Distribution of COVID-19 Vaccines to 49 Sub-Saharan African Countries: Which Vaccines Go Where and How? †

Naoko Takasu[1] and Tatsufumi Yamagata[2]

Abstract

Sub-Saharan Africa faces difficulties in securing COVID-19 vaccines. Which sub-Saharan African countries procure more vaccines than others? Do relatively rich and populous countries gain more vaccines irrespective of their need? Alternatively, is the seriousness of the infection reflected in the number of distributed vaccines on the continent? This study concludes that the need for vaccines, proxied by the number of infection cases and deaths due to COVID-19, is a determinant of vaccine distribution, even after the income and size of recipient countries are controlled. The data used for this study were from UNICEF's COVID-19 Vaccine Market Dashboard. Analyses by mode indicate that commercial transactions and COVAX distribution reflect the need while higher-income countries in the region tend to receive vaccines without disclosing their sources.

Keywords: COVID-19, vaccine, Africa, COVAX

1. Introduction

Sub-Saharan Africa desperately needs COVID-19 vaccines. By the end of 2021, most of the population in developed countries would have received two doses of vaccines, while only 195 million doses have been distributed to 1.1 billion people living in sub-Saharan Africa (as of November 14, 2021, as detailed in the main text). The international community is urged to secure vaccines for sub-Saharan Africa.

It is noticeable that the main modes of procurement of COVID-19 vaccines are distinct between sub-Saharan Africa and the rest of the world. As detailed subsequently, sub-Saharan Africa depends on COVAX, a UN-backed collaboration scheme to develop and distribute COVID-19 vaccines worldwide, while the rest of the world largely purchases vaccines by either bilateral or multilateral agreements if those of which sources are unknown are put aside. Some sub-Saharan African countries have managed to purchase vaccines, while others have not. In addition, some

---

† The authors acknowledge Oscar A. Gomez, Sangho Kim, participants at a seminar of the Ritsumeikan Asia Pacific University and two referees of this journal for useful comments.

[1] PhD student, Ritsumeikan Asia Pacific University, Japan.
E-mail: ta20n2fr@apu.ac.jp
[2] Professor, Ritsumeikan Asia Pacific University, Japan.
E-mail: yama-apu@apu.ac.jp

countries have received donation of vaccines besides COVAX vaccines. Another scheme to procure vaccines is led by the African Union, named African Vaccine Acquisition Trust (AVAT), initiated in August 2021. Thus, sub-Saharan African countries have different mechanisms to secure COVID-19 vaccines from the rest of the world.

How have countries in sub-Saharan Africa procured COVID-19 vaccines? Which vaccines have been distributed to the continent more? Are there any differences in the mode of distribution among various vaccine products? Does a country that needs more vaccines receive more? Instead, is it only a country's population or economy that determine the distribution of vaccines? What is the mechanism of vaccine distribution in sub-Saharan Africa? These are the questions posed in this study.

To address the above questions, the authors of this study used an interesting and useful data source maintained by the United Nations Children's Fund (UNICEF), called "COVID-19 Vaccine Market Dashboard." This data release mechanism covers approximately 210 countries and territories worldwide. All COVID-19 vaccine transactions are counted in units of doses for commercial trade and donation, even though a considerable number of doses are transacted without disclosing a mode and whose source is labeled as "unknown". While procurement of COVID-19 vaccines depends on political, social and cultural factors, this study limited the scope of research to an empirical analysis using the unique dataset.

This study concludes that vaccine distribution to each sub-Saharan African country reflects the need for COVID-19 vaccines even after the scale and capacity of each country are controlled. More precisely, the need for COVID-19 vaccines is proxied by the number of confirmed COVID-19 cases and deaths. The scale and capacity of an economy are represented by population and per capita income, respectively. All 49 sub-Saharan African countries were analyzed as a cross-country study. It is well known that the absolute scale of the number of vaccine deliveries to sub-Saharan Africa is too small. However, it is good to know that COVID-19 vaccines are more likely to be delivered to a country with more infected people and consequential deaths.

An additional finding is the sharp division of labor among various vaccine products according to the country where a vaccine is developed. Vaccines developed in China by Sinopharm or Sinovac are likely to be delivered to sub-Saharan African countries through commercial transactions and donations outside COVAX. Meanwhile, vaccines developed in Europe or the USA are more likely to be distributed to the continent through COVAX and AVAT. The underlying mechanism of this clear differentiation is yet to be fully elucidated. However, this feature is interesting for understanding the determinants of COVID-19 distribution in this region.

The remainder of this paper is structured as follows. Section 2 provides a literature review, which focuses on policy-oriented works. Section 3 describes the data used in this study and the way it is structured and processed. Section 4 is devoted to empirical analyses to draw conclusions. Cross-country analyses were developed by treating 49 sub-Saharan African countries as samples. Section 5 concludes the paper.

2. Social Science Oriented Analyses on COVID-19: Literature Review

While social science-oriented research on COVID-19 vaccines is emerging, three categories of journal studies have been identified so far. The first one discusses the importance of expanding the vaccine supply capacity. Ahuja et al. (2021) explore the best magnitude and structure of public intervention that align social and private benefits while expanding vaccine production capacity. The study concludes that expanding the manufacturing capacity for a wide range of vaccine portfolios has significant benefits during the pandemic. The authors point out that the COVAX facility played the role of a central procurement vehicle to coordinate donations to low-income countries. At the same time, their analysis shows that higher-income countries prefer to purchase bilaterally if COVAX allocates vaccines in proportion to the population. Castillo et al. (2021) analyze and estimate the financial benefits of investment in expanding vaccine production capacity. The authors conclude that expanding the production capacity would generate substantial global benefits and that production capacity could mitigate conflicts over distribution. The authors also argue that COVAX can facilitate efficient allocation across countries. While both studies mention the role of COVAX in vaccine distribution, their primary focus is production capacity analysis.

The second category of the literature asserts vaccine equity. Singh and Chattu (2021) examine how global health diplomacy (GHD) can play a role in equitable access to vaccines. The authors describe healthcare divide, particularly the wide gap between the higher-income and lower-income countries regarding the accessibility of COVID-19 vaccines. They argue that GHD plays a critical role in creating successful global partnerships and funding mechanisms. Aborode et al. (2021) also discuss the equal access and distribution of COVID-19 vaccines focusing on the situation in Africa. They highlight that most African nations depend on the COVAX facility. They describe challenges such as limited healthcare facilities, limited infrastructure to handle vaccines at constant and cold temperatures, vaccine hesitancy in Africa, and limited availability of vaccines due to higher-income countries prioritizing their citizens. The authors emphasize “a need for African based framework for accelerated and equal distribution of COVID-19 vaccines and technologies to Africa” (Aborode et al., 2021, p. 5214).

The third category explores the determinants of access to COVID-19 vaccines. Roghani (2021) examines the relationship between COVID-19 vaccine distribution and two macro-socioeconomic measures, GDP per capita and the Human Development Index (HDI), in 25 countries in February and August 2021. The author uses GDP as an indicator of country’s ability to produce and distribute vaccines and HDI as an indicator of public health infrastructure availability. The author concludes that higher GDP per capita is associated with greater vaccinations and no significant relationship between HDI and vaccination rate. It should be noted that the 25 countries the author selected are mainly from Europe and North America, while only Indonesia from Asia is included, and none from the African continent. It is also notable that COVID-19 vaccine-producing countries, such as China, Russia, and India are not included in the analysis. The study by de Oliveira et al. (2021) analyzes determinants of access to COVID-19 vaccines as of February 2021 in 189 countries, using GDP and HDI (socio-economic aspects) and COVID-19 cases and deaths (country's impact) as explanatory variables. The authors use structural equation modeling (SEM) to identify relations among variables. Its main result is the "Country Impact," which includes cases, deaths, and tests of COVID-19, significantly and positively correlated with total vaccine doses distributed to each country. The approach of de Oliveira et al. (2021) is close to what these authors are going to present in this study. The conclusion of de Oliveira et al. (2021) concerning causality from COVID-19 cases and deaths to total vaccine doses is similar to that attained in this study's authors' research. However, de Oliveira et al. (2021) attempted to identify only the structure of relations among the variables mentioned above using SEM. They did not explore multivariate interactions using regression analysis. In addition, they did not highlight vaccine distribution by products and modes.

In conclusion, during the course of the research, the authors did not find any study discussing the cross-sectional analysis of vaccine distribution based on vaccine products and distribution mode, studies focusing on empirical analysis of vaccine distribution in sub-Saharan Africa, or studies using data from UNICEF Vaccine Dashboard.

3. Data of COVID-19 Infection and Vaccine Distribution

According to the World Health Organization (WHO) Coronavirus Dashboard, there have been 251,266,207 confirmed cases of COVID-19 worldwide, including 5,070,244 deaths[3]. Among them, 5,973,267 confirmed cases, including 149,517 deaths, were from 49 countries[4] in sub-Saharan Africa. These absolute figures may give the impression that the scale of COVID-19 is relatively small. However, if one reviews total confirmed cases, deaths, and vaccine doses delivered per 100,000 population in four sub-regions of sub-Saharan Africa, it becomes clear that the situation in Southern Africa is alarming (Table 1).

[3] See WHO (2021). While this dashboard is updated daily, the number of cases and deaths used in this study are based on the global table data downloaded on November 12, 2021.
[4] In this study, 49 countries of sub-Saharan Africa are those listed in Appendix Table 2.

Table 1. COVID-19 Cases, Deaths, and Vaccines per Sub-Region in Sub-Saharan Africa

	Cases - cumulative total per 100000 population	Deaths - cumulative total per 100000 population	Total doses delivered per 100000 population
Global	3,223.62	65.05	107,853.61
Sub Saharan Africa	525.33	13.15	17,168.76
Eastern Africa	335.55	7.37	17,593.45
Western Africa	175.06	2.63	15,397.37
Middle Africa	176.37	3.15	9,579.63
Southern Africa	4,911.21	144.16	44,834.28

Sources: COVID-19 cases and deaths, WHO Coronavirus (COVID-19) Dashboard as of November 12, 2021; COVID-19 vaccine delivery, UNICEF COVID-19 Vaccine Market Dashboard as of November 14, 2021; Population data, United Nations Department of Economic and Social Affairs, *World Population Prospects 2019*. https://population.un.org/wpp/Download/Standard/Population/

Vaccine distribution data released by UNICEF illustrate the inequality and distinctive nature of vaccine distributions in sub-Saharan Africa compared to the rest of the world. While the total population in sub-Saharan Africa accounts for 14.6% of the total global population, they received only 1.2% of the total vaccines distributed worldwide (Table 2).

Table 2. Global COVID-19 Vaccine Distribution as of August 13, 2021 (Unit: 1,000 doses, %)

Region	Bilateral/multilateral agreement	Donation	COVAX	Unknown	Total	%
World	1,831,442 (40.2)	83,484 (1.8)	192,939 (4.2)	2,443,589 (53.7)	4,551,453 (100.0)	100.0
East Asia and Pacific	209,344 (9.4)	25,476 (1.1)	54,948 (2.5)	1,948,532 (87.1)	2,238,300 (100.0)	49.2
South Asia	174,990 (40.5)	12,083 (2.8)	27,708 (6.4)	216,771 (50.2)	431,551 (100.0)	9.5
Middle East and North Africa	71,126 (40.8)	6,697 (3.8)	22,364 (12.8)	74,347 (42.6)	174,534 (100.0)	3.8
Europe and Central Asia	566,076 (73.5)	2,424 (0.3)	12,712 (1.7)	188,702 (24.5)	769,914 (100.0)	16.9
Latin America and Caribbean	344,888 (81.4)	28,123 (6.6)	35,748 (8.4)	14,878 (3.5)	423,637 (100.0)	9.3
USA and Canada	455,752 (99.6)	1,000 (0.2)	972 (0.2)	0 (0.0)	457,725 (100.0)	10.1
Sub-Saharan Africa	9,265 (16.6)	7,682 (13.8)	38,486 (69.0)	359 (0.6)	55,792 (100.0)	1.2

Source: UNICEF, COVID-19 Vaccine Market Dashboard (http://bit.ly/2NgN9w0) as of August 13, 2021.
Note: The African Vaccine Acquisition Trust (AVAT) began procuring and distributing vaccines to its member countries in early August 2021. Therefore, no doses were distributed through AVAT when the above figures were collected.

Globally, procurement through bilateral and multilateral agreements is the main mode of vaccine distribution. Note that this mode is commercial trade after bilateral or multilateral negotiations. In sub-Saharan Africa, in contrast, the majority (69%) of vaccines are distributed through the COVID-19 Vaccines Global Access (COVAX), and donation is also an important route, accounting for 13.8%. COVAX is the vaccines pillar of the Access to COVID-19 Tools Accelerator, a global collaboration to accelerate the development, production, and equitable access to COVID-19 tests, treatments, and vaccines[5] (COVAX, 2021). Another distinctive feature of vaccine distribution in sub-Saharan Africa is the presence of the African Vaccine Acquisition Trust (AVAT), a centralized purchasing agent of the African Union, that aims to vaccinate at least 60% of the African population (AU, 2021). There is also a stark difference between global trends and sub-Saharan Africa in sources labelled as "unknown[6]". Globally, over half of vaccines (53.7%) are distributed through "unknown" mode, whereas only 0.6% is "unknown" in sub-Saharan Africa. As shown in Table 2, East Asia and the Pacific incorporate a majority of source-unknown doses (around 1.9 billion doses out of 2.4 billion of world total source-unknown doses). China does not disclose the modes and products of any vaccines jabbed inside the country, which amounts to approximately 1.8 billion. Japan follows China in the region that classifies 92 million doses in the "unknown" category. In contrast, the vaccine distribution to sub-Saharan Africa is more transparent. Therefore, it is worth reviewing the vaccine distribution data in sub-Saharan Africa in more detail.

The main data source of this research is UNICEF's COVID-19 Vaccine Market Dashboard. This information source has unique characteristics. In December 2020, UNICEF launched a dashboard, which provides the latest information on the world's COVID-19 vaccine market and the COVAX Facilities' vaccine deliveries (UNICEF, 2020). The dashboard is currently divided into seven categories: an overview, products (status of global vaccine approvals), vaccine production capacity, publicly announced supply agreements, reported vaccine price per dose, vaccine deliveries by supply source, and immunization device deliveries (UNICEF, 2021). The dashboard is updated daily[7], using data UNICEF possesses as the designated COVAX procurement coordinator

---

[5] Signatory countries of COVAX are categorized into "self-financing participants" and "AMC eligible economies." AMC stands for the Advance Market Commitment, a facility to promote the development and distribution of vaccines for developing countries. COVID-19 vaccines are distributed to AMC eligible countries free of charge. sub-Saharan Africa, Botswana, Gabon, Mauritius, Namibia, and South Africa are included in the group of "self-financing participants"(WHO, 2021c).

[6] An explanatory note in UNICEF's Dashboard states that "where the number of doses administered by OWID (plus 10% wastage) is greater than the total number of reported deliveries for a country/territory, the difference between the doses administered (plus 10% wastage) and the doses delivered (through COVAX, AVAT, donations, and/or bilateral/multilateral) is categorized as 'Unknown'" (UNICEF, 2021).

[7] A disclaimer on UNICEF's Dashboard states that "UNICEF does not commit to it being up to date" (UNICEF, 2021); meanwhile, one of the authors of this study has monitored this dashboard since August 2021 and witnessed daily updates in the delivery section.

and agent and those reported by public sources[8]. Similar websites or data providers for the global situation on COVID-19 vaccines include the IMF-WHO COVID-19 Vaccine Tracker, Our World in Data's Coronavirus (COVID-19) Vaccinations, and Airfinity. However, IMF-WHO's dashboard relies on data from UNICEF and does not provide details of all countries (IMF, 2021). Our World in Data is focused on vaccination instead of vaccine delivery (OWID, 2021), and Airfinity is a private company that provides health intelligence and analytics to its clients (Airfinity, 2021). The United Nations Development Programme (UNDP), WHO, and the University of Oxford also launched the "Global Dashboard on Vaccine Equity" in July 2021. However, this dashboard focuses on vaccination combined with socio-economic information collaborating with other UN agencies (UNDP et al., 2021). Therefore, the authors of this study consider UNICEF's dashboard as the most comprehensive, detailed, and publicly available dataset in terms of global vaccine distribution. The authors recorded vaccine delivery data (doses per vaccine product and delivery mode) for all 49 countries in sub-Saharan Africa on November 14, 2021. There were nine vaccine products distributed in sub-Saharan Africa, and basic information on these nine vaccines are given in Table 3. A wide variety of vaccines distributed on the continent is another distinctive feature. It is worth investigating whether there are any differences in the distribution mode among various vaccine products.

Table 3. Varieties of COVID-19 Vaccines Distributed in Sub-Saharan Africa as of November 14, 2021

Developer/Product	Type	WHO's approval for emergency use/approval date
AstraZeneca/University of Oxford: Vaxzevria	Virus vector	Yes, February 15, 2021
Bharat Biotech: Covaxin	Inactivated	Yes, November 3, 2021
Gamaleya Research Institute: Sputnik V	Virus vector	
Johnson & Johnson/Janssen: Ad26.COV 2-S	Virus vector	Yes, March 12, 2021
Moderna: Spikevax	Messenger RNA	Yes, April 30, 2021
Pfizer/BioNTech: Comirnaty	Messenger RNA	Yes, December 31, 2020
Serum Institute of India: Covishield	Virus vector	Yes, February 15, 2021
Sinopharm: BBIBP-CorV	Inactivated	Yes, May 7, 2021
Sinovac: Coronavac	Inactivated	Yes, June 1, 2021

Source: UNICEF, COVID-19 Vaccine Market Dashboard (http://bit.ly/2NgN9w0), WHO (2021b).

4. Analyses: Which Vaccines Go Where and How

As detailed in the previous section, UNICEF's COVID-19 Vaccine Market Dashboard

[8] An explanatory note in UNICEF's Dashboard states that "the number of administered doses from Our World in Data plus a standard 10% multi-dose wastage rate is used as a proxy", where "the number of reported doses delivered is unavailable or inconsistent" (UNICEF, 2021).

offers informative and widely accessible data to scrutinize the vaccines' distribution to sub-Saharan African countries. In this section, factors that determine destinations and the amount of various COVID-19 vaccine products are examined by exploring the data. The main question is whether vaccines are distributed more to countries needing them. The need for vaccines is proxied by infection cases and deaths. A null hypothesis to be tested is that the destinations and amounts of COVID-19 vaccine distribution are solely determined by the economic capacity to purchase them and do not depend on the need for vaccines. Economic capacity is represented by per capita income and the size of each country, namely the population. Another important aspect governing the vaccine supply mechanism to sub-Saharan African countries is the distribution mode. As previously mentioned, there are four modes: bilateral/multilateral agreements, donation, COVAX, and AVAT. Recipient countries have to pay for vaccines by the mode of "bilateral/multilateral agreements," while they can obtain vaccines free of charge by the modes of "donation," "COVAX," and "AVAT" in most cases. Thus, the procurement of vaccines by bilateral/multilateral agreements is expected to be influenced by the economic capacity of recipient countries. Donation may be affected by the political and economic closeness between a recipient country and a vaccine-donating country. In the meantime, COVAX and AVAT are operated by international coordinating functions so that their vaccine distribution may depend more on the need for vaccines reflected by the number of COVID-19 cases and deaths. The determinants of vaccine distribution by mode were explored by statistical analyses of the data collected from the COVID-19 Vaccine Market Dashboard on November 14, 2021.

4.1. Distribution of COVID-19 Vaccines by Mode and Product

Before proceeding to the statistical analyses, a grand picture of COVID-19 vaccine distribution to sub-Saharan African countries by mode is presented in Table 4. Its complete dataset is displayed as Appendix Tables 2-4.

As of November 14, 2021, nine COVID-19 vaccine products were distributed. AstraZeneca's vaccine was developed in cooperation with the University of Oxford. A significant portion of its vaccines are manufactured by the Serum Institute of India. The figures displayed in the table are based on vaccine developers, not manufacturers. The Serum Institute of India has a vaccine named "Covishield," which is a variation of Vaxzevria developed by AstraZeneca and the University of Oxford. In India, there is another vaccine developer, Bharat Biotech. Johnson & Johnson wholly own Janssen, hence, Janssen's vaccine is sometimes referred to as Johnson & Johnson. Those developed by Moderna and Pfizer/BioNTech are messenger RNA vaccines. Sinopharm and Sinovac are Chinese pharmaceuticals, while Sputnik is the brand name of the virus vector vaccine developed by the Gamaleya Research Institute of Russia.

Table 4 reveals interesting specialization patterns of COVID-19 vaccine distribution by mode and vaccine products. These specialization patterns are insightful because those in sub-Saharan Africa are distinct from those in the rest of the world, as shown in Table 2.

First, distribution through COVAX, which accounts for 67.% of the total doses arriving in the region (Table 4), is mainly supplied in products developed in either Europe or the United States. Pfizer/BioNTech and AstraZeneca's vaccines supply more than a quarter of the total doses that reached the region through COVAX (Table 4). Combining Janssen (11.7%) and Moderna (7.8%), these four European and US developers' vaccines jointly amounted to almost three-quarters (73.1%) of total COVAX distributions. The Serum Institute of India (12.5%) and Sinopharm (12.0%) followed European and US pharmaceuticals. As the WHO has not approved Sputnik, no dose of Sputnik is offered through COVAX.

A stark contrast is the dominance of Chinese vaccine distribution through the mode of "bilateral/multilateral agreements." As mentioned above, this is a mode of vaccine supply through commercial trade. Sinovac (43.1%) and Sinopharm (42.3%) are the two prevailing suppliers by this mode, followed by the Serum Institute of India (8.3%).

The presence of Chinese vaccines is outstanding through the mode of donation, too. The greatest contributor to this mode was Sinopharm (45.9%). Combining those of Sinovac, the two Chinese developers offer as much as 58.5% of the total vaccines by the mode of donation. Interestingly, Chinese developers lead vaccine distribution by the two modes, commercial trade and donation, even though the relative number of doses offered by the two modes is not substantial (17.2% as the sum of 6.8% and 10.4%. See Table 4). AstraZeneca's vaccines (27.4%) followed Sinopharm, probably because developed countries released AstraZeneca's vaccines to African countries after they noticed that they had procured more than the required quantity of COVID-19 vaccines.

AVAT is a scheme based on an agreement between the African Union (AU) and Johnson & Johnson (AU, 2021, Inaba, 2021 and World Bank, 2021). Therefore, by construction, Janssen supplied vaccines under the AVAT scheme.

Finally, "unknown" sources of vaccines have drawn attention. Out of the total number of vaccines from "unknown" sources, which is 18.7 million doses, only 234 thousand were revealed to be donations. The rest were not associated with any mode or vaccine products. Appendix Table 4 shows that South Africa is the highest contributor of source-unknown doses with 15.5 million doses, while the source-unknown doses in the region amount to 18.7 million. Factors associated with the number of source-unknown vaccines are analyzed in Subsection 4.3.

Table 4. Vaccine Distribution by Products and Modes (Units: Dose and Percent)

Product/ Mode	AstraZeneca	Bharat Biotech	Janssen	Moderna	Pfizer BioNTech	Serum Institute of India	Sinopharm	Sinovac	Sputnik	Unknown	Total
Bilateral/ multilateral agreements	0 (0.0) [0.0]	200,000 (1.5) [0.1]	80,000 (0.6) [0.0]	0 (0.0) [0.0]	325,260 (2.5) [0.2]	1,102,000 (8.3) [0.6]	5,594,000 (42.3) [2.9]	5,703,000 (43.1) [2.9]	221,000 (1.7) [0.1]	0 (0.0) [0.0]	13,225,260 (100.0) [6.8]
Donation	5,546,600 (27.4) [2.8]	30,000 (0.1) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	756,140 (3.7) [0.4]	1,645,000 (8.1) [0.8]	9,298,340 (45.9) [4.8]	2,550,000 (12.6) [1.3]	210,000 (1.0) [0.1]	234,000 (1.2) [0.1]	20,270,080 (100.0) [10.4]
COVAX	34,636,240 (26.4) [17.7]	0 (0.0) [0.0]	15,382,000 (11.7) [7.9]	10,268,920 (7.8) [5.3]	35,489,610 (27.1) [18.2]	16,327,200 (12.5) [8.4]	15,719,877 (12.0) [8.1]	3,184,800 (2.4) [1.6]	0 (0.0) [0.0]	0 (0.0) [0.0]	131,008,647 (100.0) [67.1]
AVAT	0 (0.0) [0.0]	0 (0.0) [0.0]	12,259,200 (100.0) [6.3]	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	12,259,200 (100.0) [6.3]
Unknown	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	0 (0.0) [0.0]	18,452,555 (100.0) [9.5]	18,452,555 (100.0) [9.5]
Total	40,182,840 (20.6) [20.6]	230,000 (0.1) [0.1]	27,721,200 (14.2) [14.2]	10,268,920 (5.3) [5.3]	36,571,010 (18.7) [18.7]	19,074,200 (9.8) [9.8]	30,612,217 (15.7) [15.7]	11,437,800 (5.9) [5.9]	431,000 (0.2) [0.2]	18,686,555 (9.6) [9.6]	195,215,742 (100.0) [100.0]

Note: Vaccine products are displayed in alphabetical order. The values in parentheses are ratios of the total vaccines by mode, while those in square brackets are ratios of the total vaccines delivered to all sub-Saharan Africa.

4.2. Are COVID-19 Vaccines Distributed by Need or Economic Capacity?

The delivery of COVID-19 vaccines to sub-Saharan Africa is a global challenge. This challenge involves two steps. One is how to secure vaccines for the entire sub-Saharan Africa. The other is how to effectively distribute the vaccines inside the region. The former issue is a tremendous task to be undertaken by all stakeholders worldwide. The latter is also an important question posed to the global community. The latter issue is elaborated in this subsection.

The effectiveness in terms of the need for vaccines is measured in the incidence and impact of COVID-19 infection. In this section, it is assumed that the number of COVID-19 cases signifies the incidence, while the number of deaths due to COVID-19 reflects the impact of the infection. Let us call this claim of effective allocation of vaccines with respect to the need for vaccines as the need hypothesis. Meanwhile, recipient countries exert economic and political power to secure vaccines. Therefore, the economic capacity of recipient countries may be a strong determinant of vaccine distribution, which can be called the capacity hypothesis. If the capacity of recipient countries solely determines the distribution of the vaccines, and if low-capacity and great-need countries cannot attain sufficient vaccines at all, we would have to say that the vaccine distribution mechanism in sub-Saharan Africa was inefficient. Which factors, capacity or need, influence the distribution of vaccines more? Is the need for vaccines significantly correlated with the number of vaccines distributed to each recipient country?

Among past studies, de Oliveira et al. (2021) found that need-reflecting variables such as cases, deaths, and tests were determinants of the number of distributed vaccines. However, de Oliveira et al. (2021) did not compare capacity and need factors as determinants of vaccine distribution.

4.2.1. Model

The following regression model was formed to address the questions raised above.

$$V_i = I_i^{\beta_1} P_i^{\beta_2} N_i^{\beta_3} e^{\beta_0 + \beta_4 D_i + u_i}. \qquad (i = 1, \cdots, 49) \qquad (1)$$

V_i: Total number of COVID-19 vaccines distributed in the *i*-th country.

I_i: Gross National Income (GNI) per capita of the *i*-th recipient country.

P_i: Population of the *i*-th recipient country.

N_i: A proxy for the need for vaccines in the *i*-th recipient country. The number of COVID-19 cases or the number of deaths due to COVID-19 was included in this variable.

D_i: A dummy variable that distinguishes self-financing countries in the scheme of COVAX (Botswana, Gabon, Mauritius, Namibia, and South Africa) from the rest of the countries. The dummy variable for self-financing countries takes one, whereas the rest takes zero.

C_i: Other control variables introduced in Subsection
u_i: Error term.

$\beta_0, \beta_1, \beta_3$ and β_4 are assumed to be constant parameters. Once the logarithm is applied to both sides of equation (1), a linear regression equation is formulated as follows:

$$\ln V_i = \beta_0 + \beta_1 \ln I_i + \beta_2 \ln P_i + \beta_3 \ln N_i + \beta_4 D_i + \beta_5 \, ln \, C_i + u_i. \qquad (2)$$

Note that β_1, β_2, β_3 and β_5 can be interpreted as vaccine distribution elasticity with respect to I_i, P_i, N_i and C_i.

As part of the vaccine distribution is made as commercial trade, equation (1) can be interpreted in the context of international trade theory. The gravity equation is similar to equation (1) (Feenstra, 2004, pp. 144-146). The gravity equation explains the amount of international trade with the size of the economies of the two trading countries and the distance between them. This relationship among trade, size of economies, and distance is like Isaac Newton's law of universal gravity. Equation (1) incorporates two proxies for the size of economies, namely population and GNI per capita. Note that the product of I_i and P_i is the GNI of the *i*-th country. Thus, a reduced version of equation (2) uses GNI $(= I_i P_i)$ as a proxy for the size of an economy, assuming that $\beta_1 = \beta_2$.

4.2.2. Estimation Results

Table 5 summarizes the results of the various estimation patterns along with equation (2)[9]. The key parameters of the dependent and independent variables are listed in Appendix Table 1. The sample size is as small as 49, which is the number of sub-Saharan African countries[10]. Therefore, the number of explanatory variables was minimized to increase the degree of freedom.

The first row displays the result of the estimation of equation (2), dropping proxies for the need for vaccines and the self-financing dummy variable (Specification #1). Hence, explanatory variables representing the capacity to secure vaccines are used in this specification. The point estimates of the elasticity with respect to GNI per capita and population were 0.735 and 0.897, respectively. Both coefficients were statistically significant at the 95% level[11]. R^2 is 0.306, which

[9] Only Eritrea has not received any COVID-19 vaccines till November 14, 2021. Hence, Eritrea's value of V_i is assumed to be 1 instead of 0 to apply the logarithm.
[10] Sudan is included in this sample of sub-Saharan African countries.
[11] The heteroscedasticity consistent standard error is shown in Table 4 instead of the ordinary standard error, which incorporates a possibility of heteroscedasticity in the variance of u_i. However, the qualitative natures of estimation results with the heteroscedasticity consistent standard error are maintained even when the ordinary standard error is used instead.

implies that 30.6% of the total variation in the number of vaccines distributed to 49 sub-Saharan African countries were explained by GNI per capita and population while the rest may be explained by social and political factors. *F* statistics and their *p*-value are omitted because the significance of the *t*-value of each coefficient is indicative of the significance of *F* statistics throughout all estimation patterns exhibited in Table 5. This result suggests that the capacity of recipient countries matters how many vaccine doses are secured. It appears that a high income and large population help a sub-Saharan African country fetch some vaccines. Thus, the capacity hypothesis appears to hold.

Table 5. Regression Analysis of Total Vaccines Distributed to 49 Sub-Saharan African Countries

Spec.	Intercept	Capacity			Need		Self-Finance Dummy	R^2
		GNI Per Capita	Population	GNI	# of Infections	# of Deaths		
1	-5.397 (5.751)	0.735** (0.352)	0.897*** (0.192)	-	-	-	-	0.306
2	4.495 (2.996)	-	-	-	0.925*** (0.262)	-	-	0.272
3	8.535*** (2.052)	-	-	-	-	0.880*** (0.282)	-	0.331
4	-2.683 (4.943)	0.341 (0.252)	0.578*** (0.118)	-	0.496** (0.192)	-	-	0.340
5	0.793 (2.880)	0.295* (0.155)	0.474*** (0096)	-	-	0.577* (0.294)	-	0.377
6	-3.815 (4.317)	-	-	0.573*** (0.130)	0.453** (0.216)	-	-	0.331
7	0.050 (2.484)	-	-	0.452*** (0.097)	-	0.573* (0.300)	-	0.372
8	-3.258 (5.374)	0.407 (0.298)	0.563*** (0.116)	-	0.533** (0.221)	-	-0.538 (0.555)	0.343
9	0.205 (3.242)	0.384* (0.208)	0.463*** (0.103)	-	-	0.607* (0.321)	-0.626 (0.679)	0.381

Note: The logarithm is applied to all variables after replacing 0 with 1. The values in parentheses are heteroscedasticity-consistent standard errors. The symbols *, **, and *** signify a significance level of 90%, 95%, and 99%, respectively.

In contrast, the need hypothesis claims that a country in need of vaccines attains more doses. Specifications #2 and #3 of the estimation results displayed in the second and third rows in Table 5, examine this hypothesis. Specification #2 shows that the point estimate of elasticity to the number of infection cases is as high as 0.925. Thus, a 1% increase in the number of COVID-19 cases is associated with a 0.925% increase in the number of distributed vaccines. The estimate is positively significant at the 99% level. The R^2 is 0.272. Specification #3 indicates that the number of COVID-19 deaths plays a similar role in signifying the need for vaccines with the number of cases. The estimate of elasticity to the number of deaths was 0.888. The estimate is also positive and statistically significant at the 99% level. With this explanatory variable, 33.1% of the total variation in the number of distributed vaccines among the 49 countries. The estimations with specifications #2 and #3 suggest that the number of distributed vaccines may reflect the need for vaccines.

What if both hypotheses were tested together? The two hypotheses are not mutually exclusive. Both may hold at the same time. Specifications #4 and #5 give the regression results incorporating the proxies for capacity and need. For both specifications, the population remains highly significant even though the point estimates of its coefficient dropped to 0.578 (Specification #4) and 0.474 (Specification #5). The GNI per capita lowers the point estimates and significance. The point estimates dropped to 0.341 (specification #4) and 0.295 (specification #5). Meanwhile, the number of infection cases remains positive and statistically significant at the 95% level. The point estimate of the coefficient also declined to 0.496. It appears that the proxies for capacity and need mutually offset their impacts on the number of distributed vaccines to a certain extent. However, as long as the need is proxied by the number of infection cases, the need hypothesis still holds even when capacity-related variables are controlled.

Specification #5, with the number of deaths in place of the number of cases, exhibits a qualitatively similar result to that of Specification #4. The population is maintained significantly positive, while the point estimates of coefficients on population and GNI per capita decline. The coefficient on the number of deaths is kept significantly positive at the 90% level. Specifications #6 and #7 are a pair of estimations for a robustness test that uses GNI instead of GNI per capita and population. Again, the results are qualitatively similar to those of Specifications #4 and #5.

The self-finance dummy is introduced into the benchmark specifications (#4 and #5) as Specifications #8 and #9. Self-financing countries are required to contribute financially to COVAX. Therefore, the behaviors of these countries might be structurally different from those of the rest of the countries. Meanwhile, self-financing countries are likely to be high-income nations. The correlation coefficient between the GNI per capita and the self-finance dummy among 49 sub-Saharan African countries is as high as 0.5624. As a result, the self-finance dummy does not provide additional explanatory power to the benchmark model. Specifications #8 and #9 in Table 5 show that the coefficient estimates on the self-finance dummy are both insignificant. Thus, no differences in behavior to secure vaccines between self-financing countries and AMC-eligible countries were observed.

A natural question concerning the validity of this set of regression analyses is the endogeneity problem of the explanatory variables. The number of distributed vaccines may generally influence infection cases and deaths due to COVID-19. If this is the case, reverse causality running from the number of COVID-19 vaccines to the number of infections and deaths may work. However, reverse causality is less likely to occur in this specific case of regression analysis. COVID-19 has spread worldwide, including sub-Saharan Africa in 2020, while the systematic distribution of COVID-19 vaccines to sub-Saharan African countries began in February 2021 by COVAX. Until the authors collected the data on November 14, 2021, the impact of vaccinations to reduce infection and resultant death due to COVID-19 was small. Only 6.5% of the population of African countries were fully vaccinated by November 12, 2021[12]. In a sense, as Diamond and Robinson (2010) depict, a natural experiment is applicable to the causality running from the number of infection cases and deaths to the number of distributed vaccines. Hence, it is possible to interpret that the capacity and need to incorporate variables are determinants of the number of distributed vaccines.

4.2.3. Sensitivity Analyses

The regression analyses shown in Table 5 were limited to exercises that tested interactions with the basic key variables. Only the self-finance dummy variable was used as the control variable. In this subsection, additional control variables and modified functional forms are adopted to check the sensitivity of the results obtained in the previous subsection[13]. The results of the sensitivity analysis are summarized in Table 6.

(1) Total Vaccines Distributed per Capita as a Dependent Variable

One of the simplest modifications of the regression equation (2) is to use the logarithm of the number of vaccines distributed per person as a dependent variable instead of the logged number of vaccines. As the population is controlled by using the denominator of the dependent variable, the logged population on the right-hand side of equation (2) is dropped. Consequently, the regression equation applied to this exercise is a variation of equation (2), with the constraint $\beta_2 = 1$.

$$ln\,V_i - ln\,P_i = \beta_0 + \beta_1\,ln\,I_i + \beta_3\,ln\,N_i + u_i. \qquad (3)$$

The estimation results with regression equation (3) are displayed in the first row of Table 6. The number of infections was used as a proxy for the need for vaccines. The estimated elasticity with respect to the number of infections is 0.151. However, this difference was not statistically significant. Therefore, this specification of binding β_2 to 1 does not assure the need hypothesis.

(2) Medical Capacities and Governance of Countries as Control Variables

The estimation results from the second through fifth rows in Table 6 were produced by using some control variables concerning the capacity of each sub-Saharan African country in terms of medical services and administration of the government. The details are provided in Appendix Table 1. The first control variable is health expenditure per person based on purchasing power parity (PPP) to adjust the price levels of each country. The total number of distributed vaccines was

[12] The data source is "Our World in Data." Its categorization of "Africa" include Algeria, Egypt, Libya, Morocco, St. Helena, and Tunisia in addition to 49 sub-Saharan Africa countries used in this study.
[13] The authors of this study appreciate Sangho Kim and referees of this journal for suggestions to do these sensitivity analyses.

restored as the dependent variable. The estimated elasticity with respect to health expenditure per person was 0.525, although it was not statistically significant. Other key variables, the number of infections and population, remain significantly positive, while GNI per capita is not significant.

The second proxy for medical capacity was the number of nurses and midwives per capita. The sign of the estimate of elasticity is negative, with a value of -0.707. As the estimate is not statistically significant, it should be interpreted that this variable is not a determinant of the number of vaccines distributed. The third proxy was the number of medical doctors. The estimate of elasticity with respect to this proxy was also statistically insignificant (0.244). For both exercises, the number of infections and population were significant at the 90% level, whereas GNI per capita was not.

The fourth control variable was the overall CPIA score, which is widely used as a proxy for governance in low-income countries. CPIA is the abbreviation of "Country Policy and Institutional Assessment". The World Bank's International Development Association (IDA), which offers preferential loans to low-income countries, creates and maintains 16 CPIA indicators associated with various aspects of policy formation and institutions. The highest value of each indicator for favorable conditions was 6, while the lowest value was 1. The overall CPIA score was the average of the 16 indicators. The CPIA score is available only for countries in which IDA offers loans. Higher-income countries in sub-Saharan Africa, such as Angola, Botswana, Equatorial Guinea, Eswatini, Gabon, Mauritius, Namibia, Seychelles, and South Africa, are excluded from this regression exercise. Therefore, the sample size was reduced to 40. The estimate of elasticity of the overall CPIA score was also statistically insignificant. Meanwhile, the number of infections and population remained positive and significant.

Table 6. Results of Sensitivity Analyses

Dependent Variable	Explanatory Variables												n R^2	F p-value
	Intercept	# of Infections	# of Deaths	GNI Per Capita	Population	GNI	Health Expenditure Per Capita	# of Nurses Per Capita	# of Doctors Per Capita	CPIA	Cross Product: Infections & GNI	Cross Product: Deaths & GNI		
Vaccines Per Capita	-8.751** (3.600)	0.151 (0.239)		0.753*** (0.185)									49 0.151	9.38 [.000]
Total Vaccines	-4.925 (6.215)	0.343** (0.152)		0.158 (0.286)	0.731*** (0.197)		0.525 (0.412)						48 0.352	5.84 [.001]
Total Vaccines	-4.581 (6.696)	0.694* (0.366)		0.640 (0.505)	.426*** (0.123)			-0.707 (0.706)					42 0.368	12.21 [.000]
Total Vaccines	2.563 (2.816)	0.322*** (0.095)		-0.0523 (0.266)	0.590*** (0.080)				0.244 (0.203)				35 0.838	105.30 [.000]
Total Vaccines	-2.257 (5.581)	0.415** (0.171)		-0.107 (0.436)	0.452*** (0.161)					4.959 (3.895)			40 0.419	7.34 [.000]
Total Vaccines	-23.456 (30.464)	2.369 (2.752)				1.399 (1.199)					-0.080 (0.108)		49 0.338	37.06 [.000]
Total Vaccines	-20.051 (21.324)		3.664 (3.246)			1.317 (0.838)						-0.132 (0.127)	49 0.395	42.16 [.000]

Note: Definitions of the independent variables are given in Appendix Table 1.

(3) Interactions between Need and Economic Capacity

The final sensitivity analysis tested the presence of interactive effects between proxies for needs and economic capacity. This analysis examines whether a low-capacity country exhibits a higher impact of a proxy for the need for vaccines than a high-capacity country. The need-capacity interaction hypothesis can be tested using the following regression equation: (It is assumed that $GNI(= I_i P_i)$ is assumed to be used as a proxy for economic capacity.)

$$ln\, V_i = \beta_0 + \beta_1\, ln\, GNI_i + \beta_2\, ln\, N_i + \beta_3 (ln\, GNI_i \cdot ln\, N_i) + u_i. \quad (4)$$

With this specification, the elasticity of vaccine distribution with respect to a proxy for the need for vaccines is derived as

$$\frac{d\, ln\, V_i}{d\, ln\, N_i} = \beta_2 + \beta_3\, ln\, GNI_i. \quad (5)$$

If the hypothesis of a greater impact of the need for vaccines in low-capacity countries is true, the sign of β_3 is negative.

In Table 6, $ln\, GNI_i \cdot ln\, N_i$ is referred to as a cross product between the logged GNI and logarithm of the proxies for the need for vaccines. Both the number of infections and deaths were used in this exercise. The estimation results are presented in the sixth and seventh rows of Table 6. Irrespective of the proxies for the need for vaccines, the estimates of β_3 is negative and insignificant. It is notable that the estimates of the coefficients of $ln\, GNI_i$ and $ln\, N_i$ turned insignificant.

4.2.4. A Summary of Subsection 4.2

As the analyses in Subsection 4.2.2 indicate, the capacity and need hypotheses hold as the mechanisms of COVID-19 vaccine distribution in sub-Saharan Africa if regression analyses are made with only basic proxies for the need for vaccines and economic capacity. Although large and wealthy countries are likely to secure more vaccines, nations with more COVID-19 cases and deaths tend to receive more vaccines even after the capacity proxies are controlled. Therefore, the need for vaccines is reflected in the number of distributed vaccines.

This conclusion becomes obscure once a different functional form is adopted for the estimation and if cross-products between proxies for the need for vaccines and economic capacity are introduced as explanatory variables, as discussed in Subsection 4.2.3. However, a general tendency displayed in Table 6 is that the number of infections remains significantly positive, even after introducing control variables with the original specification in most cases at the 95% level. These results supported the need hypothesis. The determinants of vaccine distribution among sub-Saharan African countries are explored in the next subsection. .

4.3. Determinants of Vaccine Distribution by Mode

In this subsection, the mechanism of vaccine distribution is examined by mode. There are different modes to procure vaccines such as by payment or free of charge, as mentioned above. Procurement by "bilateral/multilateral agreements" accompanies payments. Vaccines through COVAX are free of charge for low-income countries. Those through "donation" do not require payment by construction. In subsection 4.1, it was found that some vaccine products have mode specializations. In this section, the attributes of vaccine distribution by mode were investigated. The underlying mechanism linking vaccine distribution by mode with some factors is the same as in equation (2). However, the dependent variables in this section are components of V_i by mode, and the explanatory variables are selectively regressed to each dependent variable.

Table 7 displays the ratios of countries that receive COVID-19 vaccines by each distribution mode to the total number of sub-Saharan African countries in this sample of 49. The first column of the table shows that 22.4% of sub-Saharan African countries purchased vaccines under bilateral or multilateral agreements. This implies that more than three-quarter of the countries did not buy any vaccines. Appendix Table 2 details the number of vaccines distributed to each country by mode and product as of November 14, 2021.

Table 7. Ratios of Countries Receiving Vaccines in Each Mode of Distribution

Mode	Bilateral/multilateral agreements	Donation	COVAX	AVAT	Unknown
Ratio	0.224	0.898	0.918	0.592	0.184

Table 7 reveals that approximately 90% of sub-Saharan African countries procured vaccines through donation and COVAX, respectively. Notably, Eritrea is the only country out of 49 that attained no vaccine by the date of data collection. The proportion of countries that received vaccines by AVAT was 59.2%. Since the establishment of AVAT in early August, the prevalence of this mode was still moderate up to November 2021. Intriguingly, 18.4% of countries received a certain number of vaccines by the "unknown" mode. This implies that nine out of 49 countries had some sources of vaccine procurements, which the recipient or source country did not want to disclose information about, such as the name of the vaccine product or the mode of distribution. Which recipient countries are likely to conceal such information? Some factors correlated with the number of distributed vaccines by mode are explored below.

Table 8 summarizes the simple regression analyses based on equation (2), introduced in subsection 4.1. The regression analysis presented in the previous subsection indicated that population is a strong determinant of the total number of distributed vaccines. Therefore, the population was excluded from the analyses in this subsection. Instead, correlations between the number of distributed vaccines by mode and one among GNI per capita, the number of COVID-19 infection cases, and the number of deaths due to COVID-19 were examined using simple ordinary least squares (OLS) regressions.

As applied to the analyses incorporated in Table 5, the need for vaccines is proxied by the number of COVID-19 infection cases and deaths. Likewise, GNI per capita is used as a proxy for the economic and financial capacity to procure vaccines. Moreover, GNI per capita symbolizes the monetary income richness of each recipient country.

Table 8. Summary of Simple Regression Analyses of Vaccine Distribution by Mode

	Capacity	Need	
Mode	Gross National Income Per Capita	Number of COVID-19 Infection Cases	Number of Deaths Due to COVID-19
Bilateral/multilateral agreements	1.440* (0.757) [0.063]	1.391*** (0.515) [0.010]	1.045** (0.474) [0.032]
Donation	0.307 (0.517) [0.556]	0.174 (0.681) [0.799]	0.039 (0.572) [0.946]
COVAX	-0.287 (0.692) [0.680]	1.431*** (0.421) [0.001]	1.585*** (0.422) [0.000]
AVAT	0.153 (0.978) [0.877]	1.541* (0.880) [0.086]	1.330* (0.734) [0.076]
Unknown	1.957*** (0.729) [0.010]	0.609 (0.735) [0.411]	0.319 (0.629) [0.615]

Note: The logarithm is applied to all variables after replacing 0 with 1. The values in parentheses are heteroscedasticity-consistent standard errors. Those in square brackets are *p*-values. The symbols *, **, and *** signify a significance level of 90%, 95%, and 99%, respectively.

The dependent variables of the analyses summarized in Table 8 are the number of vaccines distributed by each mode on which the logarithm is applied. For countries that do not receive any vaccine in a particular mode, unity is substituted in place of zero. These logged numbers of vaccines distributed by mode were regressed to either GNI per capita, the number of COVID-19 infection cases, or the number of deaths.

An interesting observation found in Table 8 is that while vaccine distribution by "bilateral/multilateral agreements," and "COVAX" are offered generally according to the need for vaccines proxied by infection cases and deaths, those by "donation" do not follow the need at all. Certain criteria beyond the need for vaccines seem to be included in the decision-making mechanism.

Higher income countries are likely to procure more vaccines through payment. The coefficient on GNI per capita in the regression for the mode of "bilateral/multilateral agreements" is significantly positive at the 90% level. The *p*-value of the coefficient with the heteroscedasticity-consistent standard error was 6.3%. Another mode that responds to GNI per capita is vaccine distribution by the "unknown" mode. An interpretation of this observation is that higher income countries in sub-Saharan Africa or their counterparts-sourcing countries tend to hide source and mode of the vaccines. As a result, even the citizens of the recipient country cannot know the number and source of vaccine procurement. This low transparency is more likely to be applied to higher income countries in sub-Saharan Africa.

5. Concluding Remarks

The distribution of COVID-19 vaccines to sub-Saharan Africa is a great challenge in the contemporary world. Since the end of 2019, the world has experienced several waves of COVID-19 infection. These are driven by new strains of the virus. The omicron strain will be spreading in the world by the end of 2021. To mitigate infection with various strains worldwide, the prevalence of vaccination in sub-Saharan Africa is necessary. It is a global risk to keep a geographical area unvaccinated.

This study attempted to address the challenge of enhancing COVID-19 vaccination in sub-Saharan Africa by investigating the mechanism of vaccine distribution within the region. Sub-Saharan African countries try to secure COVID-19 vaccines from various sources in various modes. Which countries have succeeded in obtaining more vaccines? How did they succeed? In contrast, what types of countries are less likely to procure vaccines? These were questions to be addressed in this study.

A feature of this study is the use UNICEF's COVID-19 Vaccine Market Dashboard, which openly provides detailed information on COVID-19 vaccine distribution to around 200 countries and territories. To the best of authors' knowledge, this is the first quantitative study that examines efficiency of vaccine distribution with this data source.

The most appealing finding in this study is that vaccines tend to reach countries where the infection is higher. In that sense, as long as vaccine distribution within sub-Saharan Africa is concerned, a certain degree of efficiency is shown. However, this does not mean that the COVID-19 vaccines supply to sub-Saharan Africa is efficient because the analyses in this study limited its scope to the allocation of vaccines within the continent. Another exercise ahead is a study covering all countries besides sub-Saharan Africa.

Another interesting finding from the analyses of vaccine distribution by mode is that higher income countries in sub-Saharan Africa tend to purchase more vaccines and conceal the sources of vaccines. This is where the strategic actions of the recipient and source countries are involved.

Finally, certain vaccine products follow mode specifications that may incorporate intrinsic vaccine distribution and procurement mechanisms. The dominance of European and US vaccines for vaccine distribution through COVAX may be caused due to the late approval of Chinese vaccines for COVAX. The outstanding presence of Chinese vaccines in commercial sales (bilateral/multilateral agreements) and donations may be the fruit of vaccine diplomacy by China.

A reservation of the conclusions given above is that some are susceptible to functional forms for the regression analyses and control variables introduced to the main explanatory variables, as shown in Table 6. The proxy for the need for vaccines was found to be statistically insignificant when a variation of the original regression equation was used, and when cross products were introduced as explanatory variables. It appears that they are, at least partially, caused by the small sample size of the data used in this study, which should be counted as an intrinsic weakness of this analysis.

The distribution of COVID-19 vaccines in sub-Saharan African countries is not completely random. Large and high-income countries tend to procure more vaccines by exerting economic and political power. However, they are not the sole determinants of vaccine distribution. Though the capacity effect is evident, there exist mechanisms that distribute vaccines based on the number of infections and deaths. There may be more factors manipulating the vaccine distribution by mode and product, which were indicated, but not sufficiently elaborated in this study.

References

Aborode, A.T., Olofinsao, O.A., Osmond, E., Batubo, A.P., Fayemiro, A., Sherifdeen, O., Muraina, L., Obadawo, B.S., Ahmad, S. & Fajemisin, E.A. (2021). Equal access of COVID-19 vaccine distribution in Africa: challenges and way forward. *Journal of Medical Virology, 93*, pp.5212-5215.

African Union (AU). (2021). About AVAT. https://au.int/en/newsevents/20210903/african-vaccine-acquisition-trust-delivers-12-000-doses-covid-19-vaccine-african

Ahuja, A., Athey, S., Baker, A., Budish, E., Castillo, J.C., Glennerster, R., Kominers, S.D., Kremer, M., Lee, J., Prendergast, C., Snyder, C.M., Tabarrok, A., Tan, B.J. & Więcek, W. (2021). Preparing for a Pandemic: Accelerating Vaccine Availability. *AEA Papers and Proceedings, 111*, pp.331-35. DOI: 10.1257/pandp.20211103

Airfinity (2021). Airfinity COVID-19. https://www.airfinity.com/areas/covid-19

Castillo, J.C., Ahuja, A., Athey, S., Baker, A., Budish, E., Chipty, T., Glennerster, R., Kominers, S.D., Kremer, M., Larson, G., Lee, J., Prendergast, C., Snyder, C.M., Tabarrok, A., Tan, B.J. & Więcek, W. (2021). Market design to accelerate COVID-19 vaccine supply. *Science, 371*(6534), pp.1107-1109. DOI: 10.1126/science.abg0889

COVAX (2021). What is COVAX? https://www.gavi.org/covax-facility

de Oliveira, B.R.B., et al. (2021). Determinants of access to the SARS-Cov-2 Vaccine: A preliminary approach. *International Journal for Equity in Health, 20*(183). DOI: 10.1186/s12939-021-01520-4

Diamond, J. & Robinson, J. (Ed.) (2010). *Natural experiments of history*. Massachusetts: Belknap Press of Harvard University Press.

Feenstra, R. C. (2004). *Advanced international trade: Theory and evidence*. Princeton University Press.

Inaba, M. (2021). Post-Corona wo kirihiraku Africa no shozo (in Japanese: Africa's great figures who lead the post-Corona world). *Sekai* (949), 190-199.

International Monetary Fund (IMF) and World Health Organization (WHO). (2021). IMF-WHO COVID-19 Vaccine Tracker. https://www.imf.org/en/Topics/imf-and-covid19/IMF-WHO-COVID-19-Vaccine-Tracker

Our World in Data (OWID). (2021). Statistics and Research: Coronavirus (COVID-19) Vaccinations. https://ourworldindata.org/covid-vaccinations

Roghani, A. (2021). The relationship between macro-socioeconomic determinants and COVID-19 vaccine distribution. *AIMS Public Health, 8*(4), pp.655–664. DOI: 10.3934/publichealth.2021052

Singh, B. & Chattu, V.K. (2021). Prioritizing 'equity' in COVID-19 vaccine distribution through Global Health Diplomacy. *Health Promotion Perspectives, 11*(3), pp.281-287. DOI: 10.34172/hpp.2021.36

United Nations Development Programme (UNDP), WHO, and the University of Oxford. (2021). Global Dashboard for Vaccine Equity. https://data.undp.org/vaccine-equity/

United Nations Children's Fund (UNICEF). (2020). UNICEF launches COVID-19 vaccine market dashboard. https://www.unicef.org/rosa/press-releases/unicef-launches-covid-19-vaccine-market-dashboard

United Nations Children's Fund (UNICEF). (2021). COVID-19 vaccine market dashboard. https://www.unicef.org/supply/covid-19-vaccine-market-dashboard

World Bank. (2021). Press Release. https://www.worldbank.org/en/news/press-release/2021/08/05/africa-announces-the-rollout-of-400m-vaccine-doses-to-the-african-union-member-states-and-the-caribbean

World Health Organization (WHO). (2021a). WHO Coronavirus (COVID-19) Dashboard, Situation by Region, Country, Territory & Area. https://covid19.who.int/table

World Health Organization (WHO). (2021b). COVID-19 Vaccines EUL issued. https://extranet.who.int/pqweb/vaccinescovid-19-vaccine-eul-issued

World Health Organization (WHO). (2021c). The COVAX facility, First round of allocation: Astra Zeneca/Oxford vaccine (manufactured by AstraZeneca & licensed and manufactured by Serum

Institute of India), Feb-May 2021. 2 March. https://cdn.who.int/media/docs/default-source/3rd-edl-submissions/covax-first-round-allocation-of-az-and-sii-az---overview-tablev2.pdf?sfvrsn=85879c81_1&download=true

Appendices

Appendix Table 1. Basic Statistics of Key Variables

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Total Vaccines Distributed (Unit: doses. As of November 14, 2021)	49	3,983,995	5,590,988	0	26,200,000
GNI per Capita (USD, 2020)	49	2,190	2,839	104	14,505
Population (Estimate, 2020)	49	23,200,000	35,600,000	98,462	206,000,000
Number of Infected People (As of November 12, 2021)	49	121,909	415,858	3,730	2,924,622
Deaths Due to COVID-19 (As of November 12, 2021)	49	3,051	12,688	14	89,435
Current Health Expenditure Per Capita (2019. Purchasing Power Parity. Current International $)	48	276	356	41	1476
Number of Nurses and Midwives Per 1,000 People (Latest Value within 2016-2019)	42	1.13	0.95	0.12	4.14
Number of Physicians Per 1,000 People (Latest Value within 2016-2019)	35	0.32	0.57	0.04	2.53
Overall CPIA Score (2020)	40	3.11	0.54	1.48	4.07

Note: CPIA is the abbreviation of Country Policy and Institutional Assessment. The overall CPIA score is known as "IDA resource allocation index". The International Development Association (IDA), a body of the World Bank serving for low income countries. CPIA consists of 16 indices taking 1 as the lowest and 6 as the highest. The overall CPIA score is the average of 16 indices.

Sources:

Total Vaccines Distributed. UNICEF, COVID-19 Vaccine Market Dashboard (http://bit.ly/2NgN9w0).

GNI per Capita. United Nations Department of Economic and Social Affairs (https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/2021-retrospective-review-official.xlsx)

Population. United Nations Department of Economic and Social Affairs, *World Population Prospects 2019*.

Number of Infected People and Deaths Due to COVID-19. WHO Coronavirus (COVID-19) Dashboard (https://covid19.who.int/).

Health Expenditure, Nurses and Midwives, Physicians and CPIA. World Bank, World Development Indicators (https://databank.worldbank.org/source/world-development-indicators)

Appendix Table 2. Vaccines Distributed by Bilateral and Multilateral Agreements (Doses)

	Bharat Biotech	Janssen	Pfizer BioNTech	Serum Institute	Sinopharm	Sinovac	Sputnik
Angola	0	0	0	0	0	0	40,000
Benin	0	0	0	0	0	103,000	0
Botswana	0	0	0	0	0	0	0
Burkina Faso	0	0	0	0	0	0	0
Burundi	0	0	0	0	0	0	0
Cabo Verde	0	0	0	0	0	0	0
Cameroon	0	0	0	0	0	0	0
Central African Republic	0	0	0	0	0	0	0
Chad	0	0	0	0	0	0	0
Comoros	0	0	0	0	0	0	0
Congo, Democratic Republic of	0	0	0	0	0	0	0
Congo, Republic of	0	0	0	0	0	0	0
Cote d'Ivoire	0	0	0	0	0	0	0
Djibouti	0	0	0	0	0	100,000	0
Equatorial Guinea	0	0	0	0	0	0	0
Eritrea	0	0	0	0	0	0	0
Eswatini	0	0	0	0	0	0	0
Ethiopia	0	0	0	0	0	0	0
Gabon	0	0	0	0	0	0	0
Gambia	0	0	0	0	0	0	0
Ghana	0	0	0	2,000	0	0	21,000
Guinea	0	0	0	0	0	300,000	40,000
Guinea-Bissau	0	0	0	0	0	0	0
Kenya	0	0	0	0	0	0	0
Lesotho	0	0	0	0	0	0	0
Liberia	0	0	0	0	0	0	0
Madagascar	0	0	0	0	0	0	0
Malawi	0	0	0	0	0	0	0
Mali	0	0	0	0	0	0	0
Mauritania	0	0	0	0	0	0	0
Mauritius	200,000	0	0	100,000	0	0	120,000
Mozambique	0	0	0	0	1,500,000	0	0
Namibia	0	0	0	0	250,000	0	0
Niger	0	0	0	0	0	0	0
Nigeria	0	0	0	0	0	0	0
Rwanda	0	0	0	0	0	0	0
Sao Tome and Principe	0	0	0	0	0	0	0
Senegal	0	0	0	0	200,000	0	0
Seychelles	0	0	0	0	0	0	0
Sierra Leone	0	0	0	0	0	0	0
Somalia	0	0	0	0	0	0	0
South Africa	0	80,000	325,260	1,000,000	0	0	0
South Sudan	0	0	0	0	0	0	0
Sudan	0	0	0	0	0	0	0
Tanzania	0	0	0	0	0	0	0
Togo	0	0	0	0	0	0	0
Uganda	0	0	0	0	0	0	0
Zambia	0	0	0	0	0	0	0
Zimbabwe	0	0	0	0	3,644,000	5,200,000	0

Source: UNICEF, COVID-19 Vaccine Market Dashboard (http://bit.ly/2NgN9w0) (As of November 14, 2021).

Appendix Table 3. Vaccines Distributed as Donation (Doses)

	AstraZeneca	Bharat Biotech	Pfizer BioNTech	Serum Institute	Sinopharm	Sinovac	Sputnik	Unknown
Angola	720,000	0	0	0	200,000	0	50,000	50,000
Benin	0	0	0	0	0	100,000	0	0
Botswana	0	30,000	0	0	0	200,000	0	0
Burkina Faso	0	0	0	0	0	0	0	0
Burundi	0	0	0	0	500,000	0	0	0
Cabo Verde	0	0	0	0	50,000	0	0	48,000
Cameroon	0	0	0	0	200,000	0	0	0
Central African Republic	0	0	0	0	0	150,000	0	0
Chad	0	0	0	0	200,000	0	0	0
Comoros	0	0	0	0	100,000	0	0	0
Congo, Democratic Republic of	0	0	0	50,000	0	400,000	0	0
Congo, Republic of	0	0	0	0	400,000	0	0	0
Cote d'Ivoire	0	0	0	50,000	100,000	0	0	0
Djibouti	0	0	0	0	200,000	0	0	0
Equatorial Guinea	0	0	0	0	300,000	0	0	0
Eritrea	0	0	0	0	0	0	0	0
Eswatini	0	0	0	20,000	0	0	0	0
Ethiopia	0	0	0	0	1,500,000	200,000	0	0
Gabon	0	0	0	0	400,000	0	0	0
Gambia	0	0	0	0	10,000	0	0	0
Ghana	1,500,000	0	0	215,000	0	0	0	0
Guinea	0	0	0	0	400,000	0	0	0
Guinea-Bissau	0	0	0	12,000	300,000	0	0	24,000
Kenya	1,622,100	0	0	100,000	200,000	0	0	0
Lesotho	0	0	0	0	203,340	0	0	0
Liberia	0	0	0	27,000	0	0	0	0
Madagascar	0	0	0	0	0	0	0	0
Malawi	0	0	0	152,000	0	0	0	0
Mali	0	0	0	0	0	0	0	0
Mauritania	0	0	5,000	0	330,000	0	0	0
Mauritius	0	0	0	100,000	100,000	0	0	0
Mozambique	0	0	0	100,000	260,000	0	0	100,000
Namibia	275,000	0	0	30,000	20,000	100,000	45,000	0
Niger	0	0	0	25,000	400,000	0	0	0
Nigeria	0	0	0	400,000	0	0	0	0
Rwanda	1,057,000	0	751,140	50,000	200,000	0	0	0
Sao Tome and Principe	37,000	0	0	0	0	0	0	12,000
Senegal	0	0	0	25,000	300,000	0	0	0
Seychelles	0	0	0	50,000	75,000	0	0	0
Sierra Leone	0	0	0	0	400,000	0	0	0
Somalia	0	0	0	0	200,000	0	0	0
South Africa	0	0	0	0	0	0	0	0
South Sudan	0	0	0	59,000	0	0	0	0
Sudan	0	0	0	0	250,000	0	0	0
Tanzania	0	0	0	0	500,000	0	0	0
Togo	0	0	0	45,000	0	400,000	0	0
Uganda	335,500	0	0	100,000	0	1,000,000	0	0
Zambia	0	0	0	0	100,000	0	50,000	0
Zimbabwe	0	0	0	35,000	900,000	0	65,000	0

Source: UNICEF, COVID-19 Vaccine Market Dashboard (http://bit.ly/2NgN9w0) (As of November 14, 2021).

Appendix Table 4. By COVAX, African Vaccine Acquisition Trust, Unknown and Total (Doses)

	COVAX							AVAT	Unknown	Total
	AstraZeneca	Janssen	Moderna	Pfizer BioNTech	Serum Institute	Sinopharm	Sinovac	Janssen		
Angola	1,181,040	0	0	3,518,190	1,119,000	1,226,400	0	468,000	0	8,572,630
Benin	134,400	806,400	0	332,280	144,000	0	50,400	297,600	0	1,968,080
Botswana	502,560	0	0	101,790	0	0	0	432,000	0	1,266,350
Burkina Faso	222,800	302,400	0	0	0	674,400	0	151,200	0	1,350,800
Burundi	0	0	0	0	0	0	0	0	0	500,000
Cabo Verde	31,200	0	100,100	5,850	24,000	0	0	0	320,429	579,579
Cameroon	198,400	639,050	0	0	391,200	0	0	460,800	0	1,889,450
Central African Republic	80,160	638,400	0	0	80,000	0	0	0	0	948,560
Chad	0	0	0	333,450	0	0	0	0	0	533,450
Comoros	0	0	0	0	0	0	0	0	397,874	497,874
Congo, Democratic Republic of	51,840	0	250,320	749,970	271,000	0	0	756,000	0	2,529,130
Cote d'Ivoire	1,981,140	0	0	2,069,730	604,000	1,165,200	0	230,400	0	6,200,470
Djibouti	0	151,200	0	0	24,000	0	0	0	0	475,200
Equatorial Guinea	0	0	0	0	0	0	0	0	182,311	482,311
Eritrea	0	0	0	0	0	0	0	0	0	0
Eswatini	14,400	302,400	0	100,620	24,000	0	0	0	0	461,420
Ethiopia	2,779,440	2,621,750	0	1,552,590	2,184,000	1,993,200	0	271,200	0	13,102,180
Gabon	0	168,000	0	202,410	0	0	0	0	0	770,410
Gambia	38,400	302,400	0	0	36,000	0	0	52,800	0	439,600
Ghana	1,714,320	0	1,229,620	1,330,290	950,000	0	0	1,178,400	0	8,140,630
Guinea	305,760	336,000	188,400	588,510	194,400	0	1,272,000	108,000	0	3,733,070
Guinea-Bissau	28,800	302,400	0	0	28,800	0	0	0	0	696,000
Kenya	2,516,240	0	1,760,780	2,032,290	1,092,000	0	0	897,600	0	10,221,010
Lesotho	36,000	302,400	0	100,620	36,000	0	0	259,200	0	937,560
Liberia	192,000	470,400	0	0	96,000	0	0	381,600	0	1,167,000
Madagascar	242,240	638,750	0	0	250,000	468,000	0	0	0	1,598,990
Malawi	1,273,440	640,350	0	186,030	360,000	0	0	151,200	0	2,763,020
Mali	79,200	319,200	0	0	296,000	0	835,200	0	0	1,529,600
Mauritania	484,800	302,400	0	104,130	69,600	0	0	352,800	214,681	1,863,411
Mauritius	100,800	0	0	76,050	0	0	0	288,000	855,930	1,940,780
Mozambique	1,610,620	638,400	0	0	384,000	2,715,477	0	705,600	191,285	8,205,382
Namibia	108,000	0	0	224,640	0	0	0	331,200	0	1,383,840
Niger	206,400	638,400	0	0	355,200	928,800	0	0	0	2,553,800
Nigeria	9,716,240	0	4,000,080	3,577,860	3,924,000	0	0	1,797,600	0	23,415,780
Rwanda	1,081,100	0	0	2,261,610	370,000	690,000	0	259,200	722,128	7,442,178
Sao Tome and Principe	24,000	0	0	0	24,000	0	0	79,200	0	176,200
Senegal	1,329,260	638,400	0	265,590	324,000	277,200	0	158,400	0	3,517,850
Seychelles	0	0	0	35,100	0	0	0	0	27,482	187,582
Sierra Leone	280,800	151,200	0	401,310	96,000	0	0	240,000	0	1,569,310
Somalia	880,800	638,900	0	0	300,000	231,600	0	0	0	2,251,300
South Africa	0	0	0	9,269,910	0	0	0	0	15,540,435	26,215,605
South Sudan	59,520	152,950	0	0	60,000	0	0	0	0	331,470
Sudan	876,000	606,700	0	499,590	828,000	1,317,600	0	158,400	0	4,536,290
Congo, Republic of	0	470,400	0	0	0	228,000	0	204,000	0	1,302,400
Togo	383,160	0	0	405,990	296,000	0	1,027,200	592,800	0	3,150,150
Uganda	3,133,660	0	2,551,220	5,163,210	864,000	346,800	0	657,600	0	14,151,990
Tanzania	0	1,228,350	0	0	0	2,078,400	0	0	0	3,806,750
Zambia	757,300	974,400	188,400	0	228,000	0	0	338,400	0	2,636,500
Zimbabwe	0	0	0	0	0	1,378,800	0	0	0	11,222,800

Source: UNICEF, COVID-19 Vaccine Market Dashboard (http://bit.ly/2NgN9w0) (As of November 14, 2021).