

Distributing a billion vaccines: COVAX successes, challenges, and opportunities

Eric Budish,^{*} Hannah Kettler,^{**} Scott Duke Kominers,^{***}
Erik Osland,[†] Canice Prendergast,^{††} and
Andrew A. Torkelson^{†††}

Abstract: By January 2022, the COVAX international vaccine collaboration had allocated over a billion vaccines to over 140 countries. We describe and review the allocation process chosen, which reflected both an objective of equitably distributing vaccines across the world and the need to fund that mission. We show how vaccine supply limitations and constraints on some countries' absorptive capacity have affected overall allocative outcomes. We also discuss market design approaches that were considered but not implemented, including the use of an exchange mechanism to better match countries' vaccine allocations to their preferences, as well as a vaccine brokerage under which countries could sell excess vaccines to countries with ongoing need. Our analysis addresses some criticisms of COVAX, and offers suggestions for agencies organizing global vaccine cooperation for future pandemics.

Keywords: Covid-19, pandemic, vaccines, allocation, exchange, brokerage, market design, COVAX

JEL classification: D47, D63, D64, D69, H51, H87, I14, I15, I18, O12

^{*} Booth School of Business, University of Chicago, USA, e-mail: eric.budish@chicagobooth.edu

^{**} COVAX and Gavi, the Vaccine Alliance, Switzerland, e-mail: hkettler@gavi.org

^{***} Entrepreneurial Management Unit, Harvard Business School; Department of Economics and Center of Mathematical Sciences & Applications, Harvard University; and a16z crypto, USA, e-mail: kominers@fas.harvard.edu

[†] Linksbridge SPC, USA, e-mail: erik.osland@linksbridge.com

^{††} Booth School of Business, University of Chicago, USA, e-mail: canice.prendergast@chicagobooth.edu

^{†††} Linksbridge SPC, USA, e-mail: andy.torkelson@linksbridge.com

The authors thank Anais Colombini, Battal Doğan, Andrew Freeman, Lada Georgieva, Nicki Lurie, Sana Mostaghim, Claudia Nannei, Madhav Raghavan, Alex Teytelboym, and members of the Accelerating Health Technologies team—especially Susan Athey, Rachel Glennerster, Michael Kremer, Chris Snyder, and Alex Tabarrok—for helpful discussions and comments. A McKinsey team led by Bart Van de Vyver provided helpful input into examining the logistics of vaccine exchange and brokerage. Kominers gratefully acknowledges the support of the Washington Center for Equitable Growth, as well as the Ng Fund and the Mathematics in Economics Research Fund of the Harvard Center of Mathematical Sciences and Applications. Budish, Kominers, and Prendergast served on a *pro bono* expert group that advised on COVAX allocation and exchange design. Osland and Torkelson, data scientists at Linksbridge SPC, developed the allocation tool algorithm in collaboration with the Joint Allocation Taskforce (JAT) and COVAX through funding from the Bill & Melinda Gates Foundation. A draft of this paper was reviewed and approved by COVAX prior to submission.

<https://doi.org/10.1093/oxrep/grac038>

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I. Introduction

In January 2022, COVAX delivered its billionth Covid-19 vaccine. This was a remarkable achievement—especially since the process of procuring and distributing vaccines globally had been challenging on many fronts. COVAX faced difficulties sourcing vaccines, especially in light of initial global supply scarcity. In addition, COVAX needed to design a complex allocation system to determine which countries would receive which doses when. Some vaccines then had to be reallocated after-the-fact when their recipient countries proved unable or unwilling to absorb them. This all needed to be accomplished equitably—and efficiently—against the backdrop of the worldwide pandemic.

This article describes the evolving mechanisms COVAX used to allocate vaccines to countries, and examines the way in which those mechanisms affected distributional outcomes. In addition to providing insight into the choices COVAX made in its vaccine distribution process and illustrating the resulting market design, our analysis addresses criticism of COVAX, and offers suggestions for agencies organizing international vaccine cooperation for future pandemics.

II. COVAX

COVAX is a partnership of international health organizations led by the Coalition for Epidemic Preparedness Innovations (CEPI), Gavi, the Vaccine Alliance, and the World Health Organization (WHO), along with partner agencies UNICEF and PAHO. From its inception in April 2020, COVAX sought to enable fair and equitable worldwide access to Covid-19 vaccines (see, for example, [Gavi, 2020a](#)). To achieve this, COVAX aimed to establish mechanisms through which all countries, rich and poor, could source vaccines through a pooled procurement facility. At least in theory, if all countries signed up for COVAX, then it could be the common clearinghouse for vaccine purchasing in a way that could enable equitable and efficient worldwide vaccine distribution to be achieved.

From its inception, COVAX faced a series of challenges, some more predictable than others. First, it needed adequate financing to fulfil its mission, which required support from donor agencies, as well as involvement and financial commitments from both high- and middle-income countries. Donors did make substantial pledges early on, and COVAX reached its fundraising targets for its Advanced Market Commitment (AMC) fund. However, COVAX could only close purchasing deals once the donors fulfilled their pledges. Meanwhile, many countries decided to join COVAX as participants out of self-interest—as an insurance mechanism alongside their bilateral deals—rather than being motivated by the broader objective of ensuring worldwide vaccine access through a global mechanism. This left COVAX procuring vaccines in the shadow of countries' bilateral deals, which both limited COVAX's access to vaccine supply until late 2021 and undermined the objective of trying to pace overall vaccination equally across countries. The countries with bilateral deals were able to vaccinate at faster rates than the countries without them, who were more dependent on COVAX. Additionally, the financing model of COVAX was predicated on mostly sourcing low-cost vaccines, yet global supply issues meant that COVAX ended up being more reliant on mRNA vaccines, which were more expensive to purchase and distribute.

COVAX needed funding and political buy-in from a wide range of countries and international organizations. As a result, it designed varied mechanisms for different countries to participate and pay for vaccines.

To encourage participation among high- and upper-middle-income countries, COVAX offered two possible ways for them to purchase vaccines: direct commitments to buy vaccines—the *Committed Purchase* model—or purchase of options on vaccine doses that could be exercised later—the *Optional Purchase* model. One important distinction is that COVAX's vaccine allocation process determined which vaccines the Committed Purchasers received, while the Optional Purchasers were offered the option of procuring some vaccines of each type as they became available.

Through these mechanisms, COVAX attracted 64 countries to participate:

- 35 high-income and upper-middle-income countries became '*Optional Self-Financing Purchasers*'. Here a country such as the United Kingdom agreed to hold an option on vaccine doses, where it would decide whether to exercise that option when those vaccines became available. Each country in this category chose a fraction of its population (between 10 and 50 per cent) as the extent of its option contract. These contracts involved a non-refundable upfront fee of \$3.10 per vaccine dose, and a further fee of \$7.45 per vaccine dose if it exercised the option (COVAX, 2020).
- 29 mostly middle-income countries that joined COVAX chose the second category of membership, becoming '*Committed Self-Financing Purchasers*'. These buyers committed to vaccine contracts up to a specified percentage of their population. Unlike the Optional Purchasers, these members committed to purchase vaccines from COVAX, and COVAX determined which vaccine(s) they would be offered via its centralized allocation mechanism. These contracts had a lower upfront fee at \$1.60 per dose, with a further \$8.95 due upon receipt (COVAX, 2020).

The final group of COVAX members comprised the *Advanced Market Commitment* ('AMC') countries, comprising 89 (out of the 92 eligible) low- and lower-middle-income countries. These countries could receive vaccines free of charge, initially funded through an 'AMC Fund' managed through COVAX. As with the Committed Purchasers, the COVAX allocation mechanism determined which vaccines the AMC countries would receive. In addition to sourcing vaccines directly, COVAX also eventually designed and implemented a mechanism called *Dose Sharing* through which COVAX could receive and distribute vaccine donations, primarily from high-income countries and to AMC countries.¹

In order to better understand the distinction across countries in practice, it is useful to provide some examples of each category. Optional Purchasers were high-income countries like Canada and the United Kingdom, as well as upper-middle-income countries such as Argentina, Brazil, and Chile. Committed Purchasers included Colombia, Peru, and South Africa. The AMC countries were typically low-income countries—including many of the most populous nations in the world, such as Bangladesh, Indonesia,

¹ Especially early-on in the Dose Sharing programme, donors would often earmark specific countries for receipt, some of whom were self-financing countries rather than AMC countries.

Table 1: Summary of the three COVAX country participation models

Country type	Optional purchase	Committed purchase	AMC
Number	35	29	89
Funding source	Self	Self	AMC Fund
Product	Options on vaccines in the COVAX portfolio	Vaccines allocated by COVAX	Vaccines allocated by COVAX
Upfront payment	\$3.10 per dose	\$1.60 per dose	—
<i>Ex post</i> payment	\$7.45 per dose (if option exercised)	\$8.95 per dose	—
Example countries	Argentina, Brazil, Canada, Chile, United Kingdom	Colombia, Peru, South Africa	Bangladesh, Indonesia, Nigeria, Pakistan, the Philippines

Nigeria, Pakistan, and the Philippines.² The three participation models are summarized in [Table 1](#).

The breadth of participation meant that COVAX had to decide how to allocate vaccines across countries fairly as those vaccines became available. COVAX mapped its overall allocative goals into an *allocation mechanism* that determined how each set of vaccine supply contracts to be fulfilled in a given time period would be distributed across COVAX participants; we discuss this mechanism and its implications for overall vaccine access in detail in the next section.

Sometimes countries could not distribute the vaccines COVAX allocated—for example on account of insufficient health care system capacity, or vaccine hesitancy. When a country refused allocated vaccines, COVAX needed a mechanism to fairly reallocate those doses. In section IV, we discuss the *reallocation mechanisms* that COVAX chose to implement, as well as other potential reallocation and exchange mechanisms that COVAX considered but decided not to use.

Our article primarily focuses on COVAX's decisions around allocation and reallocation. As we discuss in section V, just as in other markets, in the context of vaccine distribution, allocation and reallocation are to some degree substitutes for each other. The more effectively the allocation reflects countries' respective needs and preferences, the less reallocation is needed; and conversely, a robust system of vaccine reallocation/exchange can mitigate issues with the initial allocation.

In section VI, we briefly discuss one other mechanism that could potentially have improved the efficiency of global vaccine distribution: *vaccine brokerage*. An important source of supply of vaccines for COVAX was donations from countries with excess supply. Yet some countries were unwilling or unable to donate vaccines—even when they had excess. It thus may have been possible to expand global vaccine distribution by implementing a vaccine brokerage marketplace under which countries could sell excess vaccines to countries with ongoing need.³

We close in sections VII and VIII with some overall learnings and takeaways for thinking about cross-country vaccine access and allocation in future pandemics.

² India was also one of the AMC countries, but its allocated volume in each round was managed separately.

³ COVAX considered such a system, but eventually decided not to implement it in 2021.

III. The COVAX allocation mechanism

We begin by describing the approach COVAX used to *allocate* vaccines, as this represents how its objectives were manifested in a set of policies to assign vaccines to countries. After that we describe how this allocation mechanism was reflected in *delivered* vaccines, which did not always match up with the number allocated due to contractual difficulties, differences in absorptive capacity, and, at times, an unwillingness of countries to accept certain vaccines.

(i) How many vaccines would each country be allocated?

In market design parlance, cross-country vaccine allocation is an example of a relatively novel market design problem—a form of *dynamic combinatorial assignment*.⁴ Different quantities of different vaccines become available over time, and need to be allocated among countries. Countries have heterogeneous preferences over vaccines, owing to differences in vaccine efficacy, technology, logistics, and available quantity. Countries may also need to receive portfolios of different vaccines—sometimes because a particularly desired vaccine is not available, and potentially also because of demand for variety—in an environment where intertemporal substitution of vaccines is potentially important.⁵ And there are also welfare objectives with respect to the overall allocation—for example, aiming to ensure that all countries receive enough vaccines to be able to vaccinate their highest-risk populations.

When COVAX was first established, it aimed to speed all countries towards two thresholds: 3 per cent population coverage (targeting highest-risk populations such as healthcare workers and the immunocompromised), and then 20 per cent population coverage, as supply allowed. When the 3 per cent threshold was reached across all countries, COVAX would then seek to help countries reach the more ambitious target of 20 per cent.

COVAX distributed vaccines in a series of rounds, roughly one round per month;⁶ they were rationed across countries and assigned based upon an allocation algorithm. Early on, the allocation question was essentially a *queuing* problem, determining how many doses of each vaccine tranche a given country would receive at each point in time; later, as more vaccines become available, the allocation process more directly sought to take countries' preferences into account.

⁴ For a discussion of the market design issues surrounding combinatorial assignment, see [Budish \(2011\)](#). For a broader discussion of conceptual frameworks for market design, see [Roth \(2008\)](#) and [Kominers et al. \(2017\)](#). For the specific question of market design with attention to equity in addition to efficiency, see [Dworczak \(r\) al. \(2021\)](#), [Akbarpour \(r\) al. \(2022a\)](#), and the references therein; and see [Akbarpour \(r\) al. \(2022b\)](#) for an application of the [Akbarpour \(r\) al. \(2022a\)](#) framework to the question of vaccine prioritization.

⁵ As an example, the Pfizer BioNTech Covid-19 vaccine requires cold-chain storage, while the AstraZeneca vaccine does not. As a result, the Pfizer vaccine was perceived early on as being easier to distribute in cities, and the AstraZeneca vaccine may have been preferred for distribution in rural areas. As such, all other things being equal, some countries might have requested portfolios of both Pfizer and AstraZeneca vaccines—delivered at times when their health care systems' absorptive capacity allowed it.

⁶ COVAX originally planned to organize the rounds with a predictable cadence, but due to stochasticity of vaccine supply, the rounds ended up being run as vaccines became available—and, moreover, rounds often had to be rerun or rescheduled.

An important design goal was to ensure that any country that was allocated vaccines would be able to use them effectively and quickly. Thus, before a country could receive a given allocation of vaccines, it had to satisfy a series of preparatory steps. First, it was essential to avoid allocating vaccines to a country that could not legally distribute them—either because they had not yet given the vaccine regulatory approval, or because the proper indemnification agreements with manufacturers were not in place. Additionally, countries were required to pass a ‘readiness check’ to make sure they had the proper vaccine distribution infrastructure.⁷

Given the overarching allocative constraints, COVAX aimed to implement an allocation under which all countries would track as evenly as possible in terms of population coverage. The idea was akin to filling up cups representing countries with water representing vaccine supply: each country’s cup would have a width determined by its population; and each round, water would be added to the cups with an eye towards filling them to heights that were as even as possible.

Although COVAX later adjusted the target to be in terms of total vaccine coverage in each country, initially COVAX chose to target proportional coverage in terms of COVAX-allocated vaccine doses. That is, assume that COVAX has received a total of 60 million vaccine courses by round t , and the total population of all member countries is 5 billion. Then it can vaccinate 1.2 per cent of member population in round t . Let q_{it} be the fraction of the population in country i covered by COVAX vaccines by the end of round t and let q_t be the fraction of total COVAX member population that can be covered by all vaccines procured to that point. Then the allocation mechanism was initially designed to target an outcome in which $q_{it} = q_t$.

The proportional allocation target, referred to officially as the ‘Fair Allocation Framework’, was seen as a straightforward approach to provide ‘predictability for both participating manufacturers and countries, while optimizing impact’ (World Health Organization, 2020).

Of course, because vaccines became available at different times and in different quantities, with various lower-bound lot sizes, it was not possible to implement $q_{it} = q_t$ exactly. Instead, COVAX implemented an allocation rule whereby

$$|q_{it} - q_t| < \lambda_i, \quad (1)$$

where λ_i is a tolerance bound for country i . The tolerance levels were set such that the deviation in total vaccines received had to be within one ‘lot size’—that is, the largest lot size available to a given country in the round (World Health Organization, 2021).⁸ If there was only one lot size in a given round, then the tolerance was set to

⁷ In practice, these constraints were enforced post-allocation, in the sense that—especially in early rounds—a country could in principle be allocated a tranche of vaccines that COVAX would later determine it could not receive because of regulatory, identification, or readiness constraints. In that event, the allocated doses would be reallocated *ex post*.

⁸ There was also a per-round minimum number of vaccines that each country would receive. The round minimum was allocated ahead of the proportional allocation pace, and was typically needed for countries with populations of less than 2–3 million people. The size of the round minimum was often governed by policy, and at the smallest country sizes, the round minimum also had to respect constraints around their total vaccine demand.

0, effectively requiring the country to hit its initial target exactly. Lot sizes varied by vaccine, and at times by size of the country, but usually ranged from 1,000 to 150,000 courses. Notable for what follows is that these tolerance levels resulted in an extreme form of equity between countries manifested in very small differences in coverage rates.

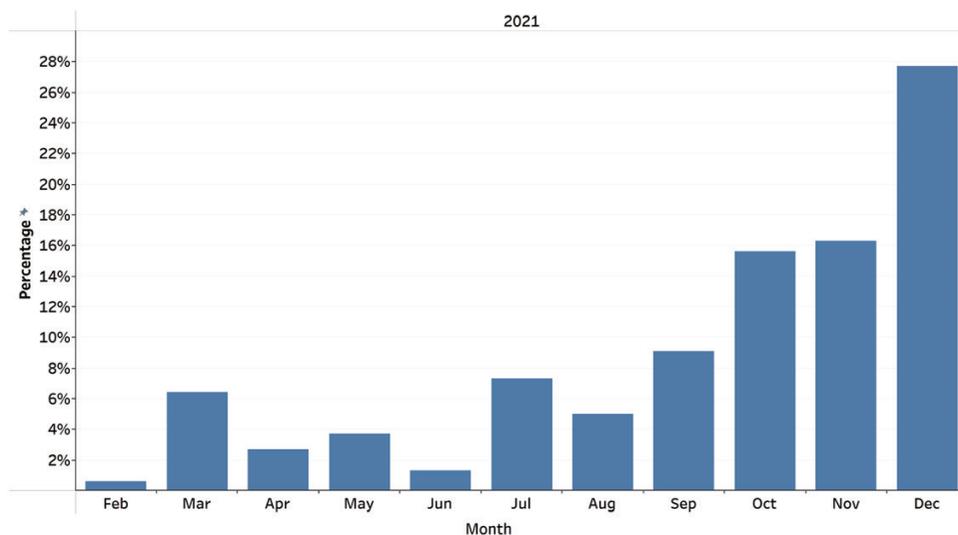
To implement the allocative objective (1), COVAX adopted a mechanism based around a two-stage optimization. First, the algorithm would seek a provisional allocation that was feasible and met the equity target as closely as possible. Then, in a second stage, the algorithm would try to optimize the allocation according to countries' preferences, subject to the constraint that the quantities assigned to each country could only deviate from those assigned in the first stage by at most λ_i per capita. Across rounds, if a country had expressed interest in receiving the same vaccine consistently, then the allocation would attempt to give that country the same vaccine across rounds, partially overriding attention to the country's stated preferences over particular vaccines. Implementing all of this through an integer programming formulation also made it possible to include a range of feasibility constraints on the allocation, including the indemnification constraints, as well as destination constraints (earmarking) and demand constraints (reflecting, for example, absorptive capacities and cold-chain storage capability).

(ii) Supply: the experience of 2021

The allocation system just described was inspired by the idea that high-, middle-, and low-income countries would proceed to vaccinate their populations at roughly the same pace. To realize that vision would require both that countries relied on COVAX for most of their vaccines (and so were allocated doses through the mechanism) and that COVAX would receive the supply of doses it needed to keep pace with countries receiving doses through bilateral deals.

The reality turned out to be very different. High-income countries and many middle-income countries negotiated multiple bilateral deals with vaccine manufacturers directly—in some cases, for volumes sufficient to vaccinate their populations many-fold. This meant that those countries had access to more supply ahead of those countries dependent on COVAX. Moreover, countries' early and large bilateral deals reduced timely supply available to COVAX and left COVAX bidding on behalf of relatively smaller volumes, with donor funds for the AMC that were provided relatively late—reducing COVAX's influence on the manufacture of early doses.

For the AMC countries, in particular, COVAX was relying on its early access to significant volumes of AstraZeneca doses through technology transfer to the Serum Institute of India. However, in March 2021, the Indian government imposed an export ban on vaccines to prioritize its domestic fight with the virus, cutting off the Serum Institute supply source until late Q3 2021. This resulted in a delay of over 130m doses—more than the total number of vaccines COVAX had distributed worldwide by June 2021. Not only were the Serum Institute doses contracted specifically for AMC countries, they were also relatively inexpensive. While COVAX substituted part of the delayed Serum Institute supply with alternative sources of AstraZeneca vaccines, it also had to look to other products—Sinovac and Sinopharm from China, as

Figure 1: COVAX vaccines (allocated) as a percentage of worldwide vaccines administered in 2021

well as the vaccines from Pfizer and Moderna, which were relatively more expensive and harder to store and distribute.⁹

Figure 1 plots the percentage of all worldwide vaccines allocated by COVAX in 2021, using data on world vaccine coverage from [Our World in Data \(2022\)](#). From a local maximum of 6.4 per cent in March, the percentage falls to only 1.2 per cent by June; and only after October does it reach double digits. But by December, COVAX allocations constituted over a quarter of all worldwide vaccine distribution.¹⁰

The decline in March and April 2021 that persisted through June coincides with India's vaccine export ban. The slow but steady ramp-up in Q3 2021 coincides with increased volumes of donations from high-income countries and, in Q4, also the lifting of the export ban and manufacturers finally fulfilling larger shares of COVAX's orders.

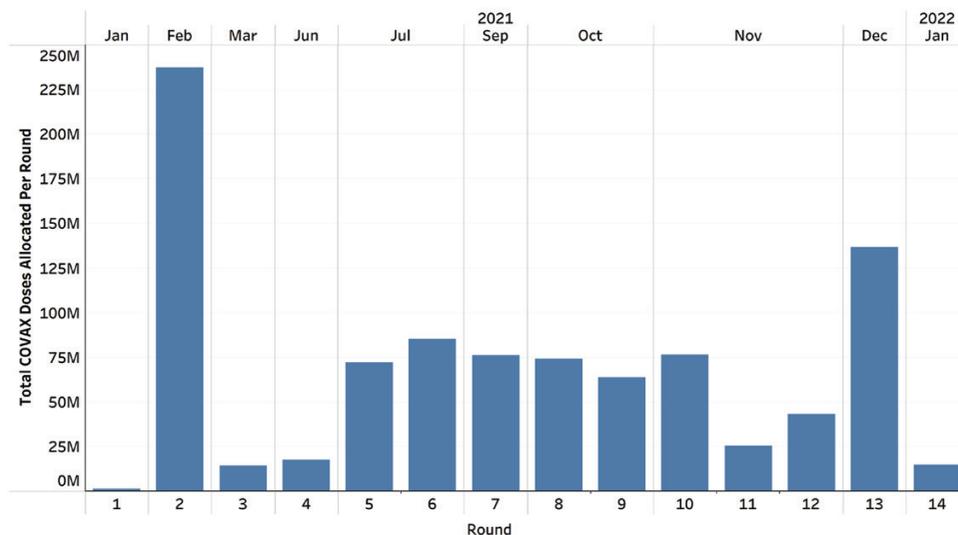
Given this backdrop, Figure 2 shows the timing and number of doses allocated by COVAX per round. We include data from the first 14 rounds, from a small allocation at the end of January 2021, to the end of January 2022. After a large allocation in round 2, COVAX began to face sourcing difficulties that continued until Q3 2021.

The distribution of vaccine types allocated by round is given in Figure 3. As Figure 3 illustrates, difficulties in sourcing vaccines had direct implications for the types of vaccines allocated. The export ban on India-made vaccines resulted in greater reliance both on AstraZeneca vaccine doses from elsewhere as well as vaccines from Pfizer BioNTech, which were available thanks in great part to the United States' provision of Pfizer vaccines to COVAX (see, for example, [Kaiser Family Foundation, 2021](#)).

The COVAX budget model had relied on access to low-cost vaccines through the Serum Institute. In round 2, COVAX was on track to meet targets with the Serum

⁹ Unfortunately, another relatively affordable and easy to distribute vaccine from Johnson & Johnson faced severe supply delays around the same time (see [Robbins et al., 2021](#)).

¹⁰ After that, volumes dropped steeply again—although this time due to slow/limited demand rather than limited supply.

Figure 2: COVAX round dates and vaccines allocated¹¹

Institute and AstraZeneca vaccines, the former representing 60 per cent of vaccines allocated. However, the need to rely more on mRNA vaccines put pressure on the budget: even though many of those vaccine doses were donated, they were still more expensive to distribute because of the need for cold-chain storage.

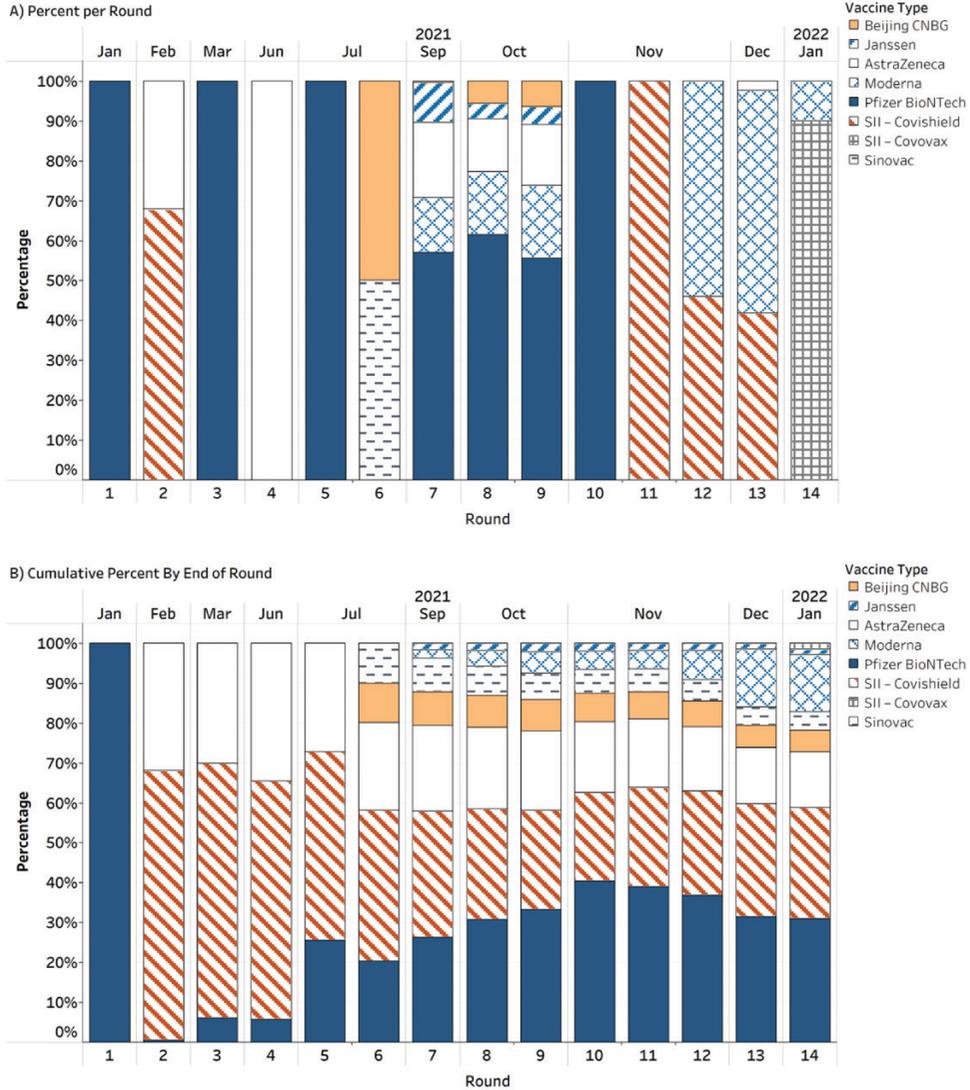
(iii) Vaccine distribution across countries

We now turn to how COVAX distributed its supply of vaccines. We first show a variety of measures reflecting how COVAX's preferences for equitable vaccines were implemented, and then evaluate the allocation in the broader context of country-level vaccine coverage.

We first show that the equity rule in (1) performed as intended, by equalizing per capita vaccine coverage from COVAX as much as possible. As an example, [Figure 4](#) shows coverage rates in allocation round 2 for countries earmarked for AstraZeneca vaccines manufactured by SK bioscience, which occurred in February 2021; the figure shows the relationship between total coverage from COVAX (percentage of population) and both the log of courses allocated and log population. Note here the extent to which the allocations for the AMC and Committed countries almost perfectly lie on the 'Target for Round' line, meaning that these countries received almost precisely what they were intended to receive under the equity rule (1). Indeed, for countries above a population of 1 million, outcomes almost perfectly matched the target rule. Countries with a population below 1 million were allocated the per-round minimum, leading there to be a gradual increase in total coverage as

¹¹ Round 1 allocated 1.2m doses—small relative to subsequent rounds, and thus difficult to see in the figure's scale.

Figure 3: Vaccine types allocated by COVAX



population decreased. Total coverage was capped at 20 per cent to prevent the round minimum from increasing the total coverage of countries with populations below 200,000 from exceeding the Phase 1 target. The only substantive differences were for very small countries such as Nauru and Bermuda, where the lot size reflected a substantive fraction of required coverage in each round.

Moreover, as can be seen in Figure 4, for most countries, allocated doses by the end of round 2 very closely corresponded to 2.1 per cent coverage rates.

We now more broadly illustrate COVAX’s commitment to its equity rule. First, Figure 5 shows population coverage from COVAX-distributed vaccines for each buyer type.

Figure 4: The relationship between population and COVAX vaccine allocations by the end of round 2 for countries earmarked for AstraZeneca manufactured by SK bioscience

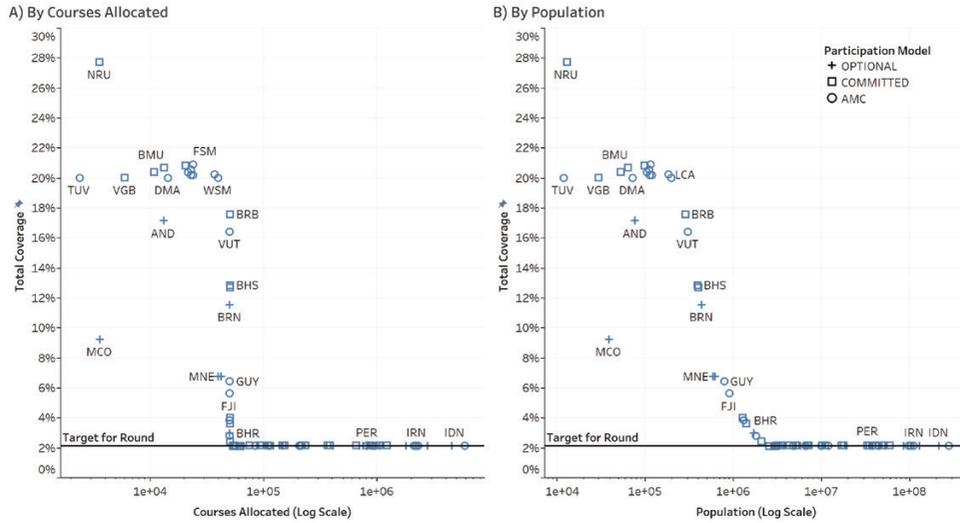


Figure 5: Cumulative course coverage allocated by COVAX by allocation round (population-weighted)

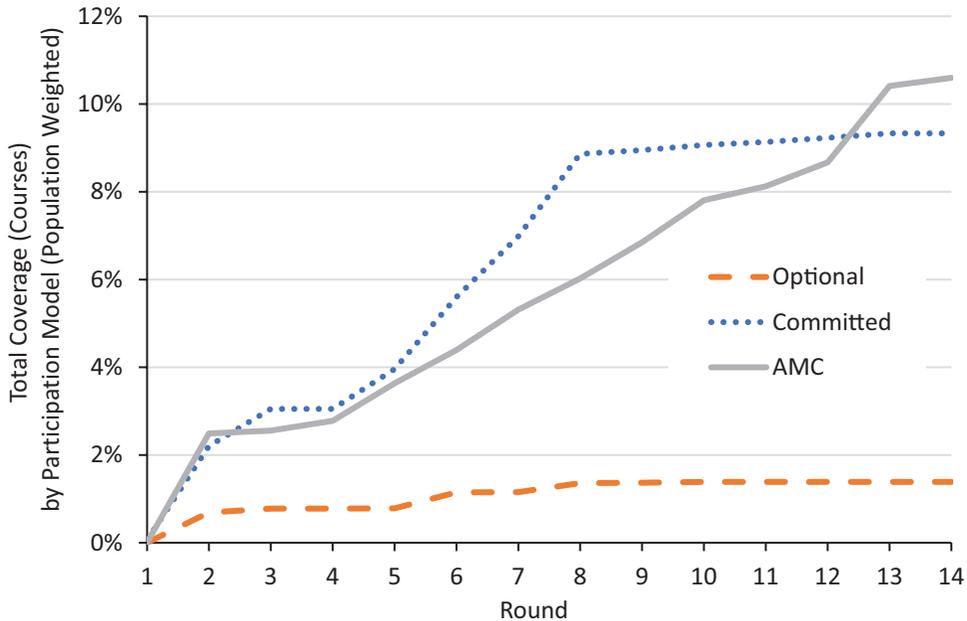
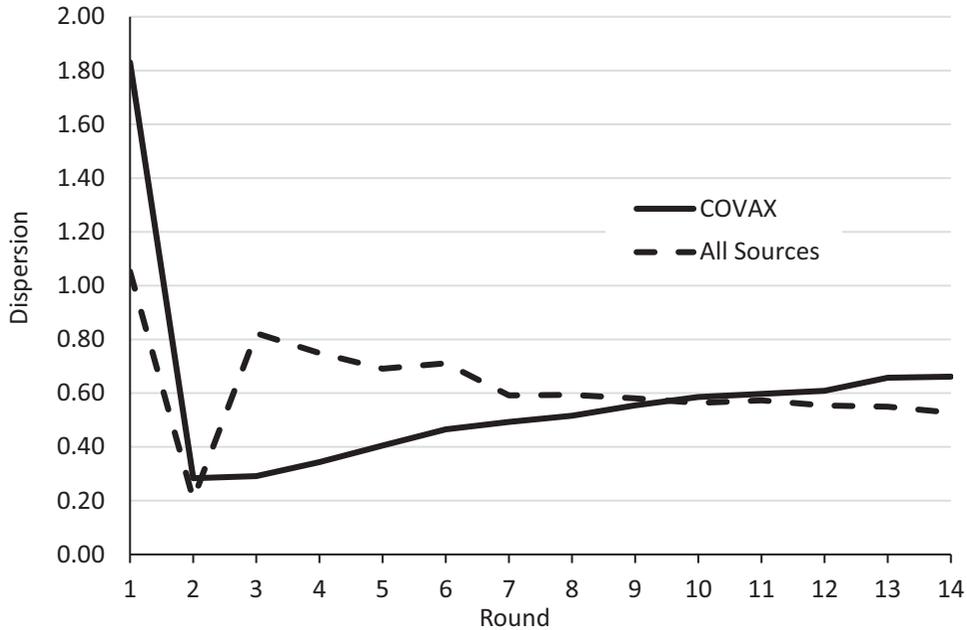


Figure 5 shows the extent to which outcomes throughout 2021 reflected COVAX’s stated objectives. Coverage for both Committed and AMC countries overall tracked each other closely. While coverage rates from COVAX vaccines for the Committed countries were higher than for AMC countries until the start of 2022, this is in part

Figure 6: The dispersion of COVAX allocations and total population coverage across countries by round (Committed Purchase and AMC Countries only)



because AMC countries were disproportionately impacted by India’s vaccine export ban. By the end of round 14 (January 2022), vaccines from COVAX had offered total courses to roughly 9–10 per cent of both buyer groups.

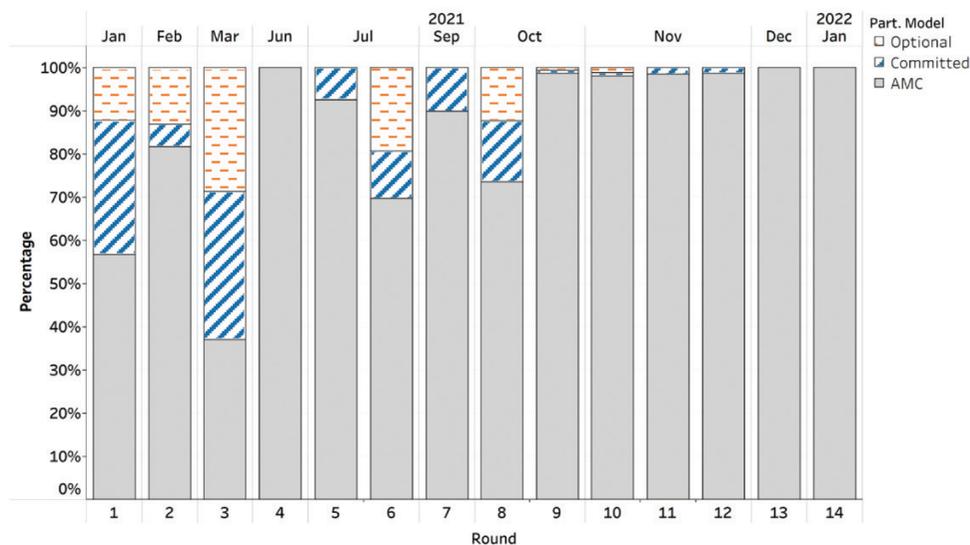
Also note the significant number of vaccines allocated to the Optional Purchasers early on. By round 10, COVAX had fulfilled its obligations to Optional Purchasers; it fulfilled its obligations to the Committed Purchasers by round 12. After those dates, COVAX vaccines were allocated almost exclusively to AMC countries.

A single aggregate measure of cross-country dispersion in allocations from COVAX is the average absolute deviation of vaccine distribution from the rule posited above. Let \bar{q}_{it} be the total per capita distribution of vaccines from COVAX to country i up to and including round t . Let \bar{q}_t be the average of \bar{q}_{it} across all countries. Finally, let ω_i be the share of total member population that is country i . Then

$$S_t = \sum_i \omega_i \left| \frac{\bar{q}_{it} - \bar{q}_t}{\bar{q}_t} \right|$$

measures the average proportional distance that a randomly chosen vaccine is from the conceptual benchmark of equal per capita allocations from COVAX. The unit of analysis is the representative vaccine, not the representative country—that is, S_t is weighted by country size to reduce the weight on the small countries, in order to better represent average outcomes. An advantage of this measure is that it also makes it possible to see variation in vaccine coverage within the AMC and Committed Purchase country groups. The solid line in Figure 6 presents S_t for all rounds for AMC and Committed countries.¹²

¹² The data are not meaningful for round 1, as this was an initial test with very few vaccines.

Figure 7: COVAX vaccines allocated to each country type in each round

Notable from [Figure 6](#) is COVAX's strong commitment to equity in allocations in its early rounds. Until round 4 (roughly summer of 2021), dispersion averaged 0.3, meaning that the average vaccine allocated was within 30 per cent of the conceptual benchmark of equal allocations across countries. A significant reason for *any* observed variation from equality was that some AMC countries were ineligible for the vaccines that were available early (especially the Pfizer vaccine, which required cold-chain storage), and/or that they had low absorptive capacity and simply could not distribute the share of vaccines that they otherwise would have received.

Overall, S_t for COVAX-distributed vaccines increased from 0.29 in March 2021 to 0.66 by December 2021. This reflected several considerations. First, after the summer of 2021, COVAX re-evaluated its allocation process and began to prioritize based on total population coverage rather than coverage just from COVAX vaccines. This led to more direct targeting of those countries that had not received vaccines through bilateral deals. Second, as already discussed, by the later rounds, COVAX had largely met its commitments to the Optional and Committed Purchasers, allowing it to focus on the AMC countries (see [Figure 7](#)). Third, many of the Optional Purchaser countries did not take up their full share of the allocation owed, leaving more to the AMC and Committed countries. It is the case that some deals—both some of COVAX's advance purchase agreements and some donations—earmarked specific countries, leaving some countries out of a round if they were not eligible for any of the vaccines available. For these reasons, the allocation rule deviated from pure equality as the year unfolded.

One final point is important to note here. We have seen that COVAX implemented a rule of equal (proportional) coverage across Committed and AMC countries and fulfilled obligations to Optional Purchasers. Nevertheless, it is still the case that the typical vaccine was allocated to an AMC country. This is for two reasons: First, there were more AMC countries than Committed and Optional Purchasers. Second, the AMC countries included some of the largest vaccine recipients—in particular, the Philippines, Indonesia, and Nigeria. The distribution of vaccines by round across the three types of

recipients is given in [Figure 7](#). Over 80 per cent of all COVAX vaccines were allocated to AMC countries.

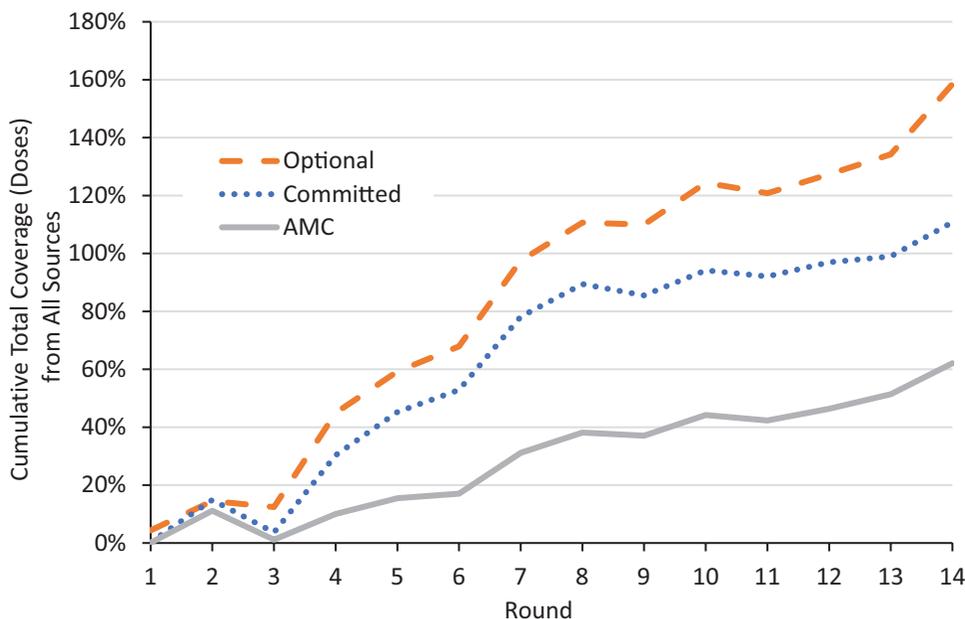
The stated objective of COVAX was to work towards a fair allocation of vaccines across countries, initially implemented through the allocation of the same number of vaccines per capita to each of its member countries. Our analysis shows that COVAX was broadly successful in achieving that objective in its allocation process. However, two issues arose that we address below. First, COVAX's equity target spoke to *how many* vaccines a country should receive but offered little guidance as to *which* vaccines should be allocated to each country. As one example, should a vaccine with 95 per cent efficacy be seen as equivalent to one with 50 per cent efficacy? The allocation rule did not distinguish, instead treating all vaccines as equally valuable—yet countries in practice did not typically think of vaccines as interchangeable. Second, the bounds imposed by the λ_i tolerance constraints were very tight, which in practice meant that the algorithm often had few alternatives to offer a country, making it hard to match on preferences over vaccine type.

From its inception, COVAX was effectively planning for three phases of vaccine distribution: (i) an *early phase*, when vaccine supply would be low, with all countries having significant need; (ii) a *middle phase*, when there was still excess demand for vaccines, but more vaccine types and doses were available; and (iii) a *late phase*, in which there would be excess supply of vaccines. Much of the benefit of COVAX's sourcing and allocation system was likely to arise in the middle phase, where large numbers of vaccines would have to be distributed. Yet the experience has been that because low-income countries played the role of residual claimants on the demands of higher-income countries, the middle phase lasted little more than two or three months. Instead, many low-income countries quickly transitioned from a state where they could not get any significant number of vaccines to one where they could receive more than they could absorb.

It also ended up being unclear that targeting equal (proportional) allocations of COVAX doses was optimal from a welfare perspective in the first place. As we already discussed, in the initial rounds, COVAX's allocation to countries was initially not based on population coverage from *all* sources of vaccines but rather on the number of vaccines per capita that the country had been allocated from COVAX (or the COVAX coverage cap—whichever was lowest). Yet countries rapidly diverged in overall population coverage rates because of bilateral deals; this led COVAX to change its targeting objective to reflect overall coverage (rather than just COVAX dose coverage), to the extent that the requisite data were available.

Bilateral deals so dominated the landscape of vaccine supply in 2021 that they exposed COVAX to criticism for failing to focus on those countries most in need. It is well known that the highest-income countries primarily vaccinated their populations through bilateral deals rather than through COVAX. Important, and less well known, is the rapid divergence between upper-middle-income countries, middle-income countries, and the low-income countries that were members of the AMC. By Q3 2021, many of the upper-middle-income countries and middle-income countries had achieved widespread vaccination. For instance, Colombia reached a 70 per cent vaccination rate by September 2021, and Turkey did so by October 2021, while the low-income countries often remained in the low double digits ([Our World in Data, 2022](#)).

[Figure 8](#) gives data on total population coverage for the three groups. Notable here is that by round 4 (summer 2021), the average Optional Purchaser country had two-dose coverage for roughly a quarter of its population, while two-dose coverage for the

Figure 8: Cumulative population vaccine coverage (doses) from all sources, not just COVAX

Committed Purchaser countries was around 15 per cent. By 2022, those coverage levels were at 80 per cent and 55 per cent, respectively. Yet coverage in the average AMC country hovered around 5–10 per cent in summer 2021 (rounds 4–6), and only reached around 30 per cent by 2022. Despite this, [Figure 5](#) shows that not only were distributions still being made to the Optional Purchasers but, strikingly, more doses were offered to the Committed Purchasers per capita until 2022 than to the AMCs.

A few examples should illustrate the perceived difficulty, and the kind of challenges that led to considerable media criticism. First, in June 2021, COVAX delivered 522,000 doses to the United Kingdom, ‘more than twice the amount that went to Africa’ in that month ([Cheng and Hinnant, 2021](#)). Yet this was in some sense necessary because the participation of the Optional Purchasers provided crucial upfront financing, and their contracts required COVAX to meet their demand in real time. Meanwhile, in November 2021, COVAX allocated 1.02m vaccines to Chile ([Pan American Health Organization, 2022](#)), which had already vaccinated 87.8 per cent of its population and had given 44.8 per cent booster shots ([Statista, 2022](#)), while vaccination rates in many African countries had not reached 5 per cent. This imbalance arose not only because of contractual commitments to Optional Purchasers, but also because many AMC countries were not able to distribute the types of vaccines allocated in many of the earlier rounds.

In an environment in which some countries were sourcing most of their vaccines through bilateral deals outside COVAX, it seems hard to interpret the average population fraction S_t covered by COVAX as a plausible measure of the welfare created by allocating vaccines. Offering a vaccine to Chile with 80 per cent total population coverage and one to Mali with 1.9 per cent population coverage seem very different, even if they represent a similar allocation share from COVAX. More simply, it is hard to appreciate the allocation rule (1) when COVAX was allocating a tiny fraction of worldwide vaccines.

While COVAX did adjust its allocation scheme to focus more on its poorest members, it is possible that COVAX should have done so more rapidly. We offered a dispersion measure S_t for COVAX-allocated vaccines. It is useful to compare this targeting of vaccines to countries relative to the dispersion of population vaccine coverage from all vaccine sources. Let \bar{Q}_{it} be the total population coverage of country i up to round t , and let \bar{Q}_t be the average of \bar{Q}_{it} across all member countries. Let

$$R_t = \sum_i \omega_i \left| \frac{\bar{Q}_{it} - \bar{Q}_t}{\bar{Q}_t} \right|.$$

The measure R_t represents how far from equitable coverage the average vaccine is, across all three groups of countries covered by COVAX. This is plotted as the dashed line in Figure 6. We see that by round 6 (June 2021), there was substantial divergence in total population coverage, with a dispersion measure averaging 0.7 from March to September 2021. Only by the beginning of 2022 does COVAX vaccine targeting occur at the same level of dispersion as overall population coverage.

(iv) Targeting the most needy

Much of the criticism of COVAX has entailed its supposed failure to distribute vaccines effectively to those countries most in need. Thus far we have assessed this through COVAX's implemented allocation rule oriented towards equity in allocation (Figure 3 against the backdrop of bilateral deals represented in Figure 6) and the distribution of the typical vaccine (Figure 5). We now offer data on the extent to which COVAX vaccines were allocated to those countries that had the lowest coverage rates. We do this at the country level, so that we can examine not just differences across, say, AMC and Committed countries, but additionally whether vaccines were being allocated more to those AMC countries that had the lowest population coverage.

We consider the covariance between COVAX allocations and population coverage. Let

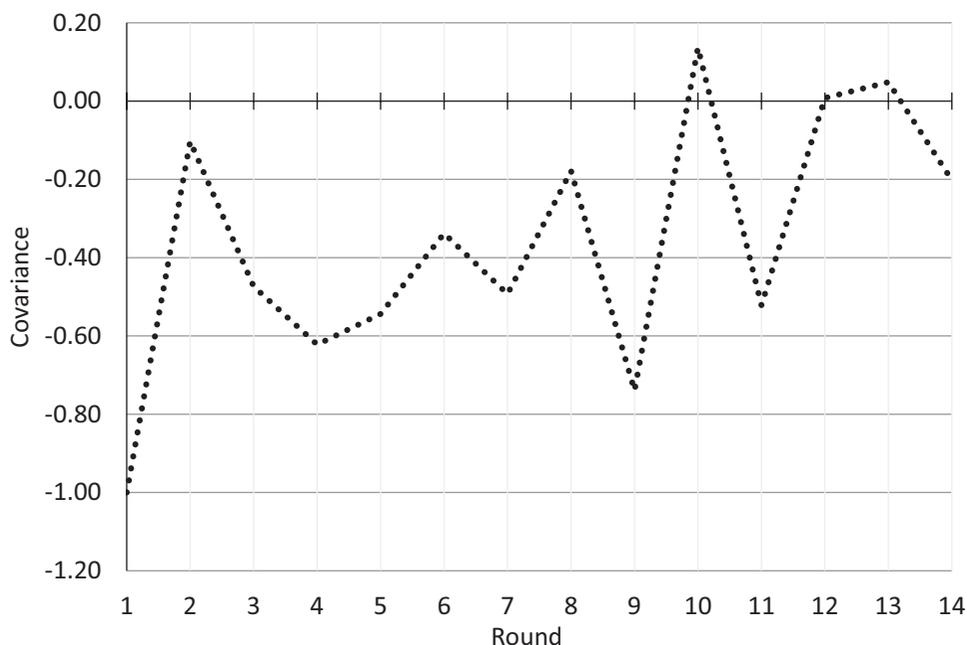
$$W_t = \sum_i \omega_i \left(\frac{q_{it} - q_t}{q_t} \right) \left(\frac{\bar{Q}_{i(t-1)} - \bar{Q}_{(t-1)}}{\bar{Q}_{(t-1)}} \right).$$

The first term in parentheses is the proportional per capita allocation of vaccines to country i in round t , relative to the average per capita allocation in round t . If this is positive, then country i received more than an equal share. The second bracketed term is population coverage for country i at the point that round t 's allocation is made. Then W_t measures the covariance between COVAX allocations and population coverage, weighted by country size. A value of $W_t = 0$ would reflect no targeting towards those with few bilateral deals and more negative values would demonstrate a policy of allocating to the countries in most need.

Data on W_t for the combined AMC and Committed countries is given in Figure 9.

We see from Figure 9 that for most of 2021, COVAX *did* target allocations of vaccines towards those countries with least overall coverage. Until Q3 2021, the covariance W_t is around -0.4 , *despite* COVAX's commitment to an allocation rule that offered equal population coverage during this period. This largely arose because (i) there were more

Figure 9: The relationship between COVAX allocations and total population coverage (Committed Purchase and AMC Countries only)



AMC countries than Committed countries, and (ii) AMC countries had much lower population coverage. Furthermore, AMC countries like the Philippines and Indonesia are quite large relative to the average country, and had lower than average population coverage rates. Hence, even with COVAX's rule aiming at equity in distribution, vaccines ended up being moderately targeted towards low-coverage recipients.

The second notable feature is that after round 9, there is no longer any evidence of COVAX targeting vaccines to countries with low population coverage, as the average W_t after that is ≈ 0 . In other words, COVAX was then as likely to give a vaccine to a country with high coverage as one with low coverage. By that point, almost all COVAX vaccines were allocated to AMC countries—yet it turns out that within the AMC countries, there was considerable variation in population coverage. For instance, by the end of 2021, Rwanda had apparently vaccinated 41 per cent of its population, compared to 1.9 per cent in Mali and 2 per cent in Nigeria (Mwai, 2021).

The absence of any correlation between need—as measured by population coverage—and vaccine distribution speaks to the changing nature of the constraint on vaccinating low-income countries. Specifically, at the point in time when vaccines became readily available—the end of 2021—many countries still lagging in vaccination faced various constraints on their ability to distribute vaccines. Towards the end of 2021, COVAX added explicit consideration of countries' absorptive capacity, in hopes of avoiding vaccine waste due to allocating countries vaccines they were unable to distribute. As a result, COVAX allocations effectively moved to being governed by absorptive capacity and willingness to distribute vaccines, which appears to have been largely independent of population coverage levels at the time.

One lesson from this experience—specifically, from [Figure 2](#)—is that supply of vaccines to COVAX (and especially supply to AMC countries) is remarkably elastic to the needs of higher-income countries (and possibly also to vaccine nationalism). Again, it is hard to avoid the conclusion that COVAX and lower-income countries were in some sense residual claimants on the demand of wealthier countries. When there was vaccine demand elsewhere, COVAX and lower-income countries received little, yet vaccines became freely available to them when supply in high-income countries outstripped those countries' demand.

The inability of COVAX to source vaccines early highlights the overall limitations on the extent to which the allocation process could implement the stated mission of 'equitable vaccine distribution'. While COVAX could do its best to distribute the vaccines it sourced equitably, it had no control over global supply. If countries received equal (proportional) shares of COVAX doses, this would lead to huge disparities because of differences in access to bilateral deals.

The allocation algorithm offered equal per capita allocations to countries of very different income levels. In an alternative scenario in which COVAX had sourced enough vaccines that they could bring AMC countries up to, say, 35 per cent coverage by the fall of 2021, the starkness of allocating vaccines to upper-middle-income countries with vaccination rates of 70 per cent would have looked less glaring than when the typical AMC country remained at single-digit population coverage rates. In this sense, the inability to source vaccines heightened that problem and served to provide ammunition for those who felt that COVAX was failing in its mission to vaccinate low-income countries.

While it might be tempting to conclude that COVAX simply used the 'wrong objective' in its allocation process, the allocation (1) cannot be evaluated without addressing the financing of COVAX. As of February 2021, donor governments and multilateral and private organizations provided funding of roughly \$3.95 billion, while the prepayments by countries for vaccines to be delivered yielded an additional \$2.4 billion (aggregate numbers from [Rouw *et al.* \(2021\)](#)). A significant fraction of the initial financing for COVAX came from *pre*-payments for vaccines by both Optional and Committed countries. From that perspective, many countries had paid a down-payment and were now awaiting receipt of the goods they had bought. Said another way, the mechanism by which COVAX had been financed limited its ability to focus exclusively on low-income countries.

In a world of relatively scarce global supply, the disproportionately strong buying power of high-income countries meant that low-income countries that were dependent upon COVAX got left behind. However, it would be naïve to think that the construction and implementation of COVAX could avoid responding to countries' incentives to act in their own self-interest. Shipping on the order of 500,000 vaccines to the United Kingdom in June 2021, for example, may have made for poor media coverage but may have been part of the price needed to construct an institution such as COVAX in the first place—especially since those doses had been allocated earlier in the year.¹³ At a more substantive level, it was also difficult to prioritize low-income countries over middle-income countries such as Brazil and Mexico, which had made budgetary sacrifices in order to make commitments to COVAX. This is likely relevant to understanding and interpreting any future agency like COVAX, where the need to seek finance will shape the design and execution of the mission. The key question is whether and how a cross-country vaccine allocation mechanism can

¹³ There was only one allocation of COVAX vaccines to the United Kingdom—539,370 doses allocated in round 3 (March 2021).

differentiate between countries with and without bilateral deals without discouraging the former from signing on—and providing critical upfront funds—in the first place.

One other implication seems relevant going forward. While almost all Optional Purchasers received some vaccines through COVAX, many did not exercise all of their options, as the evolution of the pandemic showed that they could readily access vaccines through bilateral deals. Yet these countries had paid \$3.10 per vaccine upfront, which COVAX could then use for other purposes. One fears that such resources may not be available in the future, as from their experience of the Covid-19 pandemic, wealthy countries may have concluded that they can ‘go it alone’, rather than participating in a multilateral agency with a centralized procurement and allocation function.

Finally, we highlight that the countries that are residual claimants on world vaccine supply have faced a ‘feast or famine’ scenario. This can be seen from [Figure 1: COVAX allocations](#) went from less than 5 per cent of worldwide supply in May 2021 to more than 25 per cent by the end of the year. This meant a transition from stark scarcity to widespread availability in the space of about 4 months. While certainly widespread vaccine availability reflected a vast improvement overall, as an organizing economic principle for how to allocate volatile supply across the world, we saw an inversion of efficiency. High-income countries ended up having relatively stable and predictable supplies of vaccines, while low-income countries faced remarkably volatile supply. Yet just as those who have savings are better able to handle risky income streams than those on the breadline, economic efficiency generally implies allocating volatile asset streams to agents who can best handle that volatility.

The limitations on health care capacity are much greater in low-income countries, which means that, for those countries, ‘slow and steady’ is the most efficient intertemporal allocation. Yet worldwide vaccine supply initially offered very few vaccines to African countries—especially given that many of the earliest vaccines available required cold-chain storage capabilities those countries lacked—and then a huge supply became available, even though their health care systems could not distribute such a large quantity at once. There have been anecdotal accounts of this resulting in some vaccines being wasted: South Sudan destroying 60,000 vaccines, for example, or the Democratic Republic of Congo returning 1 million vaccines close to expiration ([Goldhill, 2021](#)). In some countries, this lack of use was stark: Reuters ([Guarascio, 2022](#)) reported that ‘more than 30 poorer nations, including the Congo and Nigeria, have used fewer than half the doses they received’.

(v) Which vaccines?

So far, we have only considered how many vaccines a country should be allocated at each point in time. Yet vaccines also vary in their attributes and desirability—and the extent to which the Covid-19 vaccines were differentiated, in some instances, of become clearer over time—leading to a question of which vaccines a given country should receive. The allocation mechanism thus gave some consideration to countries’ preferences over vaccines.

It is useful to distinguish here between vertical and horizontal differentiation.

- *Vertical differentiation* arises when most countries prefer one vaccine over another. For instance, all else equal, a vaccine with higher efficacy is preferred to one with lower efficacy. In practice, many countries also preferred US or European

vaccines over their Chinese counterparts. Finally, countries naturally preferred vaccines with further-out expiration dates.

- *Horizontal differentiation* occurs when some vaccine attribute is desired by one country, while another country sees it as a drawback. Examples here would be mRNA vaccines, which required cold-chain storage: some countries preferred mRNA vaccines for their higher efficacy, while others found them too difficult to store and distribute. Horizontal preferences also arose with regards to delivery time: while all countries sought early to increase their vaccine supplies, they varied in their ability to absorb and deploy more doses at any given point in time, perhaps due to differences in timing of vaccines from deals made outside of COVAX.

Three features describe how preferences over vaccines were manifested in allocations during 2021. First, as we have already mentioned, COVAX implemented an allocation framework under which all vaccines were treated as equally valuable; this implied that the mechanism did not have a direct way to account for vertical preferences.¹⁴ Second, at least initially, COVAX did not ask countries for their preferences over vaccines directly—instead, they only asked for preferences over vaccine attributes, such as technology platform, cold-chain storage requirements, doses per regimen, and regulatory status. Finally, as we previewed earlier, because the algorithm used in (1) fixed country quantities upfront within a very tight tolerance bound, it was difficult to make countries' allocations reflect preferences rather than just solving a packing problem on quantities. We elaborate on each of these challenges in turn.

The theory that vaccines were equally valuable meant that the allocation did not, for instance, distinguish between degrees of efficacy of different vaccines, by using an allocation system that would be based on effectively vaccinated members of the population.¹⁵

That COVAX chose to avoid this was understandable, perhaps because the process of justifying why a given country would receive a given vaccine was likely to be overwhelming. Negative sentiment may also have arisen from giving lower-income countries a vaccine that was perceived as in some way being 'worse'—even if that country in fact preferred that vaccine, perhaps because it was easier to distribute.

Yet the decision to treat vaccines as equally valuable also implied that COVAX could not respond to the inequities in worldwide vaccine coverage in a way that would have satisfied all constituencies. As one example, high-income countries have disproportionately used the Pfizer vaccine, while the AstraZeneca vaccine has been used more widely. The strategy of treating all vaccines as equivalent removed the option of approaching high-income countries and offering them the chance to get Pfizer vaccines with certainty, but in a smaller quantity—thereby freeing up more AstraZeneca for needier countries. This could have somewhat mitigated the inequality in population coverage described above.

¹⁴ While it is possible that treating vaccines as equivalent imposed some sort of *ex ante* rationality under uncertainty, some countries did apparently have some degree of *ex post* preferences, as evinced in their opting out of specific rounds.

¹⁵ The mRNA vaccines, for example, had higher efficacy than the other vaccines that were available early on, so an allocation system might in principle have treated a smaller number of mRNA vaccines as equivalent to a larger number of other vaccines (with the proportion of equivalence determined by relative differences in efficacy).

And although the allocation process treated all vaccines as equally valuable, countries did not share this belief. This is best illustrated by COVAX's experience with two Chinese vaccines, Sinopharm and Sinovac. In early summer 2021, COVAX entered into contracts that would allow it to source up to 550 million vaccines from China (Higgins-Dunn, 2021). In theory, this should have immensely relaxed its supply constraints. Yet by March 2022, only 81 million such vaccines had been distributed through COVAX. This may have reflected countries' vertical preferences for vaccines other than those from China, although it may also have been due to increased availability of donated vaccines.

Meanwhile, COVAX also faced difficulty inferring countries' preferences because it did not initially ask them for preferences over specific vaccines. Instead, countries responded to questionnaires asking them to score attributes such as single-dose delivery, refrigeration requirements, and so forth. From this, COVAX constructed aggregate scores for each country and mapped them onto available vaccines. The reasoning was partially strategic: there was concern that if countries ranked vaccines themselves and were then given a vaccine that was not their top choice, they might refuse to accept it. We have no way of knowing how prevalent this issue may have been. However, it is worth pointing out that, as an exercise in aggregating preferences, the chosen approach was far from fool-proof. Moreover, the method made it difficult for countries to understand how their preferences would map to actual vaccines received. Recognizing this, in mid-2021, COVAX switched to collecting preferences over vaccines, using a numerical scale under which countries would rate each available vaccine from 1 to 5. They also started explicitly asking countries to specify their desired numbers of vaccine products per round, whether they valued allocation consistency or not, and their absorptive capacity and cold-chain capacity. Even with these adjustments, preference information could become dated quickly, as the pandemic proved to be extremely dynamic with the rise of variants that were more or less resistant to different vaccines.

Before describing some additional issues with matching vaccine allocations to country preferences, it is important not to overstate the importance of vaccine type choice for the early phase of COVAX vaccine distribution. Most of the early allocation rounds included just a single vaccine—meaning that even though preferences were collected, they were effectively not used. This can be seen by returning to Figure 3, which shows the distribution of allocated vaccines by manufacturer for each round. Round 1 was only Pfizer; round 2 was just AstraZeneca. Round 3 only distributed the Pfizer vaccine; round 4 again only included AstraZeneca; round 5 was just Pfizer.

For six of the 14 rounds, there was only a single vaccine offered, so the role of substitution within a round was typically quite limited. The only way that preferences could have been incorporated into these rounds was through deciding whether a given country should be included or excluded from the round on the basis of their preferences; for this to be possible, COVAX would have had to allow vaccine-specific opt-outs for non-Optional Purchaser countries. Note also two other features noted above: first, the absence of the Serum Institute's Covishield vaccine from rounds 3–10, and second, the relative unpopularity of the two Chinese-made vaccines (the dotted lines), even though COVAX had contracts for hundreds of millions of doses (some in the form of options that were not exercised).

As such, much of the discussion of preference-based matching in what follows is designed to address improvements to allocation that may be valuable in settings in which greater choice is available.

The algorithm implied by (1) gave relatively little ability to match vaccine preferences to allocations. This is because of lot sizes—along with the tolerance bounds λ_i . The tolerances were so tight that there were relatively few combinations of matches of vaccine contracts to countries that could achieve them.¹⁶ While allocation mechanism did allow a degree of product swapping according to countries' preferences, the margin for doing so was lower than it could have been if the tolerance constraints had been slackened. Thus, the philosophy of offering almost identical allocations per capita to member countries likely harmed the ability of COVAX to improve the efficiency of the allocation on other dimensions.

There was one other substantive problem. A difficulty with the allocation system in (1) is that it was not transparent to member countries, and COVAX found it difficult to explain to member countries why they received the allocations that they did. Much of this arose from difficulties in explaining how priorities and preferences were manifested in outcomes because of the tight tolerance constraints.¹⁷

Finally, there was one other attribute whose importance in a sense dominated all others, namely *vaccine expiration dates*. Many vaccines are sourced—or more commonly donated—close to their expiration dates. Early vaccine donations from high-income countries included vaccines those countries had concluded they could not use themselves—and thus were closer to expiration.¹⁸ Additionally, some manufacturers struggled with supply chains, resulting in vaccines taking longer to get to countries, and thus arriving with less remaining shelf-life than expected.

There has been widespread discontent by member countries for receiving vaccines close to expiration, many of which ended up not being used. In January 2022, UNICEF said that 100 million COVAX vaccines had been turned down, predominantly for reasons of low shelf-life; 15.5 million of those vaccines were 'deemed to be destroyed' (Guarascio, 2022). The concerns over this issue resulted in a joint statement led by the African Union and Africa CDC saying that 'the majority of the donations to-date have been *ad hoc*, provided with little notice and short shelf lives' (African Union, Africa CDC, *et al.*, 2021).

Expiration date is a clear example of vertical differentiation. No country prefers vaccines that expire in 4 weeks over ones that expire in 4 months. Yet the treatment of all vaccines as equivalent implies that countries would not be incentivized to volunteer to take vaccines that are close to their expiration date, since receiving those vaccines might block them from receiving other vaccines in the future. As countries likely vary considerably in their ability to absorb vaccines quickly, this seems far from desirable.

¹⁶ The batch size was often 151,200 courses for countries that had populations greater than 5 million. As a result, the dose window was often a little over 300,000 doses, which meant that all vaccines and almost all combinations of vaccines fit within the window. However, the mechanism prohibited, say, transitioning from 1.5 million doses of a less desirable vaccine to 1 million doses of a more desirable vaccine.

¹⁷ Consistent with this, COVAX has been criticized for failing to respond to member countries' concerns. See for example Goldhill (2021) and Mueller and Robbins (2021).

¹⁸ COVAX later moved towards recruiting donations for which the 'shelf-life timer' had not yet started to tick.

Indeed, imagine that COVAX were to treat ‘close to expiration’ vaccines differently, or (as happened frequently) has to reallocate a vaccine close to expiration. It approaches countries to take these vaccines. Most countries have no reason to say yes, given the allocation rule in (1). Taking vaccines close to expiration likely involves some costs and disruption to ensure delivery, if delivery is even possible on such short notice. Yet by taking them, the coverage rates increase in (1), reducing vaccine allocations in the future. Few countries are likely to opt into that deal.

Thus, vaccines that are close to their expiration date likely should entail a deviation from the philosophy of ‘a vaccine is a vaccine’. The allocation system in (1) does not target such vaccines to countries best able to allocate them, nor does it give other countries a reason to take them as excess vaccines. This is a place where a designation of ‘bonus’ vaccines might become apposite: bonus vaccines would be offered to countries we are confident can distribute them quickly. And critically, these vaccines should not count towards those countries’ overall allocated quantities. In effect, vaccines that otherwise would likely be wasted should be given out to countries ‘free of penalty’, in the sense that there is no current or future penalty for accepting them. This kind of approach has been used before. Specifically, in the well-known market design exercise involving food banks, not only is some food free to food banks, but food banks are rewarded for taking food that other food banks do not want—and by creating this special category, uptake of such food increased considerably (Prendergast, 2022).

(vi) Vaccines received

By focusing on vaccines *allocated* by COVAX, the analysis thus far has described how the assignment of vaccines to countries reflected the objectives of COVAX—especially the desire to vaccinate a broad range of countries in the shadow of a variety of political and financing constraints. Yet not all vaccines that were allocated were distributed to countries by the time of this writing. Thus here, we briefly examine how COVAX’s objectives were reflected in the vaccines received.

There were multiple reasons why an allocated vaccine might not ultimately be delivered to a country: manufacturers may not have been able to fulfil their contracts; or countries may not have had the absorptive capacity to receive the vaccines; or at times they might simply have refused to accept them. In the latter two cases, to the extent possible, the doses would be reallocated to other countries.

The difference between allocated and received vaccines was quite large overall, with almost 300 million of the 940 million vaccines not being delivered. Much of this arose in round 2, when the export ban on vaccines from India reduced delivered vaccines by 132 million doses. This is seen most starkly in Figure 10, where we plot the distribution of cumulative vaccine types delivered. Compared to Figure 3, which shows allocated vaccine types, for example, Pfizer rises from 31 per cent allocated to 40 per cent delivered, and the Serum Institute’s Covishield falls from 28 per cent to 17 per cent due to the export ban.

The difference between vaccines allocated and vaccines received also varied between the three types of countries. In particular, AMC countries were allocated 822 million doses but received only 492 million—40 per cent less than their allocation—by the end of Phase 1. This was in large part due to the ‘feast or famine’ dynamic described above. The Serum Institute vaccines were mostly directed towards AMC countries, which meant those countries’ deliveries were disproportionately affected by the export ban.

Figure 10: Vaccine types delivered by COVAX, cumulative by end of round

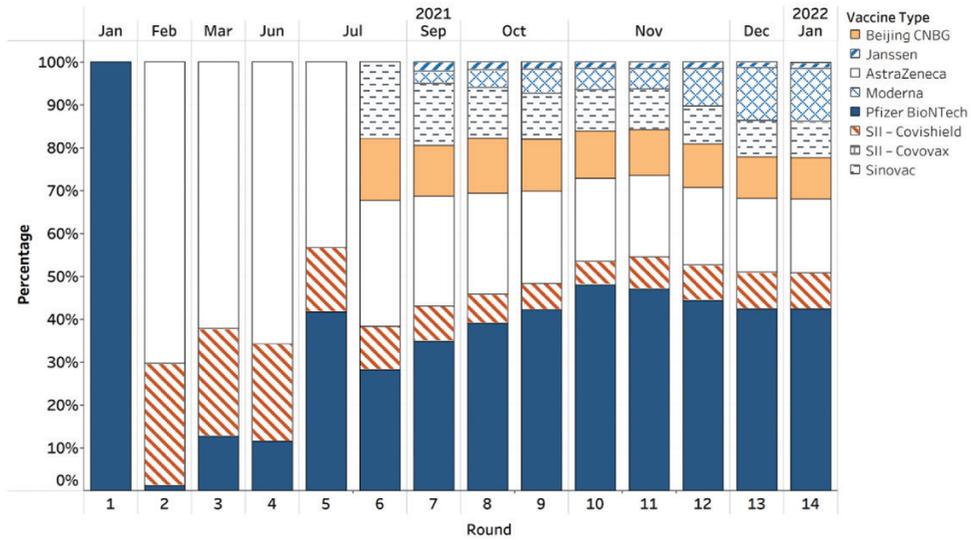
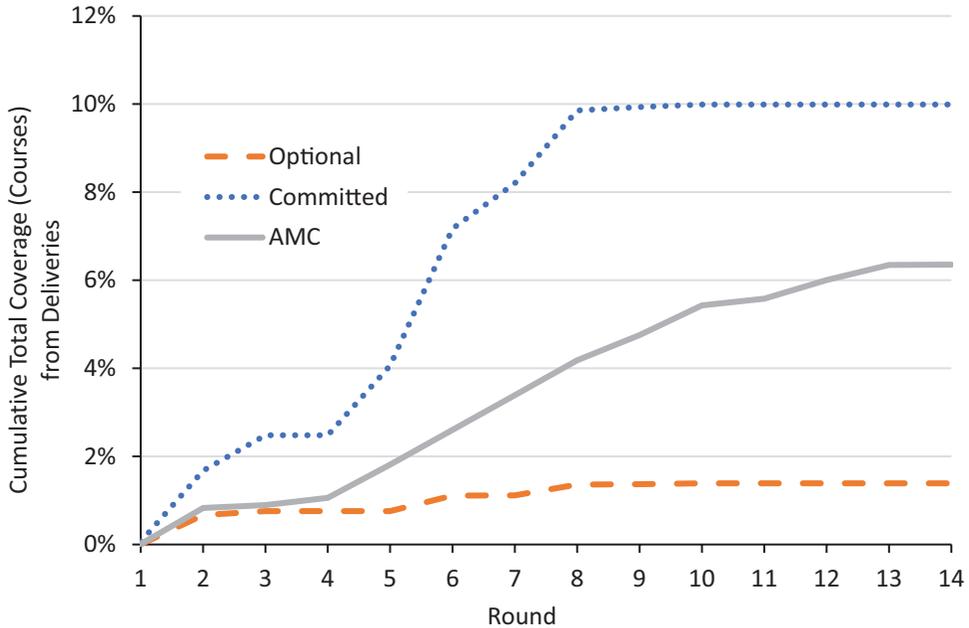


Figure 11: Cumulative course coverage from delivered COVAX vaccines by allocation round (population-weighted)



By later rounds, vaccine distribution to AMC countries caught up, but absorptive capacity constraints were binding—it was not possible for the AMC countries to accept as many vaccines as were available at once.

Figure 11 shows that compared to Figure 5 (which shows allocated vaccines), Committed countries had significantly higher delivered vaccine coverage rates relative to AMC countries. But note that while looking at delivered vaccines somewhat

changes the calculus on overall access across country types, AMC countries still received the vast majority of COVAX doses: AMC countries were allocated 88.7 per cent of COVAX vaccines; they received 80.3 per cent of delivered vaccines.¹⁹

(vii) Rethinking allocation in 2022

By early 2022, global supply of vaccines had expanded to the extent that it exceeded demand, and the overall supply forecast appeared more stable and predictable. As a result, COVAX began adapting its allocation system. The new system involved (i) long-range planning for each country, allocating likely supplies over a 6-month period; (ii) countries providing absorption limits to COVAX to guide those allocations; and (iii) a priority list by COVAX such that countries with lowest population coverage rates would be offered priority over vaccine choice. At the time of this writing, there were not yet data on the new system's effectiveness or implementation—but see [Doğan and Raghavan \(2022\)](#) for a description of the underlying allocation mechanism used.

IV. Vaccine reallocation/exchange

One consequence of the allocation system COVAX used was that countries were at times allocated vaccines that they did not want or were unable to distribute. The only options for countries who received such allocations were to either refuse those vaccines, or to take them in the hope that they could figure out how to distribute them. At least for some countries, the data suggest that the latter outcome occurred—eventually resulting in vaccine waste.

Yet economic theory suggests a natural way in which to resolve such misallocations: a reallocation system whereby vaccines could be traded between countries after the allocation round is announced. It is well known that economic efficiency can be attained either through (i) efficiently allocating resources, or (ii) allowing frictionless trade if the initial allocation is not efficient. In this sense, there is a degree of substitution between ensuring efficiency at the allocation stage and instead achieving efficiency through a series of subsequent trades. Reallocation did occur, sometimes at large scale; COVAX mostly handled reallocation through an *ad hoc* system of processing country requests by hand.

The limitation of *ad hoc* matching should be clear. Specifically, the allocation framework ended up with countries receiving vaccines they did not want, so what is to say the reallocation process would not result in a similarly suboptimal outcome? Given this, there could be value to introducing an *exchange mechanism* that would use a centralized process to manage reallocation according to countries' preferences. The environment is high-dimensional: over a hundred countries; many vaccines that differ vertically and horizontally; to be delivered at many dates from multiple locations. Identifying trades to best satisfy country needs while minimizing waste likely cannot be done through an

¹⁹ When we look at delivered vaccines, the other measures described above—reflecting the targeting of vaccines to countries with least population coverage—remain relatively unchanged, although the covariance measure plotted in [Figure 9](#) is somewhat higher at -0.5 .

informal method of iteratively identifying trades by hand. Instead, it would be preferable to use a market-clearing algorithm to maximize mutually beneficial exchange of allocated vaccines.²⁰

The appeal of introducing exchange is that it would allow a ‘bottom-up’ allocation based on choice, while maintaining the fairness that arises from implementing equitable ‘top-down’ initial allocations. By setting exchange rates in an appropriate way, no country would suffer from gaining the ability to choose. As a result, fairness in initial allocations translates into fairness in countries’ trading outcomes—and, after exchange, countries’ vaccine allocations would be better matched to those countries’ needs.

Unlike the previous section of the article, the observations on exchange here mostly derive from a mechanism that was investigated but never implemented. COVAX initially considered the possibility of having a formalized exchange, even going so far as to write the potential option into their initial contracts with countries (see [COVAX, 2020](#)). But in the end, they opted not to set one up, in part because most early rounds were limited to a single vaccine. We discuss challenges in designing and implementing exchange that arose in the specific context of COVAX; all of the issues discussed here would likely also arise in structuring an exchange system for use in future pandemics.

(i) Benefits from exchange

There are three natural sources of benefits from allowing countries some degree of flexibility to exchange their allocated vaccine doses. First, a country may not be able to effectively distribute the doses it has been allocated. In that instance, intertemporal trade with a country that currently has excess absorptive capacity can improve outcomes. Second, when country *X* that has received vaccine *A* prefers vaccine *B*, but country *Y* that has vaccine *B* prefers vaccine *A*, trades allow countries to benefit from horizontal differentiation in preferences. Finally, when all countries prefer vaccine *A* over *B*, but value them differently in a relative sense, trade with market rates of exchange can allow differences in vertical preferences to be reflected in outcomes. Centralized market-clearing mechanisms can help to identify the need to deviate from one-for-one trade, and can be easily adapted to incorporate such changes. This has been a central component of previous successful market designs.

(ii) Design challenges

Aside from any choices made by COVAX, it is important to note particular design challenges that are likely to arise in any vaccine exchange mechanism.

Timing

Time is of the essence to ensure that shipment, delivery, and distribution occur before vaccine expiration. Any delay caused by an exchange mechanism could exacerbate these problems. As a result, any exchanges that could potentially occur would have to

²⁰ Similar algorithms have been used successfully in settings such as kidney exchange, school choice, course allocation, and the allocation of food to food banks (see [Roth \(2008\)](#) and [Kominers et al. \(2017\)](#)).

arise almost immediately after the allocation process, and also allowable trades would have to be between countries that had already passed indemnity and regulatory checks.

Other parties

One particular complication is that third parties—that is, parties other than COVAX and the countries participating in an exchange—need to be involved. First, pharmaceutical companies need both to be informed and to consent to any change in ‘customer’. In particular, pharmaceutical companies would have to be aware of (and likely weigh in on) potential changes to (i) lot sizes, (ii) packaging and labelling, (iii) payment arrangements, and (iv) shipping dates. For instance: could a contract be split in two, and shipped to two different countries, or does it need to be maintained as a single unit? What if a given trade entails sending a particular lot to a country with whom payment problems have arisen previously?

A second key question involving third parties is determining who pays when doses have been exchanged. We consider two scenarios to understand the potential problem. Turkey is allocated a million doses of the AstraZeneca vaccine at \$3 a dose. Morocco is allocated a million doses of the Pfizer vaccine, at a cost of \$30m for the donor agency Gavi. Turkey and Morocco decide to exchange vaccines. Gavi now sees itself paying \$30m for something that is ‘worth’ \$3m. This likely would be a problem for Gavi.

The scenario just presented is one in which a vaccine’s ‘sender’ pays. An alternative is where the ‘receiver’ pays. Invert the example above, so that now initially Morocco is allocated a million doses of the AstraZeneca vaccine at a cost of \$3m to Gavi. Turkey is allocated a million doses of the Pfizer vaccine, sourced at \$30 a dose. Turkey and Morocco decide to exchange vaccines with the ‘receiver’ paying. Gavi’s cost rises by \$27m. Again, this is likely to be a problem.

The final important third parties to account for are donor countries. Dose Sharing often had specific countries (or groups of countries) that the donor earmarked as destinations. What if a vaccine donated to country *X* was exchanged and ended up in country *Y*, for which the donor country has not earmarked its donation, or worse, with whom the donor had poor relations? Once again, this could be sufficiently problematic as to limit or at least place strong constraints on any exchange system.

Should we have confidence in the allocation that arises under decentralized exchange?

A central feature of allowing decentralized exchange is that there is trust in both the motives of the players, and their information. In the context of the allocation of food to food banks, for example, food bank directors both (i) serve the poor in their areas and (ii) quickly become aware of reasonable prices that should be paid for different kinds of food, which enables them to make informed decisions about what types of food to acquire (Prendergast, 2022).

But there are substantial challenges in the context of vaccine exchange. First, any mechanism that seeks to take advantage of vertical differentiation needs to effectively find ‘prices’—in this case, the rate at which the more highly valued vaccine is exchanged for a less valued one. Market designs need to find a mechanism to reach these prices. One possibility is to allow the market to do so. But this may not work in the vaccine allocation setting, where goods are new, hard to value, and changing over time with new information. Furthermore, health departments who implement these programmes

often are vastly differently resourced. As a result, any price-finding mechanism would have to be constrained in ways that ensure that the less well informed do not suffer from inequality of information or resource access.

A separate concern addresses prospects for intertemporal exchange, namely the unpredictability of supply. A recurring problem that arose throughout 2021 was non-delivery, whereby pharmaceutical companies would not have the required inputs to fulfil all their contracts. Two concerns arise here when allowing intertemporal exchange. First, how does COVAX deal with countries that have traded for a vaccine contract that is not delivered? What recourse is offered in future allocation rounds? Second, there is a potential adverse-selection concern: a country may seek to trade away contracts that it privately knows are unlikely to be fulfilled.

An additional issue that may arise is where the decision-makers are not acting in the interests of the population at large, but perhaps for an elite that wants only the highest-quality vaccines, even if that means that other parts of the population remain unvaccinated. Media accusations along these lines could seriously undermine public perception of the overall mission. Any exchange mechanism would thus likely have to entail veto power by COVAX.

For all of these reasons, an effective vaccine exchange mechanism would need to be limited in its scope and entail considerable checks and balances.

That said, the issues just described reflect the kind of specificities that are required in most market design applications, and simply require mechanisms to be tailored to their particular application contexts. While this adds difficulty to the design, it is unlikely to be insurmountable—and an appropriately crafted exchange mechanism could likely improve the efficiency of the allocation and reduce waste considerably.

(iii) A caveat regarding the ‘lock-step’ approach

All of that said, we note that the choices COVAX made in its allocation process, if extrapolated into constraints on exchange, could potentially limit the value an exchange could create. In particular, the ‘lock-step’ approach—tracking countries almost perfectly evenly in terms of population coverage in each round, and treating all vaccines as if they were perfect substitutes for each other—would significantly limit the scope for trade:

1. **Intertemporal penalties:** As we already discussed, under the COVAX allocation framework, a country agreeing to take more vaccines in a given round would see its future allocation reduced because of the concomitant increase in its total coverage rate. If this principle were extrapolated to exchange, it would mean, for instance, that there is no incentive to engage in exchange for another country’s vaccines that are near their expiration date—a central challenge for preventing vaccine waste—as these would likely be difficult to distribute quickly, and would count against future vaccine allocations. Only by introducing categories like bonus vaccines (described above) can incentives to trade for near-to-expiry vaccines be created.
2. **Eliminating vertical trades:** Realistically, many desirable trades would be likely to be vertical—and in such cases, exchanges would only happen if they could

be more than one-for-one. A country might take two vaccine doses near expiration for one with a longer remaining shelf-life, or it might take two doses of the Chinese vaccines in exchange for a Pfizer dose. The philosophy of ‘a vaccine is a vaccine’ effectively rules out such trades, even though they could potentially be welfare-enhancing. Moreover, eliminating these types of trades also makes it impossible for a country to trade in ways that increase its total quantity of available vaccines.

3. **Eliminating most horizontal trades:** Finally consider the case where two countries wish to swap vaccines one-for-one. Country X has a contract for 100,000 AstraZeneca vaccine doses and country Y has a contract for 105,000 Sinovac vaccine doses. All regulatory and indemnification issues are satisfied, and both parties wish to exchange vaccines. Under the philosophy of the allocation rule (1) used throughout 2021, however, each country needs to be within λ_i of the equal coverage allocation. Then if the tolerance bound λ_i is violated by changing either country’s allocation by 5,000, the trade cannot occur. Thus, narrow tolerance bands also serve to restrict welfare-enhancing trade.

For an exchange system to be maximally valuable, all three of the preceding issues would need to be addressed—again suggesting significant opportunities to improve the overall distribution of vaccines by relaxing the ‘lock-step’ constraints. Once more, this highlights the tension between political and economic constraints and opportunities.

V. Interaction between allocation and exchange

The purpose of the prior subsection is not to argue that an effective exchange could not have been developed. Rather, the key take-away is that implementing an exchange would likely have required relaxing the constraints that we have already argued limited allocation.

Designing an effective exchange would have entailed two components. First, the mapping of design choices to the specifics of the environment, in a way that would have allowed efficiency and fairness to coexist. Such issues are complex but common across market design applications (see Roth (2008) and Kominers *et al.* (2017)). However, it also would likely have entailed a willingness to drop the rigid enforcement of the equity goal, in favour of enabling countries to receive vaccines that better match their preferences. This would both have been a conceptual break—by allowing vaccines to be treated as imperfect substitutes in some circumstances—and a technical break—by relaxing the strong constraints imposed by (1).

We mentioned earlier that efficient distribution of goods can either occur by initially allocating goods to consumers based on relative need, or alternatively by devoting more resources to allowing consumers to trade among themselves with few frictions to overcome any allocation problems. Yet this only works if the constraints that limit allocation do not simultaneously limit exchange. In the case of COVAX, the way in which the equity constraint was imposed on country allocations likely harmed both vaccines received and any possibility of eliminating those problems through exchange or reallocation.

Perhaps a broad solution framework here (which of course would need a lot more details worked out) would be as follows:

Step 1 (Allocation)—COVAX would run a mechanism to determine the number, expiration date, and types of vaccines each country would be allocated. This allocation mechanism could be based on a variety of design goals or principles. If based around equity as in the Phase 1 allocation system, for example, countries' allocated quantities could be based on total vaccination rates and then preferences could be accounted for through a matching algorithm.

Alternatively, countries could initially all be 'endowed' with an equal share of the vaccines to be distributed in a given round.

Step 2 (Exchange)—The proposed allocation determined in Step 1 is reported to the countries. Then countries that wish to may enter an exchange process in which they can trade their allocated vaccines according to their preferences.

In this framework, Allocation (Step 1) would be like a crude dial to tune a country's allocation to approximately what it wants, and the Exchange (Step 2) would be a fine dial to allow the country to tune its allocation to *exactly* what it wants, given its preferences and available supply. Across rounds, countries' revealed preferences as seen in Step 2 can be used to update the preferences that determine the initial allocation in Step 1.

There would of course have to be significant thought put into the ground rules and guardrails for the exchange process. But a significant advantage here is that countries would have some degree of agency over their allocations.

VI. Vaccine brokerage

One other possibility COVAX considered for improving the allocation of vaccines across countries was a system under which COVAX or some other entity would broker sales of vaccines from countries that had excess relative to countries that were under-supplied. There was significant demand for this among certain high-income countries, which had signed many bilateral deals, and ended up with more vaccines than they needed at least in the short run. Moreover, vaccine brokerage could potentially facilitate 'just-in-time' matching of vaccine doses approaching the end of their shelf-life.

Running a brokerage process would have introduced substantial operational complexity associated with organizing and processing vaccine sales from countries. It likely would have made sense to limit brokerage to only the vaccine products COVAX was already set up to distribute; even so, there were significant questions about oversight and liability.

There was also some concern that introducing a brokerage option would detract from vaccine donations. Many countries donated doses to COVAX through Dose Sharing; it is possible some would have preferred to sell these doses instead if that had been an option. That said, countries' abilities to donate doses were often constrained by budgeting concerns around foreign aid—and giving them the ability to sell doses, *even*

just at cost-recovery prices, would have expanded the number they could distribute to other countries.

One question that was raised in the conversation around brokerage was whether creating a brokerage option might have the negative long-run externality of freeing high-income countries to buy up even more of the global vaccine supply *ex ante*. But this theory crucially omits strategic incentives. In practice, a relatively small number of countries—most of them high-income ones—*did* claim the vast majority of the global vaccine supply *ex ante*; a brokerage mechanism would simply have enabled them to redistribute the doses they ended up not needing *ex post*. And if the availability of such redistribution increased high-income countries' willingness to purchase, those additional excess doses still would eventually reach the rest of the world through the brokerage system. Plus, if anything, increased up-front demand from high-income countries would likely cause manufacturers to invest in additional capacity, which would speed up the global vaccination process across the board (Ahuja *et al.*, 2021).

VII. Lessons for future pandemics

In practice, COVAX faced significant constraints on its ability to achieve a fully equitable global vaccine distribution. While COVAX could control the allocation of the vaccines it had procured on behalf of its member countries, the prevalence of bilateral vaccine deals introduced fundamental asymmetries in vaccine access. Vaccine supply shocks and trade bans disproportionately affected the supply available to AMC countries, exacerbating the problem.

COVAX may have understood that setting an equity target for allocation as a function of total vaccine coverage within a country (that is, including bilateral deals, to the extent that they could be measured) was better than assessing equity solely as a function of COVAX doses delivered. However, the need to recruit the financing support of high-income countries placed some limits on COVAX's ability to target less-vaccinated countries in this way, at least early on. In order to secure their participation, Optional Purchasers had needed to be contractually guaranteed the right to exercise their options as the associated vaccines became available.

In some sense, lower-income countries ended up becoming 'residual claimants' on world vaccine supply: they faced ongoing scarcity until many other countries had achieved high population coverage, and then suddenly vaccines were in excess supply—both through donations as well as through late fulfilment of contracted orders. Put differently, the 'middle phase' of vaccine distribution, where flexible allocation was likely to be most useful, was very short.

Even once vaccines were abundant, however, limits in absorptive capacity and supply chain infrastructure—as well as competing health priorities for limited health care resources—have kept coverage rates comparatively (and absolutely) low in many lower-income countries. Because of these rate-limiting factors, the ideal allocation to those countries would have been linear and consistent, rather than the high-variance pattern that arose in practice—but again, it is not clear whether such a consistent allocation could have been achieved given the constraints on COVAX supply. Thus for

future pandemics, new financing mechanisms may be needed (Agarwal and Reed, 2022; Kominers and Tabarrok, 2022).

In terms of the overall allocation process, a key lesson was that imposing strict equity constraints with narrow tolerances leaves little space for optimizing the allocation according to country preferences over vaccines or timing—especially when minimum lot sizes may be on the same order of magnitude as the tolerance bounds. Thus, there is a trade-off between strict adherence to the equity standard and overall efficiency of the allocation—and reducing efficiency can at times result in need for *ex post* reallocation. For the same reason, it is important to account for absorptive capacity in the allocation process directly.

More broadly, as in any market context, efficient vaccine allocation and *ex post* reallocation are to a large degree substitutes. If efficient reallocation mechanisms are available, then there is not as much pressure to get the initial allocation ‘right’; by contrast, when reallocation is *ad hoc* (or not permitted at all), the allocation must do a better job of matching vaccines to countries that are willing and able to distribute them.

It is also important to note that even when reallocation or exchange is possible, there are limits to the extent that ‘one-for-one’ trading of doses (or courses) can achieve efficiency when vaccines are vertically differentiated (as in the case of Covid-19 vaccines being differentiated by efficacy). If some vaccines are preferred by many countries over others, then allowing countries to trade off ‘quality’ and quantity through rates of exchange can potentially improve *both* the efficiency and the equity of the overall allocation.

In general, solving intricate allocation problems among numerous stakeholders with multidimensional goods and equity concerns is complex, and calls for expertise in both operations and market design. Ideally, such mechanisms would be thought through and put in place ahead of a pandemic, rather than in real-time. Similarly, systems like vaccine brokerage could potentially reduce vaccine waste significantly by facilitating ‘just-in-time’ matching of vaccines close to expiry—but because of their legal and operational complexity, such mechanisms would need to be developed in advance.

VIII. Final observations

In less than one year, COVAX successfully delivered a billion vaccines, the majority of which went to the low and low-middle income countries that were least well-placed to negotiate bilateral deals for early access.

An institution such as COVAX serves many roles towards improving equity in vaccine access in a setting where vaccine supply is limited, and often highly uncertain. We have focused primarily on one role in particular that COVAX played: acting as a coordinated entity to ensure that vaccines were equitably distributed across the globe. While recognizing that the situation continues to evolve, we have attempted to evaluate COVAX’s success in that role, and to characterize the core market design issues in the vaccine allocation setting. COVAX’s allocation mechanism to a large degree facilitated vaccine access—especially for AMC countries; but nevertheless, with our lessons here, we expect it should be possible to do even better next time.

The discipline of market design, drawing upon economics, computer science, and operations research, has significant expertise in the development of fair and equitable allocation mechanisms (again, see Roth (2008) and Kominers *et al.* (2017)). The case of real-time vaccine allocation across countries has demonstrated how critical bringing this type of thinking to bear can be. Building on the experience of COVAX, as well as the allocation mechanisms and frameworks we know from established market design research, we can prepare better for the next pandemic.

As Covid-19 has proven time and time again, in the context of a global pandemic, no one can be truly safe until everyone is safe (Gavi, 2020b). And vaccine allocation is a key aspect of preparedness that is often left out. In addition to developing frameworks for financing and manufacturing vaccines quickly in a pandemic, we must design and implement mechanisms for ensuring those vaccines are made accessible equitably across the globe.

The experience of vaccine allocation in 2021 and early 2022 stands as a powerful reminder that market design is not just theory. Through COVAX, working on improving the allocation mechanism quite literally meant saving lives.

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