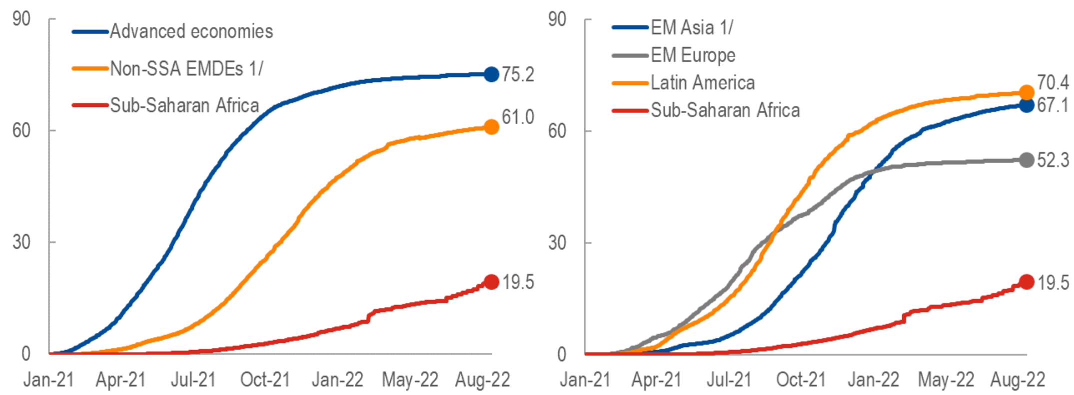
1. Introduction

Fighting the COVID-19 pandemic required vaccinations; however, ending it requires equal distribution of vaccinations. More than two years after the discovery of the virus, the world continues to grapple with new variants of the virus and renewed surge in cases. Scientific consensus on the contagious and mutable nature of the coronavirus means that no one is safe until everyone is safe, and the only way to stop the pandemic is to stamp out the virus simultaneously worldwide.

Figure 1. Unequal Distribution of Vaccinations Around the World
(Population-weighted average)



Source: Our World in Data.
Notes: As of August 18, 2022; non-SSA EMDEs = non-sub-Saharan African emerging markets and developing economies; EM = emerging markets 1/ excludes China due to lack of reporting before August 2021.

The progress in vaccinations, however, varies greatly across countries. Low- and middle-income countries so far have much lower vaccination rates than advanced countries. Sub-Saharan Africa (SSA) stands out as the least vaccinated region in the world, even in comparison to low- and middle-income countries in other regions such as emerging Europe and Latin America (Figure 1). As of mid-August 2022, only 19.5 percent of the region's population was fully vaccinated, compared to 61 percent in other emerging markets and developing economies (excluding China) and 75 percent in advanced economies.[2]

The unequal landscape of vaccinations around the world has raised concerns among policymakers about equitable distribution. Among the multitude of factors that contribute to disparities in COVID-19 vaccination coverage, two elements have garnered much attention: access to vaccines and vaccination hesitancy. Vaccine supplier and recipient countries have disagreed on which is the dominant factor behind low vaccination rates in developing countries. At the heart of the

[2] In Our World in Data, China started reporting the vaccination numbers with a delay, in August 2021, when over 50 percent of its population had been already fully vaccinated. Hence, China is excluded in the figures to smooth the series.

debate is the question: who is more responsible for the unequal landscape of vaccinations and is the distribution equitable? The answer has implications for policymakers worldwide.

This paper examines the drivers of COVID-19 vaccination rates across countries during 2021–22 and quantifies the equitable distribution of vaccinations. We use the principle of equality of opportunity to measure vaccination inequality, whereby each country has equal access to vaccines and differences in vaccination rates should only stem from factors that are under a country's control. Vaccination equality under the principle of equality of opportunity, therefore, does not imply equal vaccination rates. Instead, it means that vaccination rates should not depend on circumstances beyond country's control. Distribution of vaccinations will be considered inequitable if countries have unequal opportunities to vaccinate.

This paper finds that access to vaccines, as measured by the delivery of vaccine doses, was the dominant reason behind vaccine inequality, accounting for more than 70 percent of the vaccine inequality. Other socio-economic factors—per capita income, urbanization, spending on health, demographic structure, and human development index—play a relatively minor role.

Ensuring timely production and delivery of vaccine doses therefore plays a crucial role in reducing the unequitable distribution of vaccinations. Improving domestic distribution networks and promoting proper vaccination campaigns are also key to drive up vaccination rates.

The remainder of the paper proceeds as follows. Section 2 reviews the related literature and provides overview of vaccine logistics. Section 3 discusses the methodological approach and describes the data. Section 4 presents the results, and Section 5 concludes.

2. Background

2.1. Related Literature

At the onset of COVID-19, researchers identified potential challenges to global vaccination and frameworks to guide the vaccination efforts. The challenges focused on the factors impacting the development, dissemination, and deployment of vaccines, as categorized by Forman (2021) and Wouters et al (2021). While data were initially limited on deal making between governments and vaccine manufacturers, studies drew on the experience during the H1N1 outbreak to warn of vaccine market dominance by rich countries—a phenomenon later observed during the COVID-19 pandemic (Fidler 2010, So and Woo 2020, Bollyky et al 2020, Deb et al 2021, Agarwal and Reed 2022).

Frameworks for more equitable distribution of vaccinations centered on the economic, health, and ethical rationale. Leaving low and middle-income countries (LMICs) behind in vaccination efforts

would lead to large economic losses (Economist 2021, Deb et al 2021). The health benefits have been outlined many times. To minimize harm, ethical frameworks posited the prioritization of vulnerable groups first (Persad 2020, Emanuel et al 2020).

Countries started deploying vaccines at the end of 2020, which allowed the direct observation of the factors affecting campaign efforts. With procurement and financing difficulties for many LMICs well-documented at this point (Peacocke 2021), new areas of focus such as logistics and vaccine hesitancy began to emerge. Countries with underdeveloped health infrastructure faced difficulties in managing the stringent cold-chain requirements of mRNA vaccines (Cherif and Hakobyan 2021). Common findings regarding hesitancy included concerns of safety, side-effects of the virus, perceptions of the severity of the virus and demographic factors (men more likely to get the vaccine) (Lazarus 2021, Sallam 2021, Dabla-Norris et al 2021). Despite the perception that demand for vaccines in LMICs was low, and thereby justifying them receiving fewer vaccines, the hesitancy data showed LMICs tending to have at least as high, if not higher rates of acceptance (Solís Arce et al 2021).

Relatively few studies have empirically analyzed the drivers of COVID-19 vaccination rates globally. Our work relates closest to that of Goel and Nelson (2021), Deb et al (2021), and Agarwal and Reed (2022). Looking at subnational data in the United States, Goel and Nelson (2021) analyzed socio-economic factors influencing vaccination rates across states. The authors separate vaccine dissemination (vaccines administered) and efficiency of delivery (vaccines administered as a percent of received). They find that economic prosperity and higher rural population lead to more vaccines administered. Furthermore, the results show that vaccine efficiency improves with more nursing homes per capita, more COVID-19 deaths, and more health workers. Deb et al (2021) provide an empirical assessment of the determinants of vaccine rollouts in a cross-country setting. They find early procurement, domestic production of vaccines, and health infrastructure to be important for the pace of vaccination. While the results from our study underscore the actual delivery of vaccines as the most critical component driving vaccination rates, we share in the finding that infrastructure matters as well. Agarwal and Reed (2022) dig further into what drives deliveries of vaccines. They find 60-75 percent of the delay in vaccine deliveries to low- and middle-income countries is attributable to their signing purchase agreements later than high-income countries, which placed them further behind in the delivery line. Their study is intrinsically linked to this paper, given the latter's focus on vaccine deliveries as a key determinant of the observed vaccination rates.

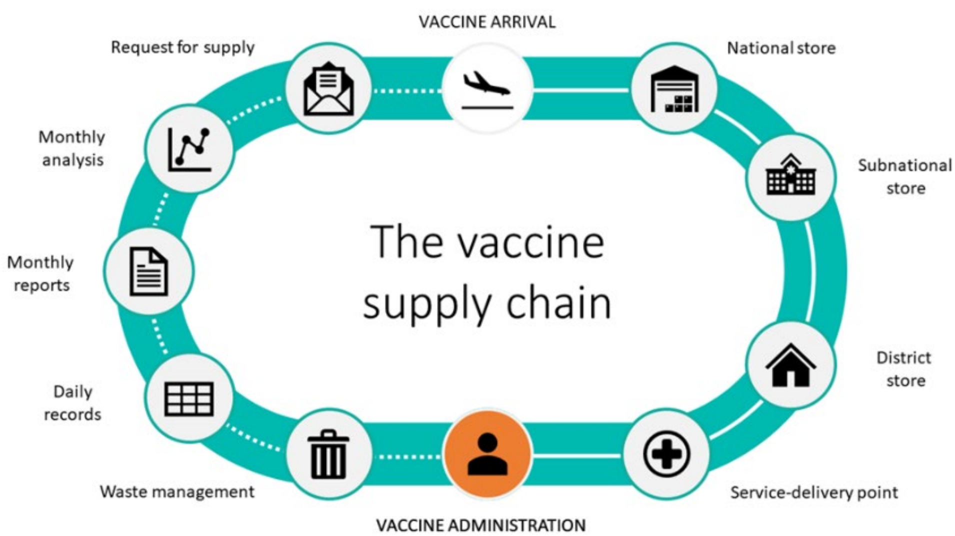
This paper contributes to the literature on the drivers of COVID-19 vaccination rates and equitable distribution of vaccinations. In particular, it builds on the relatively few studies of COVID-19 vaccination determinants in a cross-country setting by (i) examining the key drivers of the vaccination rates, (ii) constructing a measure of equitable distribution of vaccinations—grounded in the theory of equality of access (Roemer and Trannoy 2016); and (iii) quantifying the

contribution of different factors to the gap between the actual distribution and the equitable distribution. Our decomposition of the factors contributing to vaccination inequality draws on Shorrocks (2013) for the Shapely value decomposition method using Gini index as a measure of overall inequality, supplemented by other inequality indices, such as MN-measure (Magdalou and Nock 2011; Hufe et al 2021). By drawing on the experience of sub-Saharan Africa explicitly, we shed light on the inequalities LMICs could face when caught up in a global pandemic.

2.2. Vaccine Logistics

Successful vaccination programs are built upon an efficient end-to-end supply chain and logistics systems that ensure the uninterrupted availability of vaccines from manufacturing to delivery. Analyzing COVID-19 vaccination inequality and its drivers requires untangling the many intricate stages of the vaccination process (Figure 2). First, the recipient country finds vaccine suppliers and signs purchase agreements with them. In case of some countries, particularly low- and middle-income, there could be an intermediary such as the COVID-19 Vaccine Global Access (COVAX) Facility, a global risk-sharing mechanism, that facilitates the procurements and distribution of vaccines to the recipient countries. Next, the suppliers produce the vaccines and schedule a delivery—usually with a delay due to production disruptions (e.g., industrial accidents and unexpected shortages in the supply chains such as packaging inputs) and export restrictions by major vaccine producers.[3]

Figure 2. Vaccine Logistics



Source: The World Health Organization Essential Programme on Immunization.

[3] In early 2021, export controls on key ingredients into vaccine production, such as syringes and vials, hampered global vaccine manufacturing by forcing suppliers to prioritize domestic contracts (for example, in the US and UK). In April 2021, following an unprecedented surge in COVID-19 cases, India halted the exports of AstraZeneca vaccines produced by the Serum Institute of India, the main supplier of vaccines to COVAX.

Ahead of receiving the vaccine doses, countries need to develop distribution schemes, ready health infrastructure, train health workers, and generate demand. Countries form vaccination plans to prioritize who receives vaccines first (e.g., elderly, immunocompromised, or front-line workers) based on demographic composition and the evolution of the virus. Some COVID-19 vaccines require cold-chain storage capability, further complicating the in-country distribution of vaccines in countries with weak health systems. For countries with hard-to-reach populations (e.g., rural-remote areas, islands, conflict zones, refugee camps), officials devise plans to address these challenges through creative means such as drones or flying doctors to remote areas. Doses move from centralized arrival points to local health centers and into the arms of citizens. As vaccination campaigns proceed, governments need to build trust, address misinformation, and provide incentives to maintain the momentum for reaching vaccination goals.

3. Equitable Access to Vaccines

3.1. Delivery and Vaccination

In the vaccine logistics describe above, there are two key milestones: delivery of vaccine doses and vaccine administration. While the delivery of vaccine doses is predicated mostly on international circumstances, administering delivered vaccines depends primarily on domestic factors. Indeed, beyond signing the advance purchase agreements early, recipient countries have little control over the *de facto* delivery of vaccine doses, the responsibility for which almost entirely lies with the suppliers.[4] For example, in April 2021, following an unprecedented surge in COVID-19 cases, India imposed a ban on the exports of AstraZeneca vaccines produced by the Serum Institute of India, the main supplier of vaccines to COVAX facility at that time which was the major source of vaccines for low and middle-income countries.[5] Similarly, several disruptions hampered global vaccine manufacturing in early months of vaccinations, for example, industrial accidents, unexpected shortages in the supply chains such as packaging inputs, and export controls on key ingredients and inputs into vaccine production such as syringes and vials which forced suppliers to prioritize domestic contracts (e.g., in the US and UK). These events derailed vaccination campaigns and further delayed the vaccinations in low and middle-income countries, in addition to delays in signing advance purchase agreements.

The delivery of vaccine doses is therefore a moment when countries' influence on vaccination outcomes changes: the recipient countries typically have little influence on the timing of vaccine

[4] Agarwal and Reed (2022) find that 60-75 percent of the delay in vaccine deliveries to low- and middle-income countries is attributable to their signing purchase agreements later than high-income countries.

[5] The ban was rescinded in October 2021.

arrival, but once the vaccines are delivered, it is incumbent upon the recipient countries to get them administered.

Throughout the paper, we focus on vaccination rates at the country level as the main variable of interest. Ultimately, ending the COVID-19 pandemic requires high vaccination rates across all countries. It is therefore important to understand the factors that affect vaccination rates.

Two measures of vaccination rates can be used to gauge the level of vaccination across countries. The first measures the cumulative administered doses and corresponds directly to the cumulative doses delivered. The second measure captures the percent of population with at least one dose of vaccine. While the latter measure may be more meaningful from a health protection perspective, the information on the type of vaccines administered is not publicly available for a large number of countries, and therefore this measure does not correspond well to the type of vaccines delivered. We use the first measure in this paper and robustness checks using the second measure are included in the Annex III.

Specifically, we denote the cumulative administered doses per hundred people by v_i for country i. Let d_i denote country i's cumulative delivered doses per hundred people, and a_i its average administering rate at a certain date. We can write the following accounting identity for the vaccinate rate v_i:

$$v_i = d_i \cdot a_i.$$

In logarithm, we have

$$\log v_i = \log d_i + \log a_i. \quad (1)$$

While d_i is usually beyond country's control, a_i is a key variable that measures the country's efforts to vaccinate its population, as well as vaccine hesitancy among population. It is clear though that a high administering rate a_i is neither a sufficient nor a necessary condition for a high vaccination rate v_i, because of the presence of delivery d_i in equation (1).

To analyze the drivers of vaccination rates, we initially abstract from administering rates and focus on a general functional form where vaccination rates depend on delivered doses as well as a range of fundamental factors:

$$\log v_i = f(\log d_i, X_i), \quad (2)$$

where X_i is a vector of economic, health, and demographic factors. We then analyze the administering rates separately:

$$\log a_i = g(X_i). \quad (3)$$

Note that in addition to the channel through a_i in equation (3), X_i might affect v_i through d_i as well.

3.2. Equitable Access

In this paper, we resort to the principle of equality of opportunity to measure equitable distribution of vaccinations.[6] Under this principle, the distribution of vaccinations is equitable if vaccination rates do not depend on circumstances beyond country's control.

A country's borders are a natural choice to distinguish between circumstances within and beyond country's control. Delivery of vaccine doses, v_i, originates outside of country's borders, whereas vaccine administering rates, a_i, depend on factors within country's borders. As such, the decomposition in equation (1) naturally distinguishes the two stages of the vaccination process that are beyond and within a recipient country's control.

For simplicity and tractability, and as discussed in Section 3.1, this paper assumes that vaccine delivery is the only factor beyond the recipient countries' control. Under this assumption, equitable distribution of vaccinations implies that v_i should vary proportionally to a_i. In practice, whether a factor is within a country's control is less clear-cut for many reasons. For example, securing vaccine deals and signing purchase agreements may directly affect vaccine delivery (Agarwal and Reed 2022). Therefore, the delivery of vaccine doses may not be entirely beyond country's control. By the same token, domestic factors, such as demographic structure, infrastructure, and income status, are circumstances inherited from previous governments and hard to change in a short time span. Hence, the assumption that domestic factors are within country's control may also be too strong.

Consider countries $\mathcal{N} = \{1,2,,\cdots,N\}$, with the observed vaccination rates $v = (v_1, v_2, \cdots, v_N)$. Let $v^* = (v_1^*, v_2^*, \cdots, v_N^*)$ be the vaccination rates under the equitable distribution of vaccinations. When vaccination rates are equal across countries, $v_1 = v_2 \cdots = v_N = \mu$. Such perfectly egalitarian distribution of vaccination rates, however, might not be an equitable outcome, as country-specific factors, such as vaccine hesitancy, affect the eventual vaccination rates. Imagine a hypothetical scenario, where country A and country B have the same population, but 50 percent of country A's population remains vaccine-averse, whereas the entire population of country B is vaccine-receptive. It is not equitable to send country A twice as many vaccines as country B just to reach the same vaccination rates. Instead, the equitable distribution of vaccinations proposed here follows the principle of equality of opportunity, whereby the distribution does not depend on

[6] Equality of opportunity can be described as seeking to offset differences in outcomes attributable to luck, but not those differences in outcomes for which individuals are responsible (Roemer and Trannoy 2016).

factors beyond a country's control. Specifically, $v^* = (v_1^*, v_2^*, \cdots, v_N^*)$ does not depend on the delivery of vaccine doses.

To compute the equitable distribution of vaccinations, a linear regression model of vaccinations is employed:

$$\log v_i = \beta X_i^R + \gamma X_i^{NR} + \epsilon_i, \tag{4}$$

where X_i^R is a vector of domestic factors within country i's control, in logarithm, including COVID-19 cases and deaths, GDP per capita, infrastructure quality, urbanization, government spending on health, demographic structure, and human development index. X_i^{NR} is a vector of factors beyond country i's immediate control, also in logarithm. In this paper, X_i^{NR} contains only one variable, namely, the delivery of contracted or agreed vaccine doses. ϵ_i is assumed to be independent of X_i^R and X_i^{NR}, and captures unobservables such as vaccine hesitancy.

The equitable distribution of vaccinations follows:

$$\log v_i^* = \beta X_i^R + C, \tag{5}$$

where C is a constant such that $\sum v_i = \sum v_i^*$. Intuitively, $v^* = (v_1^*, v_2^*, \cdots, v_N^*)$ is a redistribution of vaccination rates based on factors within countries' immediate control, holding the total administered doses fixed.

3.3. Inequality decomposition

Having established a measure of equitable distribution of vaccinations, we quantify the contribution of different factors to the gap between the actual distribution and the equitable distribution. To this end, we follow Shorrocks (2013) and conduct a Shapely value decomposition, which can decompose any inequality index in an additive manner. We choose the Gini index as a measure of overall inequality.

The share of vaccine delivery in the overall vaccination inequality is the ratio of its contribution to the overall Gini index. Since the delivery of vaccine doses is the only factor assumed to be beyond country's control, its contribution to the overall Gini index represents the inequitable distribution of global vaccinations.

Annex I provides further details on the Shapley value decomposition. We show that the results of the Shapley value decomposition are robust to using other inequality indices, such as a MN-measure (Magdalou and Nock 2011), which is a divergence measure of inequality widely used in the literature. The MN-measure attaches higher weights to shortfalls from the equitable distribution (Hufe et al 2021) and encompasses mean log deviation—a prevalent measure in the inequality literature (e.g., Ravallion 2019)—as a special case when the equitable distribution is the

equal distribution. Since most inequality indices require non-negative inputs, a log transformation is sometimes needed.

3.4. Data

This paper uses data compiled from various sources as follows.

Vaccine delivery: Data on monthly deliveries of vaccine doses by vaccine type, covering the period from November 2020 to March 2022, are obtained from Airfinity.

Vaccination rates, COVID-19 cases and deaths: Data on daily vaccination rates, cases and deaths come from Our World in Data. For many countries in the sample, vaccination rates are reported infrequently, hence, we use the highest vaccination rate for each month in each country as the cumulative vaccination rate.

Vaccination uptake: Data on average vaccination coverage come from Airfinity (sourced from the World Health Organization and UNICEF), and include vaccination against polio, diphtheria tetanus toxoid and pertussis, hepatitis B, measles, and Hib disease.

Median travel time: Nelson et al (2019) provide estimates of travel time from any location on the Earth's surface to the nearest settlement at the pixel level with a 30 arc-second resolution. We use the travel time to nearest city that has a population between 0.5 and 1 million to compute the median of all pixel values of a country. This measure is used as a proxy for the difficulty in getting vaccines to remote populations within a country.

Economic, health, and demographic indicators: We obtain GDP per capita, quality of overall infrastructure, urban share of population, spending on health, the share of 15+ population aged 15-64, the share of population aged 65 and above from the World Bank World Development Indicators. Human development index is obtained from the United Nations Development Programme.

Table 1 shows the summary statistics for the full sample, and the sample of sub-Saharan African countries, non-SSA EMDEs, and advanced economies. Not surprisingly, vaccination rates and cumulative delivery (per 100 people) are lowest in SSA and highest in advanced economies. Among the three country groups, SSA countries have the lowest number of COVID-19 cases and deaths (per million people), lowest levels of GDP per capita, health expenditure per capita, infrastructure quality score, human development index and lowest share of urban population. SSA also boasts the smallest share of 15+ population at 61 percent, compared to 84 percent in advanced economies and 75 percent in other EMDEs.

Table 1. Summary Statistics, as of 2022Q1

	Full sample		Sub-Saharan Africa		Non-SSA EMDEs		Advanced	
	Mean	St Dev	Mean	St Dev	Mean	St Dev	Mean	St Dev
Vaccination rate (doses per 100 people)	115	77	46	54	141	62	212	25
Cumulative delivery (doses per 100 people)	148	88	68	62	177	68	264	39
Cumulative cases (per million people)	93,062	110,286	35,566	80,304	104,548	98,778	254,152	136,507
Cumulative deaths (per million people)	972	1209	347	528	1,327	1,369	850	889
GDP per capita (current 2021 USD)	15,899	20,022	4,832	6,098	18,136	20,574	46,694	18,899
Median travel time (hours)	12	24	14	18	8.0	6.4	32	79
Infrastructure quality score	3.7	1.0	3.2	0.8	3.8	0.9	5.7	0.8
Urban share of population (percent)	58	23	42	16	64	21	87	9
Health expenditure per capita (current 2021 USD)	1,097	1,357	328	425	1,060	788	4,799	1,755
Share of population age 15-64	64	6.9	57	5.2	67	5.1	66	6
Share of population age 65+	7.2	5.1	3.6	2.0	7.8	4.2	18	5
Human development index	0.7	0.1	0.6	0.1	0.7	0.1	0.9	0.0
Number of observations	95		31		57		7	

Sources: Airfinity, Our World in Data, Nelson et al. (2019), World Bank World Development Indicators, UNDP, and IMF staff calculations.

4. Results

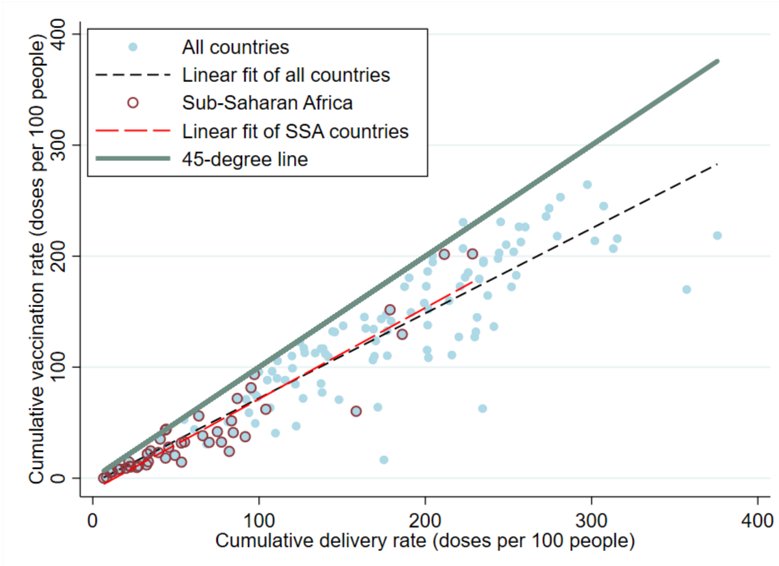
4.1. Factors affecting vaccination rates

Vaccine delivery and vaccination rates: are SSA countries different?

As shown in Figure 1, sub-Saharan Africa is one of the least vaccinated regions in the world. To examine the extent to which the delivery of vaccine doses affects vaccination rates and whether sub-Saharan Africa is different in this regard, Figure 3 plots cumulative vaccination rates against cumulative delivery rates by country at the end of 2022Q1, with red circles identifying sub-Saharan African countries. Cumulative delivery and vaccination rates are highly correlated, with most observations close to 45-degree line. On average, about 76 percent of delivered vaccine doses have been administered worldwide. Delivery rates in SSA countries are markedly lower than those in the rest of the world, reflecting the difficulty for SSA countries to obtain vaccines.

However, there is no strong evidence that SSA countries have been administering the delivered vaccine doses at a different speed from the rest of the world, particularly since the second half of 2021. To show this formally, we regress the vaccination rates on cumulative delivery rates, controlling for SSA countries and including an interaction term between SSA dummy and cumulative delivery rates. We repeat this for several points in time: end-2021Q2, 2021Q3, 2021Q4 and 2022Q1 (Table 2). The interaction term between the SSA dummy and cumulative delivery rate is negative albeit statistically insignificant in 2021Q2 and 2021Q3 (columns 1 and 2), but turns positive, remaining statistically insignificant, for the subsequent points in time (columns 3 and 4), suggesting that SSA countries, despite a slow start, were administering delivered vaccines at a similar—if not faster—speed compared to the rest of the world.

Figure 3. Vaccine Delivery and Vaccination Rates, as of 2022Q1



In addition to the number of vaccine doses delivered, the type of vaccine doses and their source (COVAX, direct purchases from manufacturers, bilateral donations) may also matter for vaccination rates. In case of the type of vaccine, concerns about safety, side effects, and effectiveness of different vaccines, especially at the beginning of the vaccination campaigns, have been widespread and even observed among health care workers.[7] mRNA-based vaccines tend to give a strong boost to vaccination rates, whereas other types either reduce vaccination rates or do not have a statistically significant impact on vaccination rates (Annex II). In terms of vaccine sources, LMICs relied heavily on deliveries from COVAX facility, having limited funds to sign advance purchase agreements. In particular, in SSA countries only vaccine deliveries from COVAX have positive and statistically significant impact on vaccination rates, whereas direct purchases from manufacturers and to a lesser extent bilateral donations are associated with higher vaccination rates in the rest of the world (Annex II). This suggests that low delivery rates in SSA reflect a combination of limited funds and insufficient donations.

[7] The suspension of AstraZeneca's rollout in some European countries, the South African data on its effectiveness and the temporary suspension of the Johnson & Johnson vaccine in the US to evaluate reports of blood clotting, affected confidence in COVID-19 vaccines. Ultimately, AstraZeneca's vaccine was refused by several countries.

Table 2. Vaccination Rates and Cumulative Delivery of Vaccines

	Log vaccination rate (doses per 100 people), as of			
	2021Q2	2021Q3	2021Q4	2022Q1
	(1)	(2)	(3)	(4)
Log cumulative delivery (doses per 100 people)	1.16***	1.18***	1.13***	1.16***
	(18.89)	(14.13)	(21.93)	(20.56)
SSA dummy	0.13	0.01	-1.01	-1.23
	(0.39)	(0.02)	(-1.48)	(-1.40)
Log cumulative delivery x SSA dummy	-0.12	-0.01	0.24	0.28
	(-1.19)	(-0.12)	(1.42)	(1.36)
Observations	146	149	150	150
R-squared	0.85	0.91	0.81	0.88

Note: t-statistics in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Sources: Airfinity, Our World in Data, and IMF staff calculations.

Drivers of vaccination rates

As shown in the previous analysis, delivery of vaccine doses is an important factor that drives vaccination rates. Once vaccines are delivered to the country, the rate at which they are administered depends on a multitude of factors such as the health care system, transportation network, demographic structure, as well as development status.

In the next set of regressions, using the vaccination and cumulative delivery rates as of 2022Q1, we sequentially add regressors controlling for a range of domestic factors that affect country's ability to administer vaccine doses (Table 3). Columns 2-8 show that each of these factors individually has a statistically significant impact on vaccination rates: higher vaccination rates are associated with higher COVID-19 cases, higher COVID-19 deaths, higher GDP per capita, better infrastructure quality, higher health spending, older population, and higher human development status.[8] The coefficient before each variable can be interpreted as an elasticity. For example, column 1 implies that when cumulative delivery increases by 10 percent, vaccination rates would increase by 12.8 percent.[9] The last row calculates that if each individual factor increases from the 25th percentile to the 75th percentile in the sample, vaccination rates would increase by about 100 percent.

[8] Median travel time, infrastructure quality score and urban share of population are proxies for the ease of in-country delivery of vaccines, and hence controlled for in the same regression. Similarly, the demographic structure is captured by two variables—share of 15-64 and 65+ population, which are included in the same regression.

[9] Note that the elasticity can be above 1. For instance, from a 20 percent vaccination rate of 100 doses delivered to a 40 percent vaccination rate of 200 doses delivered, the implied elasticity is 2/1.5 = 1.33.

When these factors are controlled for in a single regression, only cumulative delivery and quality of infrastructure matter statistically significantly for vaccination rates (column 9). This remains the case even after we drop some covariates that are highly correlated with others (column 10); cumulative deaths, median travel time, and human development index are highly correlated with cumulative cases, infrastructure score, and GDP per capita, respectively. If we think of the quality of infrastructure as a measure of the ease with which vaccines can be distributed within the country, the two statistically significant factors highlight the importance of vaccine logistics—be it international or domestic—in getting people vaccinated.

Table 3. Factors Affecting Vaccination Rates

	Log vaccination rate (doses per 100 people), as of 2022Q1									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Log cumulative delivery (doses per 100 people)	1.28***								1.38***	1.35***
	(15.67)								(9.19)	(7.91)
Log cumulative cases (per 1000 people)		0.45***							-0.17	-0.01
		(7.79)							(-1.29)	(-0.38)
Log cumulative deaths (per 1000 people)			0.39***						0.16	
			(5.14)						(1.39)	
Log GDP per capita				0.74***					-0.03	-0.13
				(8.39)					(-0.28)	(-1.57)
Log median travel time					0.03				0.03	
					(0.31)				(0.67)	
Log infrastructure quality score					2.41***				0.60**	0.42**
					(5.05)				(2.53)	(2.62)
Log urban share of population					0.78**				0.26	0.31
					(2.09)				(1.15)	(1.00)
Log health expenditure per capita						0.69***			-0.01	-0.08
						(8.92)			(-0.04)	(-0.70)
Log share of 15-64 population							6.37***		0.70	0.78
							(8.52)		(1.07)	(1.31)
Log share of 65+ population							0.48***		0.04	0.01
							(5.88)		(0.52)	(0.18)
Log human development index								4.35***	-0.90	
								(9.95)	(-1.19)	
Observations	150	149	148	150	98	145	150	150	95	104
R-squared	0.88	0.45	0.31	0.47	0.449	0.48	0.50	0.57	0.92	0.90
	Changes in vaccination rates if an individual factor increases from 25th percentile to 75th percentile									
	144%	137%	107%	119%	92%	128%	97%	137%		

Note: t-statistics in parentheses. *** p<0.01, ** p<0.05, * p<0.1. To calculate the changes in vaccinations rates for individual factors, column (5) only uses infrastructure quality score and column (7) only uses the share of population age 15-64.

Sources: Airfinity, Our World in Data, Nelson et al. (2019), World Bank World Development Indicators, UNDP, and IMF staff calculations.

4.2. Factors affecting administering rates

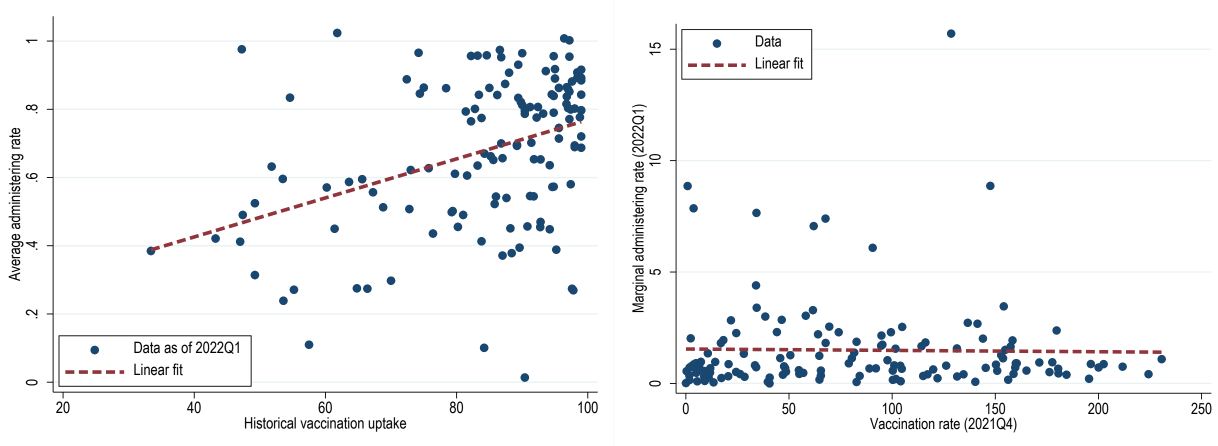
In this section, we focus on equation (3), exploring factors affecting administering rates a_i. In addition to the fundamental drivers considered in Section 4.1, one potential factor that affects administering rates is vaccine hesitancy. If a country has a historically low vaccination uptake, its population may not be willing to get COVID-19 vaccines, leading to lower administering rates. Furthermore, if a country has already vaccinated a large proportion of its population, the administering rates could be low as well.

Drivers of administering rates

Panel (a) of Figure 4 shows that countries that have had high vaccination uptake in the past tend to have higher average administering rates for COVID-19 vaccine. However, there is a great heterogeneity across countries, with some displaying a high COVID-19 vaccine administering rate despite low historic vaccination uptake.

Panel (b) compares the marginal administering rates ($\Delta a_i/\Delta d_i$) over 2022Q1 with vaccination rates as of 2021Q4 and shows that there is no correlation. In other words, even if a country has a large share of its population vaccinated by end-2021, it does not imply the marginal administering rates would be low over the next quarter. Admittedly, vaccine delivery data are not always updated in a timely fashion, resulting in marginal vaccination rates over 1 in some countries, despite aggregating the delivery and vaccination data to quarterly frequency. Dropping the observations with administering rates greater than 1 does not qualitatively alter our results.

Figure 4. Administering Rates vs. Historical vaccine uptake and GDP per capita



Panel (a) Panel (b)

Note: Administering rate is the administered share of delivered doses.
Sources: Airfinity, Our World in Data, and IMF staff calculations.

Table 4 reports the results from regressions where the dependent variable is the ratio of administered doses over delivered doses as of 2022Q1, and the economic, health, and demographic factors are added sequentially as regressors. Columns 1-8 show that higher historical vaccination uptake, higher COVID-19 cases and deaths, higher GDP per capita, better infrastructure quality, more per capita spending on health, older population, and higher human development index are associated with higher administering rates. If each individual factor increases from the 25th percentile to the 75th percentile in the sample, the administering rate increases by about 20 percent. When these factors are controlled for in a single regression, all coefficients are imprecisely estimated, in contrast to the results in Table 4 where vaccine logistics

is a significant determinant of vaccination rates. The results are qualitatively unchanged and robust to altering the date of administering rates, namely 2021Q3 and 2021Q4.

Table 4. Factors Affecting Administering Rates

	Administering rate (administered doses/delivered doses), as of										
	2022Q1									2021Q4	2021Q3
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Log vaccination uptake	0.693***								0.342	0.116	0.293
	(5.07)								(1.01)	(0.21)	(0.60)
Log cumulative cases (per 1000 people)		0.061***							0.052	-0.225	0.049
		(3.93)							(1.22)	(-1.15)	(0.73)
Log cumulative deaths (per 1000 people)			0.058***						-0.026	0.317	0.019
			(3.36)						(-0.78)	(1.58)	(0.40)
Log GDP per capita				0.116***					-0.037	0.203	0.301*
				(5.06)					(-0.40)	(1.52)	(1.91)
Log median travel time					-0.028				-0.005	0.074	-0.018
					(-1.16)				(-0.21)	(1.21)	(-0.49)
Log infrastructure quality score					0.459***				0.208	0.588*	0.114
					(3.24)				(1.37)	(1.79)	(0.51)
Log urban share of population					0.058				0.003	0.033	-0.303**
					(0.91)				(0.04)	(0.19)	(-2.22)
Log health expenditure per capita						0.116***			0.041	0.104	0.056
						(4.51)			(0.58)	(0.62)	(0.48)
Log share of 15-64 population							0.989***		0.759	1.211*	0.422
							(4.55)		(1.16)	(1.85)	(0.51)
Log share of 65+ population							0.090***		0.061	0.041	0.073
							(2.71)		(0.90)	(0.48)	(0.90)
Log human development index								0.715***	-0.470	-1.593	-1.300
								(5.34)	(-0.91)	(-1.20)	(-1.31)
Observations	135	145	143	143	91	138	144	143	84	85	89
R-squared	0.153	0.100	0.068	0.131	0.249	0.148	0.152	0.165	0.311	0.505	0.398
	Changes in administering rates if an individual factor increases from 25th percentile to 75th percentile										
	13%	21%	18%	19%	18%	22%	15%	23%			

Note: t-statistics in parentheses. *** p<0.01, ** p<0.05, * p<0.1. To calculate the changes in vaccinations rates for individual factors, column (5) only uses infrastructure quality score and column (7) only uses the share of population age 15-64.

Sources: Airfinity, Our World in Data, Nelson et al. (2019), World Bank World Development Indicators, UNDP, and IMF staff calculations.

Excess doses of vaccines

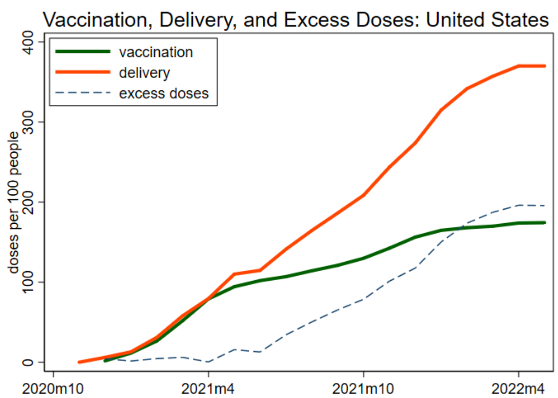
From a country's perspective, after vaccine doses are delivered, increasing administering rates is key to raising vaccination rates. However, from a global perspective, the differences in the distribution of delivered doses can be far more important than the differences in administering rates, because sharing unused vaccines of one country with another can substantially increase the vaccination rate of the recipient country at the same administering rate.

To examine the degree of unused vaccines across countries, one possible measure is the difference between the cumulative number of delivered doses and the cumulative number of administered doses, calculated as $d_i(1 - a_i)$. However, this measure does not necessarily capture the excess doses at any point in time for two reasons. First, poor and infrequent data reporting by many countries does not allow to accurately capture the timing of vaccinations, hence the computed excess doses might be overstated due to lack of vaccination data. Second, some countries might have excess demand for vaccines, but it may take them some time to get the

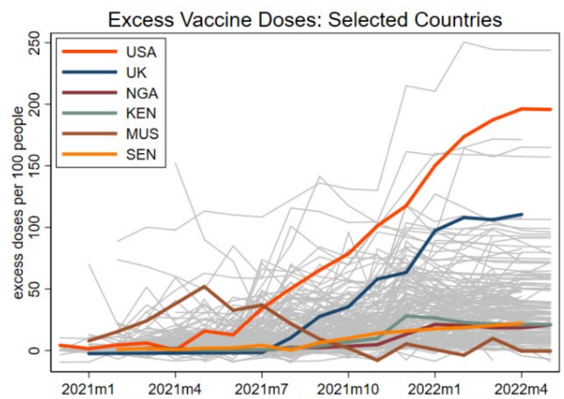
shots into arms after the vaccines have been delivered, which would also overstate the number of excess doses.

With these caveats in mind, Panel (a) of Figure 5 uses the United States as an example for such calculation. It shows that since April 2021, the excess doses of vaccines have been rising steadily, reaching almost 200 per 100 people in April 2022. Panel (b) plots excess doses of vaccines for all countries in our sample. It shows that advanced economies, such as the United States and United Kingdom, have accumulated far more excess doses than developing countries, despite vaccine hesitancy being often cited as the reason for low vaccination rates in developing countries.

Figure 5. Excess Vaccine Doses for Selected Countries



Panel (a)



Panel (b)

Sources: Airfinity and IMF staff calculations.

4.3. Equitable vaccination rates

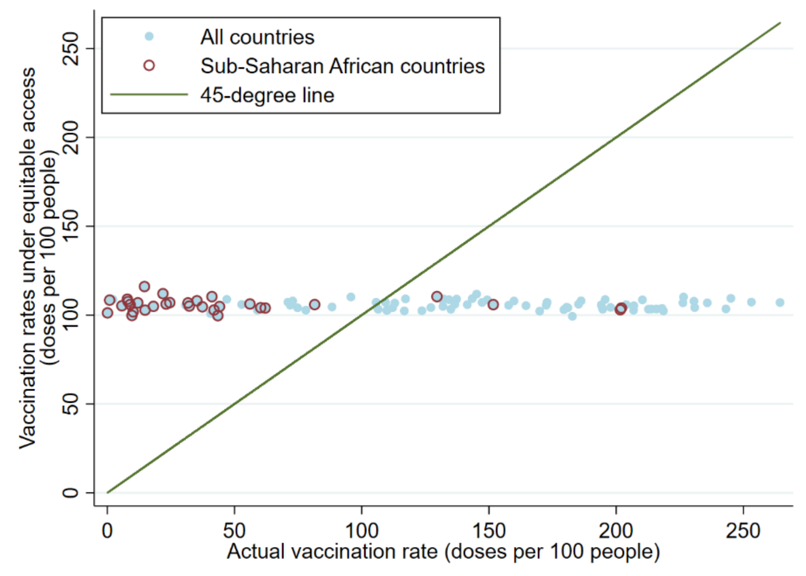
Equitable distribution of vaccinations

Figure 6 compares the actual vaccination rates (as of 2022Q1) with the estimated equitable distribution of vaccinations. Circles above the 45-degree line imply that the equitable vaccination rates are higher than actual vaccination rates.

First, it is remarkable to notice that the equitable distribution of vaccinations is close to—but not the same as—equal distribution of vaccinations. This highlights the importance of vaccine delivery in driving the overall inequality in vaccination rates: if vaccination rates only depend on factors under a country's control, they would have been close to equal across countries.

Second, the equitable distribution of vaccinations has most countries at 100 doses per 100 people, reflecting the vaccine supply capacity of the world in early 2022. Most SSA countries, however, would have had higher vaccination rates under the equitable distribution.

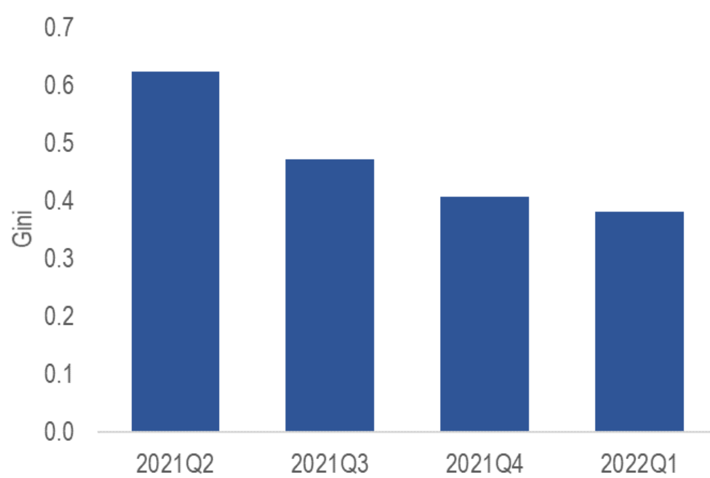
Figure 6. Actual and Equitable Distribution of Vaccinations, as of 2022Q1



4.4. Evolution of vaccination inequality

Global vaccination inequality, as measured by the Gini index of vaccination rates across countries, has been on the decline over time (Figure 7), thanks in part to increased vaccine production. However, vaccination inequality remained as high as 0.4 even at the end of 2022Q1.

Figure 7. Evolution of Global Vaccination Inequality



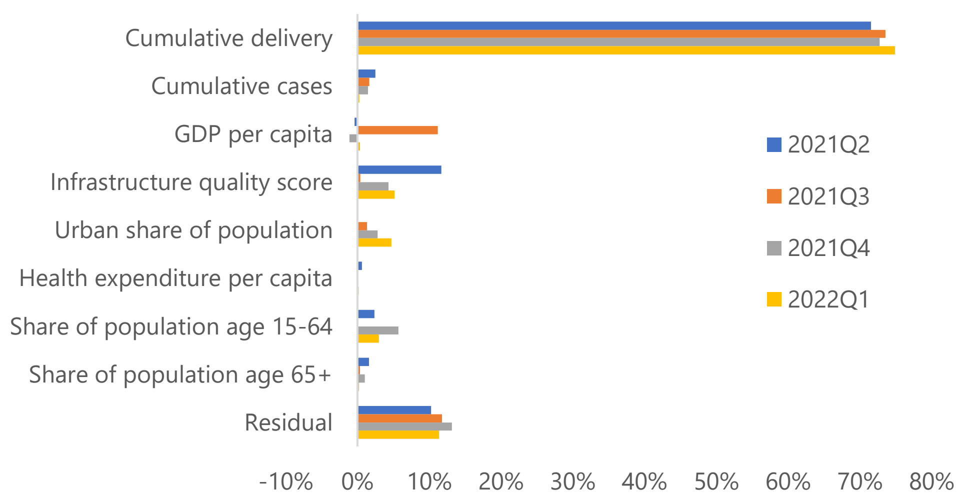
Sources: Airfinity and IMF staff calculations.

Using the Shapley value decomposition, Figure 8 examines the contribution of each factor in column 10 of Table 3 to global vaccination inequality. Vaccine delivery is clearly the dominant

factor that drives global vaccination inequality. Its importance remained the same throughout 2021Q2-2022Q1, accounting for between 70 and 80 percent of global vaccination inequality.

By contrast, other health, economic and demographic factors, such as COVID-19 cases, GDP per capita, urban share of population, and the share of 15+ population, play a minor role in global vaccination inequality. Vaccine hesitancy, while not directly observable, is captured in the residual term in Figure 8. The contribution of the residual term increased slightly over time in 2021, peaking at only 13 percent of global vaccination inequality. This suggests that vaccine hesitancy is not nearly as important as vaccine delivery for vaccination rates.

Figure 8. Decomposition of Vaccination Inequality as Measured by Gini Coefficient



5. Conclusion and policy Implications

COVID-19 vaccination rates vary greatly across countries, with low- and middle-income countries having much lower vaccination rates than advanced countries. This paper provides an empirical assessment of the importance of various factors in driving vaccination rates across countries, distinguishing between factors within a country's control (demographic structure, health and transport infrastructure and development level) and beyond (vaccine delivery). We show that even though the delivery of vaccine doses to sub-Saharan African countries lagged behind the rest of the world, the rates at which these countries administered vaccines is comparable to those of other countries. Moreover, when we control for factors within countries' control such as the health care system, transportation network, demographic structure, and development status, delivery of vaccine doses and quality of infrastructure appear to matter the most for vaccination rates, which highlights the importance of vaccine logistics—whether international or domestic—in getting jabs into people's arms. Finally, when we quantify the contribution of each factor to the overall

vaccination inequality, delivery of vaccine doses accounts for about 80 percent, while vaccine hesitancy at most for only about 13 percent of global vaccination inequality.

As we transition to fighting COVID-19 over the longer term and in preparation of future pandemics, it is pertinent for international community to acknowledge that strengthening global collaboration and systems for a faster and better response is critical to reaching the global vaccination targets. As outlined in Agarwal et al (2022), stronger multilateral institutions with high-level political support to coordinate the global response to health shocks; rapid and adequate financing windows for global public goods activated at the onset of pandemics; diversified regional manufacturing capacity with arrangements to share technology and know-how; improved regulatory frameworks to allow speedy delivery of existing and novel tools worldwide are key areas where improvements could lead to lower vaccination inequality. In their turn, countries will need to invest, and the international community should allocate additional resources to strengthen health systems to prevent, detect and respond to future threats. Only collectively can we fight future pandemics better.

Annex I. Measures of Vaccination Inequality

Shapley decomposition of the Gini index

The Shapley decomposition calculates the marginal decline in the Gini index once contributing factors are removed sequentially.[10] Since the marginal decline depends on the specific elimination path, the average marginal decline over all possible elimination paths is used as the contribution of the factor.

For example, consider the contribution of delivery of vaccine doses to the overall vaccination inequality. Suppose there are m factors in total that drive the overall inequality. One specific elimination path is to remove vaccine delivery while keeping all other $(m-1)$ factors. Let K_{m-1} denote the set of all other $(m-1)$ factors and $C\left(\text{vaccine delivery}, K_{\{m-1\}}\right)$ the marginal contribution of the delivery of vaccine doses. It follows that the contribution in this specific elimination path is:

$$C(\text{vaccine delivery}, K) = Gini\,(\text{vaccine delivery}, K_{\{m-1\}}) - Gini(K_{\{m-1\}}).$$

However, one could consider eliminating vaccine delivery from different subsets of all other factors. Each subset K has k factors with $k = 0, \cdots, m-1$. In other words, $|K| = k$. The average marginal contribution of vaccine delivery is then:

$$C(\text{vaccine delivery}) = \sum_{k=0}^{m-1} \sum_{|K|=k} \frac{(m-1-k)!k!}{m!} C(\text{vaccine delivery}, K).$$

The main analysis in this paper uses the Gini index as the baseline measure of inequality. In addition to the Gini index, we also consider an alternative measure of global vaccination inequality, which shows a similar result: global vaccination inequality declined over time and vaccine delivery remained the dominant driver of vaccine inequality.

MN-Measure

The MN-measure (Magdalou and Nock 2011) is a divergence measure of inequality widely used in the literature. It attaches higher weights to shortfalls from the equitable distribution (Hufe et al 2021) and therefore complements the Gini index when vaccination rates are highly uneven across countries.

[10] Removal here means that the differences of a factor are removed—the factor is assumed to take the mean value of different countries.

To assess the difference between the observed distribution of vaccinations and the equitable distribution, a scalar inequality measure that aggregates the divergence between the two distributions is used:

$$D(v||v^*) = \frac{1}{N}\sum_{i\in\mathcal{N}}\left(ln\frac{v_i^*}{v_i} - \frac{v_i^*-v_i}{v_i}\right). \quad (1.1)$$

This is a decomposable divergence measure of distributions that has two desirable properties for the purpose of analyzing vaccine inequality. First, a progressive transfer of vaccines from a country with a high vaccination rate to a country with a low vaccination rate reduces the inequality. Second, the measure allows the quantification of the contribution of different factors to the overall inequality.

The overall MN-measure of global vaccine inequality is given by $D(y||\bar{y})$, where $\bar{y}$ is the average vaccination rate across countries. It encompasses both the equitable and unequitable components of inequality. To compute the equitable distribution of vaccinations, a linear regression model of vaccinations is employed similar to equation (1.1),

$$\log v_i = \beta \boldsymbol{X}_i^R + \gamma \boldsymbol{X}_i^{NR} + \epsilon_i. \quad (1.2)$$

However, different from equation (1.1), the left-hand side of equation (1.2) is the logarithm of vaccination rates. This is to ensure that v^* in the MN-measure is positive and well defined in subsequent calculations. All variables on the right-hand side of equation (1.2) are also in logarithm so that the coefficients can be interpreted as elasticities.

Following the formulation in Almås et al (2011), the equitable distribution of vaccinations is obtained by assuming that it does not depend on factors beyond country's control and takes the following form:

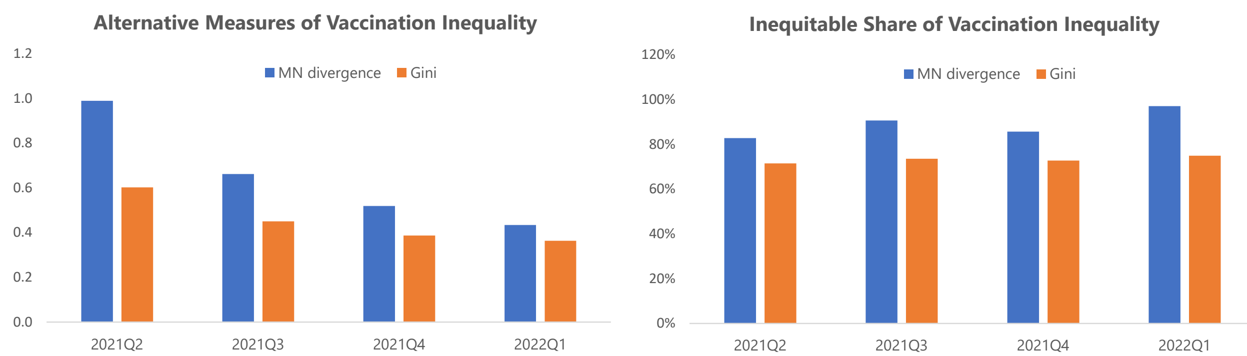
$$v_i^* = \frac{\exp(\beta \boldsymbol{X_i^R})}{\sum_j \exp(\beta \boldsymbol{X_j^R})}\sum_j v_j.$$

As before, a Shapley value decomposition is conducted to quantify the contribution of each factor to the MN-measure of global vaccine inequality.

The left panel of Figure 8 compares the evolution of global vaccine inequality as measured by the Gini index and the MN-measure. Both show that vaccination inequality declined over the course of 2021 and into 2022. The right panel, however, shows that the inequitable component of global vaccine inequality—or the component driven by vaccine delivery—remained persistently high under the MN-measure, accounting for about 90 percent of the overall global vaccination inequality.

Both measures of inequality therefore depict the same landscape of global vaccine inequality: it is declining over time but remains high, and vaccine delivery continues to be the dominant driver of such inequality.

Figure 1.1. Alternative Measures of Global Vaccination Inequality and Its Inequitable Component



Sources: Airfinity and IMF staff calculations.

Annex II. Vaccine Types and Sources

The effectiveness of various types of vaccines has attracted much media coverage, which in turn may have affected people's willingness to get vaccinated. The effectiveness of vaccines is also a factor that could shape vaccine hesitancy. To gauge the importance of vaccine type for vaccination rates, we regress vaccination rates on cumulative delivery and shares of various vaccines delivered as of 2022Q1 (Table 2.1). We group COVID-19 vaccines into four major types—mRNA (Pfizer and Moderna), AstraZeneca, Chinese vaccines, and other types of vaccines, and calculate the share of each type in total doses delivered to the country.

Column 1 shows that higher share of mRNA vaccines is associated with higher vaccination rates. This positive association increases when the United States, as the major producer of mRNA vaccines, is excluded in column 2. By contrast, columns 3 and 5 show that higher shares of AstraZeneca and Chinese vaccines are associated with lower vaccination rates. Compared to columns 3 and 5, excluding vaccine producer countries in columns 4 and 6 reduces the magnitude of the coefficient, suggesting that AstraZeneca and the Chinese vaccines are used more often in producer countries than abroad. However, none of the vaccine types affect vaccination rates in a statistically significant way.

Table 2.1. Vaccination Rates and Type of Vaccines

	Log vaccination rate (doses per 100 people), as of 2022Q1							
	All countries	excl. US	All countries	excl. UK and India	All countries	excl. China	All countries	All countries
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log cumulative delivery (doses per 100 people)	1.261***	1.265***	1.280***	1.282***	1.280***	1.279***	1.275***	1.269***
	(14.73)	(14.76)	(15.94)	(15.84)	(15.46)	(15.49)	(15.54)	(11.78)
Share of mRNA	0.153	0.186						0.107
	(1.20)	(1.48)						(0.50)
Share of AstraZeneca			-0.059	-0.085				-0.058
			(-0.36)	(-0.50)				(-0.28)
Share of Chinese vaccines					-0.104	-0.117		-0.065
					(-0.54)	(-0.58)		(-0.23)
Share of other types of vaccines							0.188	
							(1.54)	
Observations	150	149	150	148	150	149	150	150
R-squared	0.877	0.878	0.876	0.875	0.876	0.875	0.876	0.877

Note: t-statistics in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Sources: Airfinity, Our World in Data, and IMF staff calculations.

Taking a step further, we examine if the results in Table 2.1 hold for SSA countries, the region with the lowest vaccination rates, by including an SSA dummy and interaction terms of the SSA dummy and shares of various types of vaccines. Table 2.2 shows that vaccination rates in SSA countries depend on the type of delivered vaccines in a similar way to those in other countries. The

coefficient on the interaction term of the SSA dummy and the share of mRNA vaccine is statistically significant, indicating that mRNA vaccine might boost vaccination rates in SSA.

Table 2.2. Vaccination Rates and Type of Vaccines in Sub-Saharan Africa

	Log vaccination rate (doses per 100 people), as of 2022Q1				
	(1)	(2)	(3)	(4)	(5)
Log cumulative delivery (doses per 100 people)	1.256***	1.257***	1.276***	1.279***	1.247***
	(15.29)	(13.95)	(14.06)	(14.02)	(12.58)
SSA	-0.228				-0.197
	(-1.36)				(-0.85)
Share of mRNA	-0.218	-0.082	0.081	0.014	-0.205
	(-1.65)	(-0.50)	(0.51)	(0.17)	(-1.01)
SSA × Share of mRNA	1.018*				0.870*
	(1.84)				(1.77)
Share of AstraZeneca		0.117			0.081
		(0.85)			(0.38)
SSA × Share of AstraZeneca		0.319			0.244
		(0.50)			(0.45)
Share of Chinese vaccines			0.011		-0.001
			(0.06)		(-0.01)
SSA × Share of Chinese vaccines			-0.410		-0.142
			(-0.77)		(-0.35)
Share of other types of vaccines				0.196	
				(1.55)	
SSA × Share of other types				-2.214	
				(-0.58)	
Observations	150	150	150	150	150
R-squared	0.879	0.877	0.878	0.876	0.880

Note: t-statistics in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Sources: Airfinity, Our World in Data, and IMF staff calculations.

The source of vaccine deliveries may also matter for vaccination rates. As shown in Figure 2.1, SSA countries predominantly received their vaccine doses from COVAX, reflecting the fact that they did not sign advance purchase agreements with vaccine manufacturers due to financing constraints. In contrast, advanced economies relied only on direct purchases from manufacturers. Even non-SSA emerging market and developing economies sourced most of their vaccine doses directly from manufacturers.

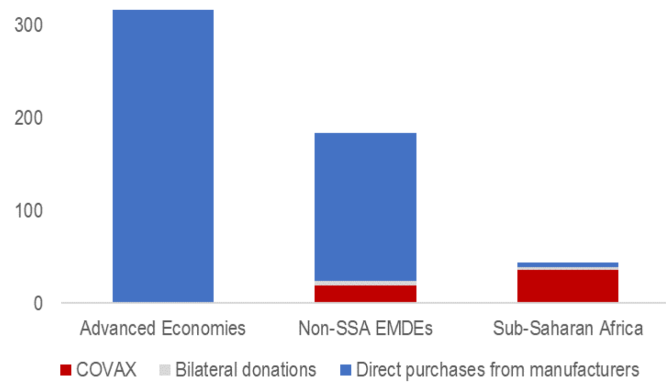
More formally, we regress the vaccination rates on cumulative delivery rates by source of vaccines (COVAX, bilateral donations and direct purchases from manufacturers),[11] controlling for SSA countries and including an interaction term between SSA dummy and cumulative delivery rates by source (Table 2.3). The interaction term between the SSA dummy and COVAX cumulative

[11] Deliveries from African Union's African Vaccine Acquisition Trust (AVAT) are counted toward COVAX. Since many countries have only deliveries from one or two sources, to maintain the sample size, we add 1 dose before taking logarithm of the variables for vaccine deliveries.

delivery rate is positive and statistically significant, whereas the interaction terms between the SSA dummy and deliveries from the other two sources of vaccines is statistically insignificant, suggesting that that low delivery rates in SSA countries reflect a combination of limited funds and insufficient donations.

Figure 2.1. Cumulative Vaccine Deliveries by Source

(Per 100 people, as of 2022Q1)



Source: Airfinity and IMF staff calculations.
Notes: EMDEs = Emerging markets and developing economies.

Table 2.3. Vaccination Rates and Sources of Vaccines in Sub-Saharan Africa

	Log vaccination rate (doses per 100 people), as of 2022Q1		
	(1)	(2)	(3)
Log cumulative delivery (doses per 100 people)			
COVAX	0.00	0.10	0.09*
	(0.07)	(1.58)	(1.69)
Manufacturers	0.33***	0.32***	0.32***
	(5.52)	(3.89)	(3.79)
Bilateral donations	0.20**	0.15**	0.15**
	(2.61)	(2.16)	(2.28)
SSA	-3.59***	-4.22***	-4.30***
	(-3.09)	(-3.44)	(-3.49)
SSA × Log COVAX delivery	0.82**	1.30***	1.32***
	(2.48)	(3.87)	(3.86)
SSA × Log manufacturers delivery	-0.01	-0.12	-0.16
	(-0.11)	(-0.79)	(-1.11)
SSA × Log bilateral donations delivery	0.14	-0.23	-0.19
	(0.98)	(-1.36)	(-1.08)
Observations	150	95	104
R-squared	0.71	0.87	0.87

Note: t-statistics in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Sources: Airfinity, Our World in Data, and IMF staff calculations.

Annex III. Robustness Checks

In Table 3, we analyze the factors that affect vaccination rates across countries. In this section, we conduct two robustness checks.

First, we rerun the regressions in Table 3 with population weights. By assigning more weights to more populous countries, this can alleviate a possible concern that potentially fast progress in vaccination in a few smaller countries drive the results. Table 3.1 shows that the coefficients on vaccine delivery in columns 1, 9 and 10 remain statistically significant and quantitatively similar to those in Table 3, suggesting that the finding that delivery is an important factor driving vaccination rates is robust. Interestingly, when weighted by population and examined individually, the coefficients before cumulative cases and deaths are no longer statistically significant, which indicates that the high correlation between the spread of COVID-19 and vaccination rates might be driven by only a few countries with small population. When all or most covariates are included in columns 9 and 10, infrastructure quality score also remains statistically significant, highlighting again the important role of logistics in vaccination rates.

Table 3.1. Factors Affecting Vaccination Rates, Weighted by Population

	Log vaccination rate (doses per 100 people), as of 2022Q1									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Log cumulative delivery (doses per 100 people)	1.28***								1.37***	1.30***
	(15.44)								(11.03)	(9.11)
Log cumulative cases (per 1000 people)		0.06							-0.18*	0.01*
		(0.41)							(-1.84)	(1.75)
Log cumulative deaths (per 1000 people)			0.05						0.17**	
			(0.34)						(2.17)	
Log GDP per capita				0.81***					0.13	0.12
				(4.88)					(1.09)	(0.80)
Log median travel time					-0.35*				-0.01	
					(-1.85)				(-0.24)	
Log infrastructure quality score					2.73***				0.68***	0.44**
					(3.70)				(3.42)	(2.08)
Log urban share of population					0.42				0.13	0.21
					(1.20)				(0.57)	(0.78)
Log health expenditure per capita						0.49***			0.10	-0.29**
						(3.13)			(0.75)	(-2.31)
Log share of 15-64 population							7.64***		1.41**	0.95
							(6.03)		(2.32)	(1.27)
Log share of 65+ population							0.53***		0.05	-0.03
							(4.25)		(0.74)	(-0.25)
Log human development index								4.45***	-2.55***	
								(5.85)	(-3.52)	
Observations	150	149	148	150	98	145	150	150	95	104
R-squared	0.92	0.02	0.01	0.48	0.50	0.33	0.73	0.54	0.96	0.95

Note: t-statistics in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Sources: Airfinity, Our World in Data, Nelson et al. (2019), World Bank World Development Indicators, UNDP, and IMF staff calculations.

Second, we take into account vaccine types by adjusting vaccination rates and delivered vaccines. In Table 3, we use administered doses per hundred people as a dependent variable, which does not fully reflect immunization coverage. In this exercise, we use the share of people who received at least one dose of COVID-19 vaccine as a dependent variable. To adjust the number of delivered vaccines accordingly, we divide deliveries of all vaccines by 2, except J&J which required only one dose. Results in Table 3.2 show that the coefficients on adjusted cumulative delivery in columns 1, 9 and 10 are statistically significant and also quantitatively similar to those in Table 3. The coefficients on infrastructure quality score continue to be statistically significant in columns 9 and 10.

Table 3.2. Factors Affecting Vaccination Rates, Accounting for Types of Vaccines

	Log vaccination rate (doses per 100 people), as of 2022Q1									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Log cumulative delivery (doses per 100 people)	1.21***								1.36***	1.33***
	(12.31)								(8.77)	(7.15)
Log cumulative cases (per 1000 people)		0.36***							-0.19	0.00
		(7.06)							(-1.53)	(0.06)
Log cumulative deaths (per 1000 people)			0.32***						0.18*	
			(4.62)						(1.68)	
Log GDP per capita				0.57***					-0.09	-0.15
				(6.84)					(-0.82)	(-1.65)
Log median travel time					0.04				0.01	
					(0.37)				(0.20)	
Log infrastructure quality score					1.94***				0.52**	0.44**
					(4.35)				(2.26)	(2.57)
Log urban share of population					0.64*				0.33	0.38
					(1.83)				(1.49)	(1.27)
Log health expenditure per capita						0.53***			-0.08	-0.15
						(7.30)			(-0.68)	(-1.29)
Log share of 15-64 population							4.98***		0.54	0.85
							(7.17)		(0.94)	(1.58)
Log share of 65+ population							0.36***		-0.01	0.03
							(5.17)		(-0.11)	(0.49)
Log human development index								3.38***	-0.09	
								(8.08)	(-0.11)	
Observations	150	149	148	150	98	145	150	150	95	104
R-squared	0.83	0.39	0.28	0.40	0.40	0.41	0.42	0.49	0.89	0.87

Note: t-statistics in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Sources: Airfinity, Our World in Data, Nelson et al. (2019), World Bank World Development Indicators, UNDP, and IMF staff calculations.

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