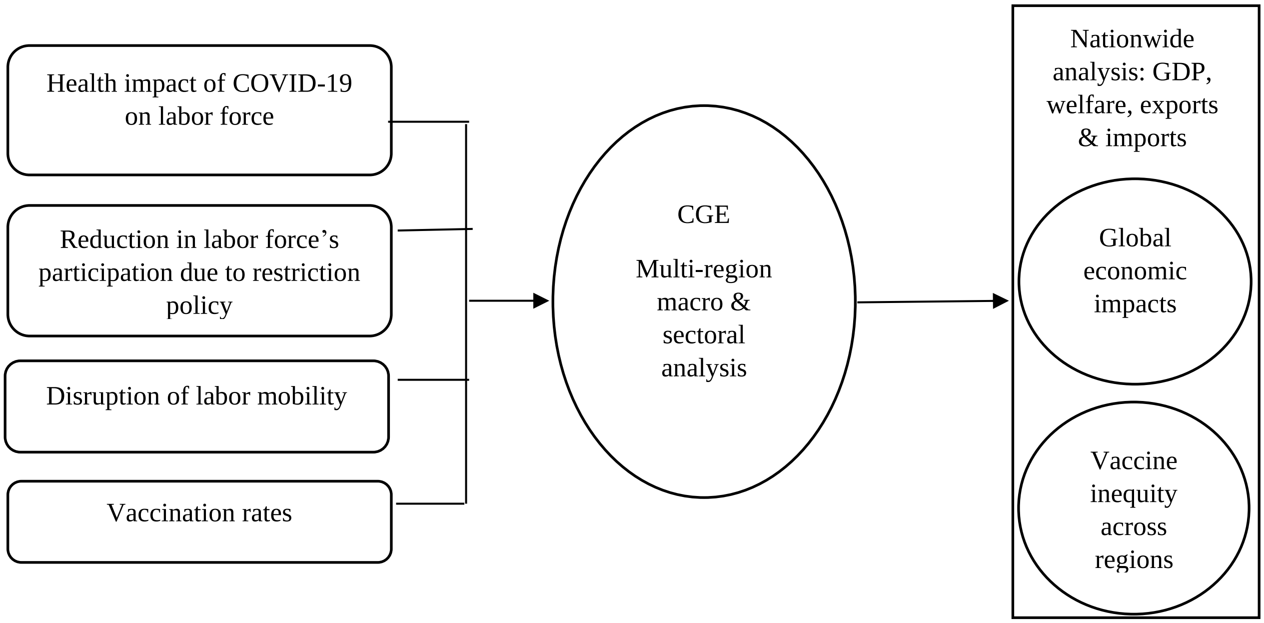
Scenario 1: Global Impact of the COVID-19 Pandemic in 2020

From a labor economics perspective, the scenario considered the decline in labor supply and productivity as a result of the high infection and mortality rates caused by COVID-19. It recognized that the loss of human resources due to mortality directly affects the available labor force. This concept aligned with the standard labor supply theory, which emphasized factors such as population size, workforce participation rates, and changes in labor availability. Labor supply loss was determined by the total workforce before COVID-19 minus the total human resources lost due to mortality. We modeled the supply-side shock from a 0.2% to a 2% reduction in labor productivity, depending on the mortality rate, for each country and region. In terms of epidemiology, the scenario acknowledged the relationship between infection and mortality rates and their impact on labor productivity. It assumed that higher mortality rates are associated with reduced labor productivity, which implies a connection between health outcomes and economic productivity. This assumption aligned with the broader understanding that health status can influence individual and population-level productivity. In other words, the first scenario relied on real-world observations and likely utilizes modeling techniques to estimate the relationship between COVID-19-related factors and labor supply and productivity.

Scenario 2: Global Economy Impact of Actual Vaccination Rate in 2021

The scenario drew upon the concept of labor market dynamics and the relationship between vaccination rates and working hours. This scenario was based on the actual vaccination rates in each country and region until December 2021. According to an International Labor Organization report on COVID-19 and the World of Work (2020), a comparable full-time job was included in the worldwide labor market for every 14 completely vaccinated persons. In the equitable distribution of vaccines worldwide, working hours would increment by 2.0 and 1.2 percentage points in low income and low-to middle income earners, respectively. We calculated an increase in working hours followed by productivity gain after vaccination which relied on empirical observations and logical reasoning based on the relationship between vaccination rates, labor market dynamics, and equitable distribution of vaccines. Furthermore, it also aligned with concepts from labor economics and the broader understanding of the relationship between vaccination, economic recovery, and job creation.

FIGURE 1
IMPLEMENTATION OF THE COVID-19 & VACCINATION SCENARIOS



Source: Adapted from Laborde et al. (2021)

Scenario 3: Increase in Vaccination Rates in 2021 on the Global Economy

Various vaccination rates reflected labor participation and productivity at different levels. The scenario mentioned the proposal to evaluate the economic impacts of vaccination rates of 75% and 100% of the vaccinated population. This indicated an interest in understanding how different levels of vaccination coverage can affect the economy. From the real vaccination rate in scenario 2, we enumerated differences in rates where labor supply and productivity gained as an additional 1% in the vaccination rate. This suggested that the focus was on quantifying the changes in labor supply and productivity resulting from an increase in vaccination rates.

Scenario 4: Varied Vaccination Rates Across Developing (Up to 30%) and Developed (Up to 75%) Countries

Nations with high vaccination rates were deliberately reopening, whereas countries with low vaccination rates-maintained lockdown policies. This was especially tough for laborers whose prolonged lockdowns equated to job losses. Vaccine coverage inequalities had direct and indirect consequences for developing and developed countries. In this scenario, we included up to 30% vaccination rates in developing countries with higher COVID-19 infection rates when compared to a 75% vaccination rate in developed economies while delineating the vaccination inequity on their economic recovery plan. This differentiation acknowledged the varying challenges and dynamics faced by different countries and regions based on their vaccination progress and infection rates. This scenario was consistent with the recognition that the rates of vaccination, reopening strategies, lockdown policies, and the distribution of vaccines can significantly affect labor markets and economic recovery.

RESULTS & DISCUSSION

The pandemic economically damaged almost all countries across the world except for China. All modeled regions showed a dramatic drop in their GDP, the output of commodities, imports/exports, and welfare. The model predicted a contraction in GDP in the US and the European Union (EU) by $488 billion (3%) and $423 billion (2.4%), respectively. It is interesting to note that China was barely affected by the pandemic, and the model predicted a marginal growth of $11.45 billion (0.08%) in overall GDP. Labor supply and productivity reductions drove most of the impacts on global GDP. The projected increase in the volume of exports was most prominent for the US, totaling about $142 billion, whereas the EU suffered a significant loss of $104.3 billion in exports. Other countries in the model underwent a uniform pattern of mild contraction in the volume of imports in 2021. For imports, the US and the EU underwent a notable negative decrease of $145.9 billion (6.5%) and $150 billion (2.25%). Reducing consumer demand in the US and EU would have stalled imports from developing countries, who have also experienced trade disruption and production downsizing. Furthermore, the US imported more products than it exported. Therefore, the recession was more significant than its trading partners. In other words, the pandemic's recessionary phase has been more significant on US imports than exports.

The countries' massive monetary and fiscal stimulus measures were relaxed to support the economy. Light and heavy manufacturing were the most severely affected sectors due to the disruption of the supply chain. Canada, Argentina, and Peru experienced a severe drop in both heavy and light manufacturing, with numbers consisting of 4.6%, 4.55%, and 5% in heavy manufacturing. In light manufacturing specifically, the decreases were 3.9%, 3.7%, and 4%. The disruption was primarily the result of the nation's lockdown measures, which lead to production halts, restrictions on people/product movement, and border closures. Therefore, the flow of raw materials and finished goods has temporarily stopped. Another disruption was the labor shortage due to these countries' high infection and mortality rates. In these instances, a 14-day home quarantine was instituted and was assumed to consume at least two weeks' absence from work for infected people. Social distancing lowered labor participation in factories as well. It is noteworthy that the vaccine was not available until December 2020.

Our model predicted that an increase in vaccination rates was associated with a substantial increase in GDP growth rates, as shown in **Table 1**. The level of disparity in GDP and vaccination rate has been observed in studied regions. The total direct economic growth from the current vaccine coverage status, which was captured by changes in real GDP, is ranked from $0.43 billion in Vietnam to $284.5 billion in the US. It must be noted that 75% of the population was vaccinated; therefore, the model indicated an increase in GDP in the economies studied. For instance, the US and the EU gained the most real GDP increase with $502.46 billion (3.08%) and $434.5 billion (2.48%). If 100% of the population became vaccinated, these numbers would increase further. It is worth noting that there was a rise in the change in GDP in all model countries. Significantly, the US and the EU observed an increase of $546.8 billion (3.36%) and $472.8 billion (2.69%). The decomposition of these issues demonstrated that consumer spending was a principal component of these economies, accounting for almost 60% to 70% of the country's GDP. The increase in demand levels and the rise in both consumption and purchasing have occurred as the economy has recovered since travel restrictions were lifted. These activities were satisfied by companies who had sold out their entire inventory. Moreover, vaccinations have advanced work mobility since the labor force is back at work physically or they are currently working from home. This led to an overall growth in the size and productivity of the workforce. Our results aligned with two studies completed by Dongarwar et al. (2021) and Basak et al. (2022), which concluded that a relationship exists between GDP and vaccination rates. While certain developed countries made solid economic recoveries, developing countries encountered slow economic growth due to vaccine inequity. For example, Peru's GDP growth was estimated at $1.03 billion (0.48%). Peru was one of the countries most affected by the inequalities, whereas the US counterpart sat at $103.56 billion (0.64%). These findings highlighted a global equity gap in access to COVID-19 vaccinations, especially for low-income countries. The vaccination protected populations in developed countries, while developing countries struggled with the pandemic since vaccination rates were lower. It can be concluded that the COVID-19 vaccine distribution was unbalanced. As a result, wealthy countries requested the vaccine at an alarming rate, while other countries had difficulty accessing it.

It is worth mentioning that developing countries dealt with several challenges when it came to developing and implementing an effective vaccination program. A vaccination program's successful implementation called for transportation, storage, adequate medical human resources, safety monitoring, and strong public awareness (Park et al., 2021). On top of that, there was a limitation to the financial stability of the country; meaning developing countries were hardly able to access the COVID-19 vaccine. Therefore, people more vulnerable to COVID-19 in these countries should have been supported to fairly join the COVID-19 vaccine rollout. In addition, if the ineffective vaccine allocation strategies had continued, these gaps may have widened, and many developing nations would not have reached the global target of vaccinating at least 40% of their population.

The COVAX facility was introduced to fairly distribute the COVID-19 vaccines to all countries, regardless of income level. Nevertheless, this program fell behind schedule. For instance, Vietnam, Colombia, Peru, and Mexico were on the COVAX list. However, the supply of COVAX was just enough for about 9 percent of Vietnam's population, which was 8.7 million doses until August 2021 (UNICEF Vietnam, 2022) and around 2 percent of Colombia's population, which was 1 million doses until April 2021 (Aljazeera, 2022). These figures were far behind the needed amount to attain community immunity. In addition, wealthy countries have still suffered high infection rates and are stockpiled more than they needed for booster vaccines, making it challenging to achieve vaccine equity in the short term.

In addition, the balance of trade under different rates of vaccinations on the path of global economic recovery is presented in **Table 2**. Almost all countries in the model were expected to undergo a trade surplus, apart from the US, the EU, the UK, and Vietnam. In this instance, the vaccination rates varied from 75% to 100%. The US, the EU, the UK, and Vietnam were predicted to suffer a trade deficit when the vaccination rates varied from 75% to 100%. This may be due to business closures in almost all industries, less productivity in some other industries, and the decline in the overall GDP. The businesses in these countries tried to meet product demand by completely selling their inventories. However, they were not increasing their overall output production of goods at the rate they had to in order to address the supply chain problem. Hence, they imported more goods to meet that demand. These countries' volume of imports relied mainly on heavy and light manufacturing, energy mining, and agricultural sectors. In the scenario where 100% of the population was vaccinated, the US imported its heavy manufacturing products mostly from China ($22.4 billion – 9.87%), the EU ($14.3 billion – 6%), and Japan ($11.6 billion – 10.4%). This sector consisted of motor vehicles and parts, machinery, and equipment. The US also imported light manufacturing goods mainly from China ($7 billion – 8.2%), India ($1 billion – 8.93%), and the EU ($6 billion – 4.19%). Light manufacturing comprised of textiles (leather, wood, rubber, and plastic products), chemicals, and basic pharmaceutical products. Over the past few years, China and India have been one of the biggest sources of basic pharmaceutical products (active pharmaceutical ingredients) imported to the US since the Food and Drug Administration approved drugs can now be offered at lower prices when compared to theirs which are produced in the US. Furthermore, Canada was the main source of energy mining (coal, oil, gas) sectors imported to the US with $2.5 billion (4%), followed by Brazil ($0.8 billion – 12.2%) and Colombia ($0.7 billion – 9.5%). Apart from the US, China also played an important role in exporting their products to Vietnam, with an amount of $0.2 billion (0.66%) in heavy manufacturing, $0.3 billion (1.7%) in light manufacturing, and $0.12 billion (6.7%) in agricultural sectors.

TABLE 1
CHANGES IN GDP UNDER DIFFERENT VACCINATION RATES

			Change in Real GDP ($2021 billion & % Change)							
Countries/ Regions	**Real GDP 2019**	**COVID-19 2019-2020**	**Actual vaccination rate**		**75% vaccination rate**		**100% vaccination rate**		**Vaccine inequity**	
	$ billion	% change	$ billion	% Change	$ billion	% Change	$ billion	% Change	$ billion	% Change
USA	21,430	-3.40%	284.5	1.75%	502.46	3.08%	546.79	3.36%	103.56	0.64%
Japan	5,150	-4.60%	2.89	0.07%	6.57	0.16%	6.96	0.17%	25.31	0.63%
India	2,870	-7.30%	8.09	0.28%	16.1	0.56%	17.6	0.61%	13.65	0.47%
Vietnam	260	2.90%	0.43	0.18%	0.77	0.32%	0.85	0.36%	1.08	0.45%
Canada	1,740	-5.20%	11.95	0.53%	20.9	0.92%	22.78	1.00%	14.66	0.65%
Mexico	1,270	-8.30%	23.32	1.61%	25.07	1.73%	29.14	2.01%	7.28	0.50%
Argentina	450	-9.90%	12.16	1.94%	18.74	2.99%	20.69	3.30%	3.94	0.63%
Brazil	1,880	-4.10%	53.02	1.83%	74.56	2.58%	83.88	2.90%	18.59	0.64%
Colombia	320	-6.80%	7.28	1.58%	10.73	2.33%	11.99	2.61%	2.33	0.51%
Peru	230	-11.10%	7.64	3.55%	7.86	3.65%	9.17	4.26%	1.03	0.48%
EU	15,690	-6%	249.08	1.42%	434.5	2.48%	472.83	2.69%	110.54	0.63%
Germany	3,890	-4.60%	1.08	0.80%	1.93	1.42%	2.1	1.56%	0.84	0.62%
UK	2,880	-9.40%	0.36	1.52%	0.72	3.07%	1.42	3.30%	0.15	0.64%
Russia	1,690	-3%	25.85	1.23%	35.78	1.71%	40.38	1.93%	12.77	0.61%

Source: World Bank (2020) and Authors' model simulation

TABLE 2
CHANGES IN IMPORTS AND EXPORTS UNDER DIFFERENT VACCINATION RATES

	Imports						Exports					
Countries/ Regions	Actual vaccination rate		75% vaccination rate		100% vaccination rate		Actual vaccination rate		75% vaccination rate		100% vaccination rate	
	$ billion	% Change	$ billion	% Change	$ billion	% Change	$ billion	% Change	$ billion	% Change	$ billion	% Change
US	57.15	2.53	145.34	6.43	151.37	6.69	-17.27	-0.74	-103.10	-4.42	-97.14	-4.17
Japan	-1.48	-0.18	-3.27	-0.39	-2.87	-0.35	13.90	1.39	40.93	4.08	42.12	4.20
India	-0.48	-0.09	-1.95	-0.37	-1.37	-0.26	5.90	1.87	17.71	5.61	18.39	5.83
Vietnam	0.52	0.26	1.47	0.73	1.60	0.79	0.58	0.36	1.33	0.84	1.33	0.84
Canada	2.9	0.45	1.20	0.19	2.69	0.42	2.86	1.16	8.83	3.56	8.51	3.43
Mexico	5.3	1.33	3.87	0.97	4.97	1.25	4.78	1.68	7.60	2.67	8.18	2.88
Argentina	0.9	1.15	1.27	1.61	1.54	1.96	1.10	2.12	2.20	4.24	2.34	4.50
Brazil	4.14	1.08	3.90	1.02	5.45	1.43	3.09	2.48	7.50	6.00	7.98	6.39
Colombia	0.94	1.54	1.37	2.25	1.69	2.78	0.80	2.31	1.78	5.14	1.88	5.41
Peru	1.04	2.14	0.95	1.95	1.15	2.35	1.09	2.82	1.52	3.91	1.72	4.42
EU	89	1.33	160.33	2.40	175.53	2.63	89.20	1.12	120.26	1.51	137.78	1.73
Germany	0.91	0.89	1.64	1.60	1.82	1.78	1.16	1.02	2.28	1.99	2.46	2.15
UK	0.2	1.34	0.41	2.77	0.45	3.03	0.13	1.39	0.24	2.52	0.26	2.73
Russia	3.7	0.93	6.85	1.73	8.44	2.13	4.90	1.00	9.02	1.84	9.75	1.99
China	-7.44	-0.35	-17.72	-0.83	-15.22	-0.71	28.70	1.53	98.39	5.22	100.04	5.31

Source: Authors' model simulation

Table 3 summarizes the regional welfare changes that resulted from our simulations. Before the vaccine was developed, almost all countries were affected by welfare loss to different degrees, such as the US ($504 billion), the EU ($408 billion), and Brazil ($63 billion). Thanks to the invention of the vaccine, countries in the model experienced a huge increase in welfare because the labor force was able to get back to work. Total welfare rates impacted a collection of components that consisted of changes in allocative efficiency as well as resources to move to more or less efficient uses and changes in terms of trade. As a country's export prices changed relative to their import prices, changes in returns to owners of capital, development in endowments, technology, and efficiency improvements were seen. When discussing actual vaccination rates, most countries still demonstrated significant contraction in welfare. This can be explained by the fact that welfare rates decreased significantly during the pandemic. As a result, an increase in vaccination rates led to a growth in welfare; however, they could not compensate for the loss in welfare in the past. For example, the US experienced the most considerable decrease in welfare with an amount of $237.6 billion (1.5%), followed by the EU ($187.2 billion – 1.5%), China ($30.5 billion – 2.3%), and Brazil ($13.8 billion – 1.2%). The endowment components (land, labor, capital) dominated in the US ($101.5 billion), the EU ($67.2 billion), Brazil ($23.8 billion), Mexico ($11 billion), and the rest of the world (ROW) ($508 billion), respectively. It can be explained that when the labor force became vaccinated, they were able to get back to work; hence, the number of laborers increased. In the scenario where 100% of the population was vaccinated, changes in welfare were large in the US ($280 billion - 1.05%) and the EU ($224.9 billion - 1.02%). These countries have had high infection rates; therefore, when people were vaccinated, welfare was affected positively. In comparison with the ROW, the vaccination rates were still not as high. However, if all people had gotten fully vaccinated, the rate of welfare would change and could have reached roughly 1.92%, which was equivalent to $1,290 billion.

TABLE 3
WELFARE CHANGE IN DIFFERENT VACCINATION RATES ($ BILLION)

Countries/ Regions	Impact of COVID-19	Actual vaccination rates		100% of population get vaccinated	
	$ Billion	% Change	$ Billion	% Change	$ Billion
US	-504.5	-1.5	-237.6	1.05	280.8
India	-9.6	-1.4	-4.3	1.12	5.9
Vietnam	-1.2	-1.5	-0.6	2.01	1.1
Canada	-14	-1.2	-2.7	0.83	9.5
Mexico	-19.5	-0.9	2.1	0.28	6.0
Argentina	-16.9	-1.3	-5.4	0.75	8.6
Brazil	-63.9	-1.2	-13.8	0.6	30.1
Colombia	-9.8	-1.3	-2.7	0.72	5.2
EU	-408.3	-1.5	-187.2	1.02	224.9
Russia	-36.3	-1.2	-8.5	0.76	21.0

Source: Authors' model simulation

Our simulations indicated the sectoral activity results in **Table 4**, highlighting the considerable expansion in sector-level production changes. Most industries registered a noticeable boost in output due to the rise in vaccination rates across all the modeled global regions. Some industries like education, human health, hospitality, and recreation registered a noticeable boost in output due to the rise in vaccination rates across certain modeled regions such as the US, Vietnam, Brazil, and the EU. The fear of COVID-19 drove significant instability and chaotic conditions in numerous businesses. The hospitality industry experienced distinctly falling revenue and was an economic sector among those most rigorously influenced by the pandemic. Globally, the number of guests fell by more than 50%. The Norwegian tourism organization NHO Reiseliv (2020) published a weekly survey containing data that stated 41% of their tourism businesses had registered cancellations, involving hotels, gastronomy, car rental services, tourism-related activities, and destination marketing organizations at the beginning of March 2020. After that, 65% of tourism businesses acknowledged difficulties paying their invoices. The survey concluded that tourism was significantly impacted compared to other economic sectors in Norway. McKinsey and Company (2020) have reported that jobs in the accommodation and food services sector occupy over 20% of all vulnerable positions, and approximately 13.4 million jobs can be affected in the restaurant industry, including 3.6 million workers in food preparation and serving, 2.6 million restaurants, and 1.3 million restaurant chefs in the USA. The labor force in the accommodation and food services sectors has the lowest annual earnings and the lowest levels of education, which alluded to the idea that the pandemic enlarged the considerable disparities in income. However, the widespread use of the COVID-19 vaccine was expected to hasten hospitality recovery. For instance, in the US, hospitality enjoyed growth of $36 billion (3.5%) and $38 billion (3.8%), while recreation saw an increase of $53 billion (3.35%) and $57 billion (3.61%) under 75% and 100% population vaccinated scenarios, respectively. In the EU, when the vaccination rate reached 75% and 100%, hospitality would gain a noticeable boost in output of $22 billion (2.82%) and $24 billion (3.05%), respectively, while recreation was $15 billion (2.82%) and $17 billion (3.05%), respectively. Their output mainly served domestic purposes. This can be explained by the fact that if the population becomes fully vaccinated, the spread of the pandemic would decrease, and governments could relax their pandemic-related travel restrictions and lockdowns for international and domestic tourism by executing vaccine passports. Moreover, recreational businesses, hotels, and restaurants resumed normal operations since labor was optimal. This provided a critical opportunity to promote travel (European Center for Disease Prevention and Control, 2022). The vaccine can enhance sectoral demand and supply conditions in vaccinated nations. As a result, the economic costs of COVID-19, from negative sectoral demand and supply, cease globally as soon as the vaccine was available.

TABLE 4
SECTORAL PRODUCTION IMPACTS OF 75% AND 100% VACCINATION RATE

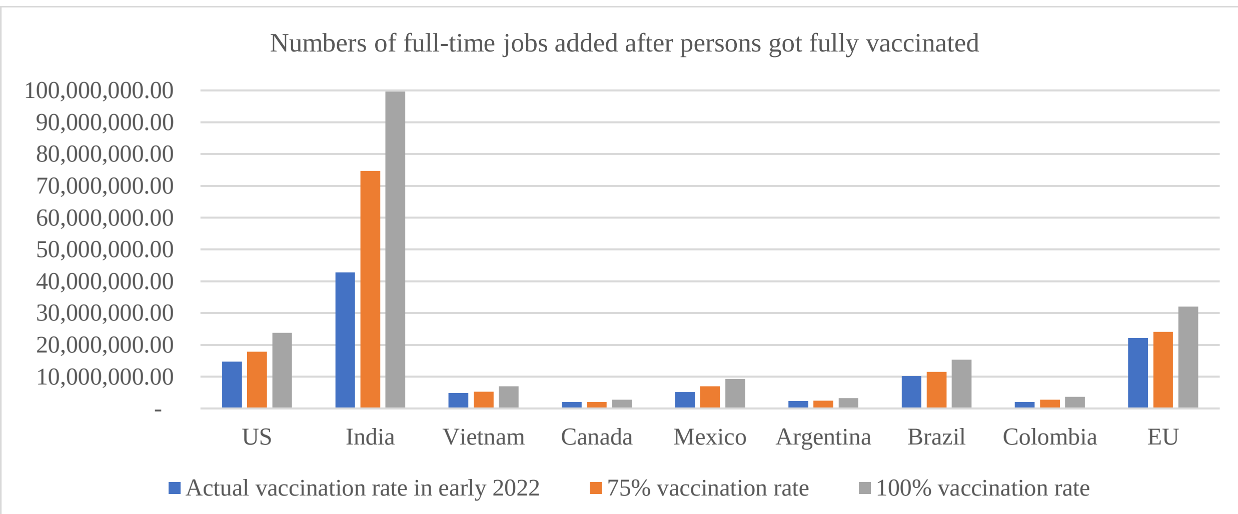
Sectoral output (% change)	US		Japan		India		Vietnam		Canada		Mexico		Brazil		EU	
	75%*	100%*	75%*	100%*	75%*	100%*	75%*	100%*	75%*	100%*	75%*	100%*	75%*	100%*	75%*	100%*
Agriculture	0.49	0.64	0.73	0.8	0.5	0.54	0.23	0.27	3.23	3.42	1.31	1.51	2.97	3.28	1.56	1.77
Light Manufacturing	0.76	1.03	0.99	1.0	1.69	1.7	0.42	0.38	2.35	2.03	2.32	2.56	3.1	3.37	1.93	2.13
Heavy Manufacturing	0.6	0.89	2.2	2.3	1.44	1.47	0.28	0.26	2.76	2.37	2.99	3.22	2.7	2.97	1.71	1.94
Hospitality	3.52	3.8	0.07	0.1	0.57	0.62	0.83	0.9	1.06	1.16	2.13	2.46	2.98	3.34	2.82	3.05
Human Health	2.11	2.39	0.01	0.0	0.46	0.53	0.8	0.89	0.62	0.72	1.41	1.72	1.87	2.21	1.91	2.14
Education	3.41	3.7	0.56	0.6	0.77	0.84	0.81	0.87	1.15	1.25	2.12	2.44	3.05	3.39	2.95	3.18
Recreation	3.35	3.61	0.24	0.25	1.53	1.6	0.69	0.74	1.19	1.25	2.1	2.42	3.03	3.39	2.82	3.05

*Vaccination rate
Source: Authors' model simulation

Walmsley et al. (2021) demonstrated that the loss in demand for the US's labor was about 22.4% during the three-month closure, equivalent to 35.2 million workers due to mandatory closures and other indirect consequences. By the end of 2021, approximately 37% of labor in the US was affected (Worldometer, 2022). Thanks to the invention of the COVID-19 vaccine, laborers were returning to work either in-person or remote work. The results of an increase in employment under varied vaccination rates scenarios are displayed in **Figure 2**. According to the International Labor Organization Monitor: COVID-19 and the world of work, sixth edition report (2020), the employment market was projected to gain one full-time job for every 14 completely immunized individuals. As illustrated, with 75% and 100% vaccination rates, India was one of the countries which generated the most jobs, which were from 75 to 99 million jobs.

Similarly, the US and EU accounted for around 18 and 24 million jobs, respectively. Since those countries were affected severely by the pandemic, the vaccine can considerably boost their economies' recovery. Overall, an increase in vaccination rates corresponded with an increase in the number of full-time positions attained in the job market.

FIGURE 2
NUMBERS OF FULL-TIME JOBS ADDED IN VARIED VACCINATION RATE SCENARIOS



Source: Authors' model simulation

CONCLUSIONS

The findings of this study have significant implications for better pandemic preparedness in the future, particularly in relation to mitigating the economic impacts of a pandemic like COVID-19. The research employed a CGE model to simulate various COVID-19 scenarios, with a particular focus on vaccine rollout. By examining the effects of increased labor supply and productivity resulting from widespread vaccine coverage, the study highlighted the crucial role of vaccination in economic recovery.

The study demonstrated the profound impact of the unprecedented COVID-19 pandemic on global economies, with reduced labor supply and productivity emerging as major contributors to the decline in GDP across multiple economies. Particularly affected were the manufacturing sectors due to disruptions in the global supply chain, as well as the travel and tourism sectors. These findings underscored the interconnectedness of international trade and the need for its revitalization to drive global economic recovery.

Furthermore, the research revealed the strong correlation between COVID-19 vaccination rates and economic recovery, specifically in terms of GDP growth driven by increased consumption. It emphasized that higher vaccination rates enable individuals to resume their activities with greater confidence, leading to significant gains in labor productivity across all industries. However, the study also highlighted the slower pace of overall global economic recovery due to relatively lower vaccination rates in certain developing countries. This highlighted the importance of vaccine equity and the imperative for collaboration between developed and developing nations to effectively control future pandemics.

The study's unique contribution lay in its comprehensive approach, combining epidemiological models, vaccination rates, and a global CGE model to quantify the global impact of the pandemic on various economic indicators such as GDP, welfare, imports, exports, and production outputs. This contribution differed from that of Laborde et al. (2021), who employed MIRAGRODEP and the epidemiological models to discuss the impact of the pandemic on poverty and food security. In addition, it provided valuable insights into the consequences of inequitable vaccine distribution, setting it apart from other studies that primarily focused on poverty, food security, or the epidemiological aspects of the pandemic. By shedding light on the economic ramifications of unequal access to vaccines, this research emphasized the need for fair and inclusive distribution strategies in future pandemic response plans, compared to other studies on the same topic, namely Asundi et al. (2021), Altindis (2022), and Basak et al. (2022).

In conclusion, the findings of this study underscored the vital role of vaccination in mitigating the economic consequences of pandemics. They highlighted the interconnectedness of global economies and the significance of international collaboration, equitable vaccine distribution, and robust pandemic preparedness measures to better safeguard against future outbreaks. By integrating epidemiological and economic models, this research contributed to a more comprehensive understanding of the complex dynamics between public health and economic resilience, ultimately guiding policymakers in developing effective strategies to address future pandemics.

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APPENDIX 1: REGIONAL GROUPING IN THE GTAP MODEL

No	Code	Description
1	USA	United States of America
2	Japan	Japan
3	India	India
4	Korea	Republic of Korea
5	Indonesia	Indonesia
6	Singapore	Singapore
7	Vietnam	Vietnam
8	China	China; Hong Kong
9	Canada	Canada
10	Mexico	Mexico
11	Argentina	Argentina
12	Brazil	Brazil
13	Colombia	Colombia
14	Peru	Peru
15	European Union	Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, and Sweden.
16	France	France
17	Germany	Germany
18	Italy	Italy
19	UK	The United Kingdom of Great Britain and Northern Ireland
20	Russia	Russia
21	UAE	The United Arab Emirates
22	ROW (Rest of the World)	Australia; New Zealand; Rest of Oceania; Mongolia; Taiwan; Rest of East Asia; Runei Darussalm; Cambodias; Lao People's Democratic Republic; Malaysia; Philippines; Thailand; Rest of Southeast Asia; Bangladesh; Nepal; Pakistan; Sri Lanka; Rest of South Asia; Rest of North America; Argentina; Bolivia; Brazil; Chile; Ecuador; Paraguay; Uruguay; Venezuela; Rest of South America; Costa Rica; Guatemala; Honduras; Nicaragua; Panama; EI Salvador; Rest of Central America; Dominican Republic; Jamaica; Puerto Rico; Trinidad and Tobago; Caribbean; Bulgaria; Croatia; Romania; Switzerland; Norway; Rest of EFTA; Albania; Belarus; Russian Federation; Ukraine; Rest of

		Eastern Europe; Rest of Europe; Kazakhstan; Kyrgyzstan; Tajikistan; Rest of Former Soviet Union; Amenia; Azerbaijan; Georgia; Bahrain; Islamic Republic of Iran; Israel; Jordan; Kuwait; Oman; Qatar; Saudi Arabia; Turkey; Rest of Western Asia; Egypt; Morocco; Tunisia; Rest of North Africa; Benin; Burkina Faso; Cameroon; Cole d'Ivoire; Ghana; Guinea; Nigeria; Senegal; Togo; Rest of Western Africa; Central Africa; South Centra Africa; Ethiopia; Kenya; Madagascar; Malawi; Mauritius; Mozambique; Rwanda; Tanzania; Uganda; Zambia; Zimbabwe; Rest of Eastern Africa; Botswana; Namibia; South Africa; Rest of South African Customs; Rest of the World

APPENDIX 2: SECTORAL GROUPING IN THE GTAP MODEL

No	Code	Description
1	Agro	Paddy rice; Wheat; Cereal grains nec; Vegetables, fruit, nuts Oil seeds; Sugar cane, sugar beet; Plant-based fibers; Crops nec; Bovine cattle, sheep and goats; Animal products nec; Raw milk; Wool, silk-worm cocoons; Fishing; Forestry
2	EnergyMining	Coal; Oil; Gas
3	Procfood	Minerals nec; Bovine meat products; Meat products nec; Vegetable oils and fats; Dairy products; Processed rice; Sugar; Food products nec; Beverages and tobacco products
4	LightManuf	Textiles; Wearing apparel; Leather products; Wood products; Paper products, publishing; Chemical products; Basic pharmaceutical products; Rubber and plastic products; Mineral products nec
5	Petroleum	Petroleum, coal products
6	HeavyManuf	Ferrous metals; Metals nec; Metal products; Computer, electronic and optic; Electrical equipment; Machinery and equipment nec; Motor vehicles and parts; Transport equipment nec, Manufactures nec
7	Utilities	Electricity; Gas manufacture, distribution; Water
8	OtherServices	Construction; Trade; Warehousing and support activities; Communication; Financial services nec; Insurance; Real estate activities; Business services nec; Public Administration and defe; Dwellings
9	Hospitality	Accommodation, Food and service
10	OtherTranspt	Transport nec; Water transport
11	AirTranspt	Air transport
12	Recreation	Recreational and other service
13	Education	Education
14	HumanHealth	Human health and social work a.