# UNDERSTANDING THE COST-EFFECTIVENESS OF COVID-19 VACCINATION IN ETHIOPIA

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## Key Messages

- Deploying viral vector vaccines (similar to AstraZeneca [AZ] and Johnson & Johnson [J&J]) in Ethiopia in 2021 would have been a highly cost-effective intervention, averting between 180,000 and 440,000 disability-adjusted life years (DALYs) over five years. Using an mRNA vaccine (like Pfizer) would have provided health benefits approximately 20 percent greater, while the health impact from an inactivated-virus vaccine (like Sinopharm) would be around 30 percent lower.
- Using a viral vector vaccine may have resulted in cost savings to the Ethiopian health sector due to reducing COVID-19 care and treatment costs. The savings could be as much as $200 million over five years. In contrast, an mRNA vaccine (with prices similar to Pfizer's) would have cost the health system between $150 million and $330 million. A Sinopharm-like vaccine would be about 2.5 to 4.5 times more expensive again.
- Our study found that viral vector vaccines would have been highly cost-effective in Ethiopia. A Sinopharm-like vaccine would not offer good value for money in Ethiopia. At between $320 and $1,200 per DALY averted, a Pfizer-like vaccine would be cost-effective in only the most optimistic scenarios we modelled and only if more cost-effective vaccines were not available.
- Vaccine price was a more substantial driver of cost-effectiveness than any other single factor. Differences in the costs of different ways to deliver vaccines matter far less.
- In terms of delivery strategy, targeting vaccines first at older people and increasing the speed of rollout improve the cost-effectiveness of the COVID-19 vaccine programme.

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## EXECUTIVE SUMMARY

### Background

COVID-19 radically changed most people's lives in 2020, including people across Africa. In Ethiopia, the disruption started with school closings, and other restrictions soon followed. Despite efforts to contain the virus, Ethiopia—like almost all countries—suffered significant health impacts. It recorded 7,000 deaths by the end of April, and there were likely many more deaths that were not recorded (*Coronavirus (COVID-19) Deaths* 2022). In 2021, vaccines offered a ray of hope, but early supplies were concentrated in high- and middle-income countries. Most low- and many lower-middle-income countries struggled to obtain doses both because the vaccines were difficult to source and because they were expensive. The Ethiopian government spends on average $23 per person per year on healthcare, so spending more than $10 per person to procure and distribute COVID-19 vaccines is a significant investment that requires careful consideration. To inform future decisions, we undertook a Health Technology Assessment (HTA) to assess whether the vaccines offered good value for money for Ethiopia in 2021. We also looked at the best ways to distribute vaccines and the effectiveness of targeting specific age groups.

### Policy Questions

1. Which vaccines should Ethiopia purchase?
2. How should these vaccines be distributed?
3. What age groups should be targeted?

### Methodology

We looked at four hypothetical vaccines designed to be similar to existing vaccines that Ethiopia considered purchasing. We modelled each from a health system perspective, with coverage rates between 25 percent and 100 percent or coverage of only individuals older than 50. We performed the modelling in September 2021 based on epidemiological conditions in Ethiopia at the time. We examined viral vector vaccines similar to AZ and J&J, an mRNA vaccine like Pfizer, and an inactivated-virus vaccine similar to Sinopharm. Table 1 describes the base price, dosing, and baseline efficacy we used in our cost-effectiveness calculations.

**Table 1. Summary of characteristics used to model each hypothetical vaccine**

| Vaccine | Base price ($) | Doses needed | Efficacy (%)[a] |
|---|---|---|---|
| Viral vector vaccine 1 (AZ-like) | 3 | 2 | 75 |
| Viral vector vaccine 2 (J&J-like) | 10 | 1 | 66 |
| Inactivated-virus vaccine (Sinopharm-like) | 30 | 2 | 51 |
| mRNA vaccine (Pfizer-like) | 17 | 2 | 90 |

[a] As defined by the reduction in symptomatic infections for the person inoculated.

We then looked at three methods for distributing the vaccines:

- Fixed posts: These are mainly health facilities and other appropriate locations.
- Vaccination campaigns: These are used to visit large population centres in a shorter time and involve going to people to inoculate them.
- Outreach posts: These are set up in remote or hard-to-reach areas where travel times to a health facility are long or there is limited access to health services.

We estimated the cost of freight (how much it costs to ship the doses from the manufacturing site to Ethiopia) at $0.90 per dose and the delivery cost at $5.29, $6.63, and $7.13 for fixed posts, vaccination campaigns, and outreach posts, respectively.

We then looked at two base case scenarios:

- Slower scenario: 10 percent of Ethiopians will be vaccinated by the end of 2021, 50 percent by the end of 2022, and 80 percent by the end of 2023.
- Faster scenario: 20 percent of Ethiopians will be vaccinated by the end of 2021, and 80 percent by the end of 2022.

While we know that COVID-19 vaccines reduce transmission, it is not clear to what extent. For this reason, we modelled all results in two ways. Our disease model output presumed the vaccines have no benefit in reducing transmission and only help the person vaccinated to avoid symptomatic illness. Our infection model presumed that the efficacy of the vaccines against infection transmission was the same as the efficacy against disease. These should be treated as the upper and lower bounds for the vaccines benefit.

We measure benefits using an incremental cost-effectiveness ratio (ICER): the difference in cost between two interventions divided by the difference in their effect. ICERs effectively tell you how much you are paying for every unit of health benefit. The comparator scenario in this study was no vaccination. The more expensive vaccines would seem less cost-effective if compared to the cheaper inoculations.

All results are based on modelling of COVID-19 vaccines before the Omicron variant became dominant and look in part at decisions that could have been made in early 2021. There are important generalisable lessons going forward for Ethiopia and elsewhere.

## Policy Question 1: Which Vaccines Should Ethiopia Purchase?

Unsurprisingly, all vaccines were shown to have large and positive health benefits. These benefits varied greatly, however, according to the speed of vaccine delivery and the vaccines' impact on transmission (which the infection model accounts for but the disease model does not). Table 2 shows the DALYs averted per vaccine. These results are primarily driven by the efficacy of the vaccine, with a Pfizer-like vaccine having the greatest health benefit, a Sinopharm-like vaccine having the least, and the two viral vector vaccines being in between.

**Table 2. DALYs averted per vaccine**

| Vaccine | Disease slower scenario | Infection slower scenario | Disease faster scenario | Infection faster scenario |
|---|---|---|---|---|
| AZ-like | 179,521 | 347,821 | 255,038 | 433,989 |
| J&J-like | 216,561 | 350,917 | 272,180 | 439,578 |
| Sinopharm-like | 123,106 | 251,203 | 169,222 | 317,690 |
| Pfizer-like | 229,367 | 414,209 | 319,263 | 537,226 |

The health system cost also varied substantially by vaccine, model used, and how quickly vaccines were rolled out. As vaccines can offer substantial savings by reducing hospital stays and other COVID-19-associated costs, some vaccines could lead to overall cost savings. Table 3 outlines the estimated overall health-sector cost by rollout scenario.

**Table 3. Health care cost per vaccine in thousands of US dollars**

| Vaccine | Disease slower scenario | Infection slower scenario | Disease faster scenario | Infection faster scenario |
|---|---|---|---|---|
| AZ-like | –$25,729 | –$143,394 | –$56,260 | –$196,305 |
| J&J-like | $4,980 | –$94,896 | $4,180 | –$123,893 |
| Sinopharm-like | $677,968 | $589,242 | $840,989 | $737,200 |
| Pfizer-like | $282,395 | $150,339 | $331,566 | $170,586 |

Measuring costs for every DALY, our modelling finds that viral vector vaccines are highly cost-effective, and in many scenarios, distributing them appears to be cost saving from a health-sector perspective, meaning the ICER is negative (positive net health gains at lower overall cost relative to no vaccination). In other words, the savings from reduced hospitalizations and other medical treatments were usually greater than the cost of vaccination. Our modelling did not look at the wider economic benefits of COVID-19 vaccines, such as reducing the need for lockdowns and increasing tourism, but these would further increase the return on investment. The faster scenario saw greater returns on investment than the slower one because the benefits of vaccination are greater the faster the population becomes vaccinated. However, there are constraints on how quickly vaccines can be rolled out.

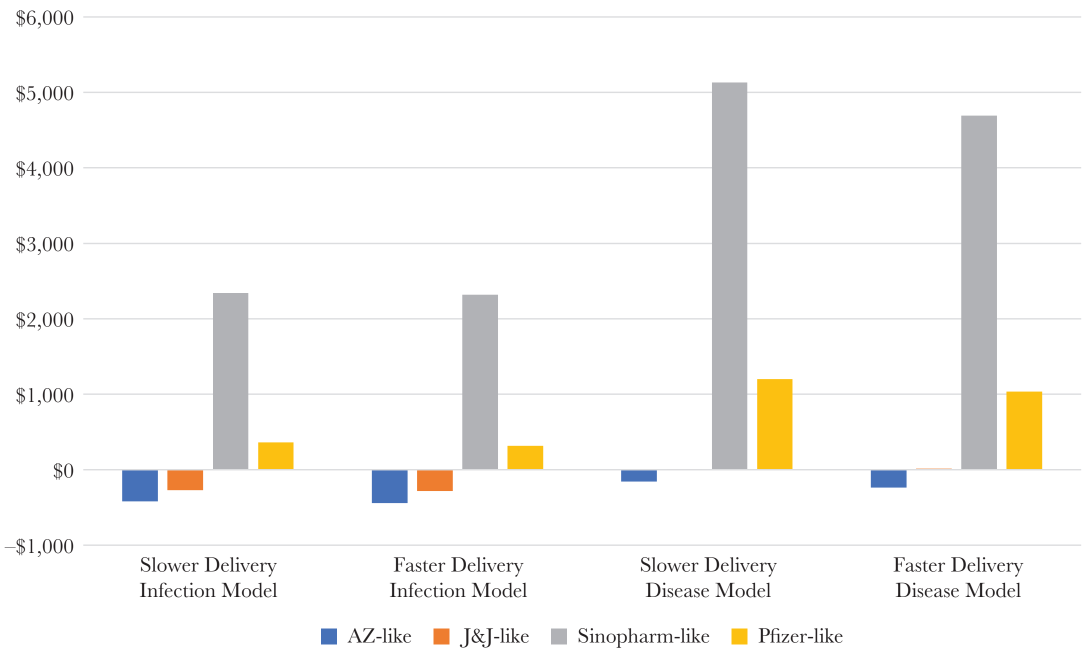
The inactivated-virus vaccine (Sinopharm-like) was both the most expensive and the least efficacious vaccine we modelled. Because of this, it likely did not make sense for Ethiopia to use this vaccine if the alternative COVID-19 vaccines modelled were available. Even if a vaccine similar to the one we modelled were the only vaccine available, our modelling suggests the Ethiopian government would likely pay between $2,300 and $5,200 per DALY averted. This is between 2.6 and 6 times Ethiopia's GDP per capita, as estimates by Ochalek, Lomas, and Claxton (2018) suggest that Ethiopia could avert between 6.3 and 20 times as many DALYs by spending this money elsewhere in its health system.

mRNA vaccines cost far more than either of the viral vector vaccines we modelled, but they are the most efficacious. The mRNA vaccine was modelled with an efficacy of 90 percent because vaccines with 60 or 70 percent efficacy have huge health benefits. Our model found that cost was a more important driver of cost-effectiveness than was efficacy. Using the above inputs, our model found that an mRNA vaccine cost at least $600 more per DALY averted than the two viral vector vaccines. If there were no other vaccines available, it plausibly would be good value for money to use an expensive mRNA vaccine with characteristics similar to those modelled in this study. However, this would offer good value for money only if officials believed the vaccine would greatly reduce transmission or if it were targeted at vulnerable groups like the elderly. In most of the scenarios we examined, the mRNA vaccine would not have offered good value for money at the listed prices.

The results above are based on comparing a vaccine to no vaccine. When we instead compared the Pfizer-like vaccine to a viral vector vaccine, the Pfizer-like vaccine had even less value for money than in the previous scenario because large costs are paid for only a small increase in health relative to the viral vector vaccines. The ICER for this comparison rises to more than $2,300 per DALY averted in every model and more than $6,000 when looking only at the disease model. A vaccine of this efficacy and price thus does not offer good value for money in Ethiopia when health officials have the option of buying viral vector vaccines—but it may if purchased at a lower price.

Figure 1 looks at the health system costs of averting a DALY using each of the four vaccines. They are examined in both the faster and slower scenarios and with both the disease model and the infection model. As shown, the two viral vector vaccines are far more cost-effective than either the mRNA or inactivated-virus vaccine, similar to Pfizer and Sinopharm, respectively. These costs have been averaged by delivery method.

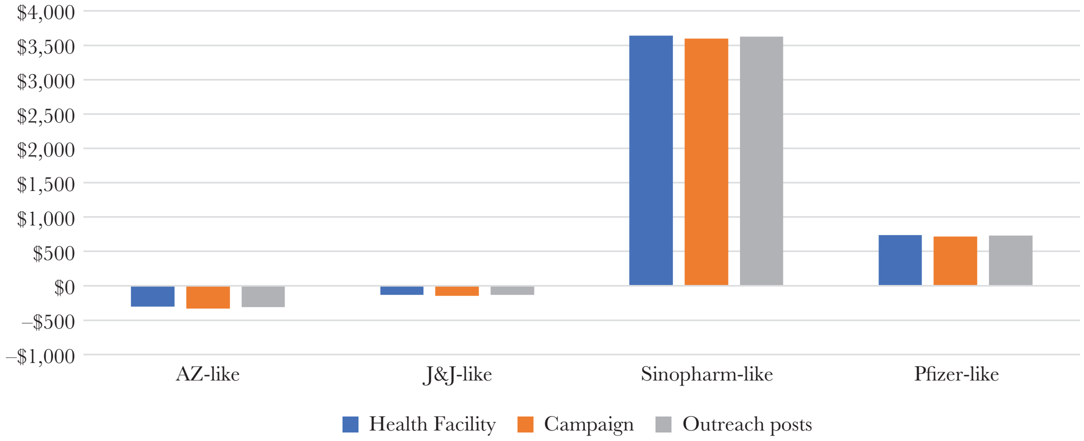
**Figure 1. Cost per DALY averted from using different vaccines in differing scenarios**



## Policy Question 2: How Should These Vaccines Be Distributed?

Our research suggests that the difference in prices of vaccine delivery methods does not have a significant impact on the overall cost-effectiveness of the vaccination program. For this reason, the government should focus on rollout mechanisms that can reach the most people or distribute vaccines fastest. Figure 2 shows the cost of averting a DALY averaged across the faster and slower scenarios in both the disease and infection models, indicating that the delivery method has a much smaller impact on the benefits of a vaccine than the type of vaccine used.

**Figure 2. Cost per DALY does not vary significantly by delivery method**




## Policy Question 3: Which Age Groups Should Be Targeted?

The vaccines are most efficacious at helping those at high risk due to COVID-19. Accordingly, vaccinating older people is far more cost-effective than vaccinating the young. It thus makes sense to prioritize older people first, and while not explicitly modelled, the same should be true for inoculating other high-risk groups. Our results suggest it is still likely cost-effective to vaccinate younger people, though only with viral vector vaccines similar to those produced by AZ and J&J, which are less expensive than mRNA vaccines. If Ethiopia could procure mRNA vaccines at a much lower cost than used in this model, these would be cost-effective in lower-risk groups.

## Conclusion

The COVID-19 pandemic is fast moving, with new variants and vaccine supply fluctuations that are hard to predict. Policymakers face incredible challenges in protecting their citizens, and we hope our analysis can help optimise future policy.

Our analysis shows that the benefits of vaccination are greatest when vaccines are administered widely and quickly, that vaccinating older and more vulnerable people first is important, and that the price of vaccines is a much stronger driver of cost-effectiveness than is efficacy. Policymakers in Ethiopia should prioritise lower-cost doses and, where possible, negotiate with pharmaceutical companies to secure an affordable price.

# 1. BACKGROUND

## 1.1 Epidemiological Context

The first COVID-19 case was detected in Ethiopia on the 13th of March, 2020. Since then, Ethiopia has had four major COVID-19 peaks: in August 2020, April 2021, August through September 2021, and December 2021 through January 2022. The most recent peaks appear to have been driven by the Delta and Omicron variants of Sars-Cov-2, respectively, and the latter has declined heavily since the start of the new year. Official statistics suggest that as of the 12th of June 2022, there have been 478,963 cases and 7,516 deaths from COVID-19 in Ethiopia, with an estimated case fatality of 1.6 percent. However, it is likely that many cases were missed due to the prohibitive cost of testing people. This has caused lower testing rates in low-income countries than in high- or upper-middle-income places. The average length of hospitalization due to COVID-19 was 12 days (9–21 days), with duration of intensive care unit stay ranging from 3 to 8 days.

Ethiopia's healthcare system, along with others globally, was significantly impacted by COVID-19. A study by Dandena, Teklewold, and Anteneh (2021) showed that many health services were impacted by COVID-19 in the period from May to October 2020, compared to the same months in 2019. Inpatient admission fell by 73 percent and surgical admission by 62 percent; the least impacted was maternal admission, which fell by 13 percent. Simultaneously, the number of patients visiting outpatient departments increased by 61 percent, whereas visits to emergency departments increased by 5 percent (Dandena, Teklewold, and Anteneh 2021).

## 1.2 Economic Context

COVID-19 has significantly impacted countries' economies in two quite different ways. The first is that domestic transmission of the virus has reduced consumer demand, often leading to governments' closing services and causing local supply chain disruptions. This has caused problems in all countries to varying degrees. Second, external demand for products, willingness to travel, and global supply chains have been disrupted (World Bank 2021). This means that even if a country had not had a single COVID-19 case, its economy could have been substantially smaller in 2020 and 2021 than if COVID-19 never had happened. It is difficult to separate these additional effects on the economy and thus to understand how much domestic COVID-19 transmission has impacted Ethiopian growth. Ethiopia's GDP grew by 6.05 percent in 2020. This is the lowest rate of growth since the country went into recession in 2003 and is far below the post-recession average of 10.3 percent. However, it is in line with the International Monetary Fund's (IMF's) pre-COVID-19 prediction of a 6.2 percent growth rate for the year and was the third highest growth rate recorded by the World Bank in 2020. These numbers are particularly impressive since only 20 (17.5 percent) of the countries tracked by the World Bank had their economies grow at all last year (*GDP Growth* 2022). Unfortunately, the economic impact of COVID-19 in 2021 has been greater, with just a 2 percent growth rate expected compared to a pre-COVID-19 prediction of 7 percent from the IMF. This delayed impact of COVID-19 on the Ethiopian economy possibly suggests that Ethiopia has been more affected by the global slowdown than by local disease.

Despite the broader economic impact, there is evidence to suggest that at the individual level, many people suffered because of the lockdown. We found only one paper looking at the social and economic impact of COVID-19 in Ethiopia. This used a longitudinal study to track more than 3,000 respondents in Ethiopia, Malawi, Nigeria, and Uganda. The results are worrying (Josephson, Kilic, and Michler 2021). Of Ethiopians who earned money from farming and responded to a longitudinal study, 63 percent said that their income fell during COVID-19—as did 22 percent of people who relied on wage income, 21 percent who relied on business income, and 20 percent who relied on other income sources. There was not a large difference between rural and urban areas for this decline.

## 1.3 Policy Context

Ethiopia applied COVID-19 restrictions that varied between the federal and the regional state levels. Schools were closed on the 12th of March 2020 and a phased return started on the 15th of May 2020. International travel also was highly curtailed. All regional states imposed heavier restrictions, ranging from full lockdowns to more targeted restrictions such as restrictions on travel and restaurants. Given the informal nature of the Ethiopian economy and low Internet access, sustaining these efforts was difficult. Both federal and local governments reduced restrictions from May 2020, when limits on the size of social gatherings became the most common restrictions to remain in place.

According to ourworldindata.org, Ethiopia had conducted 31,500 tests per million people by the 22th of November 2021. This is far below the global average of 523,000 tests per million people, and Ethiopia is ranked 182 out of 209 countries that were compared. However, this comparison should be treated cautiously as the relative cost is much greater in low-income countries like Ethiopia. For the 22 low-income countries on this list, Ethiopia is ranked 23rd and is only slightly below the low-income average (Johns Hopkins 2022).

Ethiopia's GDP is US$936 per capita, meaning that there is limited fiscal space. However, very strong growth rates during the past decade—and the fact that these were sustained during the first year of the COVID-19 pandemic—have left Ethiopia with more fiscal space than expected at the start of the pandemic. However, substantial resource utilization for the internal conflict and reduction of support from aid agencies will likely limit the short-term fiscal space.

Ethiopia has not directly purchased any vaccines and instead is relying on support from COVAX Facility, the African Union, and donor country support. Ethiopia expects to get enough AZ vaccines to cover 30 percent of the population and enough J&J to cover 20 percent. However, these deliveries have been greatly delayed (*GDP Growth* 2022). Ethiopia is therefore considering purchasing Pfizer and/or Sinopharm vaccines.

Decisions about COVID-19 vaccines are made by the Federal Ministry of Health. The vaccine task force and Ethiopian Institute for Public Health (EPHI) play a key role in advising the ministry to make evidence-informed decisions.

Ethiopia planned to inoculate 20 percent of its adult population by the end of 2021 and to offer the remaining 80 percent a vaccine in 2022 and 2023. However, delays in vaccine supply have hampered this goal. Only 9 million vaccines were given in 2021, representing 8 percent of Ethiopia's population. The rate has risen in 2022, with 21 million vaccines being given in Ethiopia by April 11, 2022, representing 18 percent of the total population (*GDP Growth* 2022).

There are different potential strategies for delivering vaccines to the population, which can be used depending on vaccine properties, vaccine availability, and characteristics of the target population. With a limited population (20 percent) being targeted for 2021, the strategy used in Ethiopia was to deliver COVID-19 vaccines using fixed posts and vaccination campaigns. Following the first phase, in addition to fixed posts, feasible modes of delivery including outreach posts and vaccination campaigns will be applied as appropriate. A combination of flexible service delivery modalities will be used based on local contexts to ensure adequate access to the target communities.

## 2. DECISION SCENARIOS FOR THIS HTA AND DECISION MAKING FOR COVID-19 VACCINES

### 2.1 Policy Questions

Three questions were selected for Ethiopia:

1) *Which COVID-19 vaccines should be bought?*
   Ethiopia, in line with the current provision of COVID-19 vaccines, is considering purchasing AZ, J&J, Pfizer, and Sinopharm vaccines. Four vaccines that have similar properties to these products in terms of doses, price, and efficacy have been modelled to help inform decisions around which doses to purchase. In our sensitivity analysis we have looked at vaccines with different price ranges based on local estimates.
2) *What is the best way to deliver the vaccines?*
   We have compared the costs and benefits of fixed posts, vaccination campaigns, and outreach posts. The three vaccine delivery mechanisms explained below are under consideration by Ethiopia.
   - Fixed posts: These are mainly at health facilities and/or other appropriate places. Ethiopia will have at least 2,063 such sites that will administer vaccines to people. People will have to visit these sites to get vaccinated.
   - Vaccination campaigns: These will be used to visit large population centres in a shorter time period and will involve going to people to inoculate them.
   - Outreach posts: These are set up in remote or hard-to-reach areas where travel times to health facilities are long or there is limited access to health services.

Information about the delivery price for each of these methods, as well as estimates for distribution speed, has been collected. Sensitivity around these assumptions has been in place.

3) *What is the cost and cost-effectiveness of vaccinating different target groups?*
We look at different age-targeting approaches, in particular at the benefit of vaccinating over 65s compared to people in the 55–62 age range and people younger than 55. Most of our scenarios presume the expected scale-up speed and look at what happens if only 10 percent of people are vaccinated this year, 50 percent next year, and a total of 80 percent by the end of 2023. We also look at what happens if only those older than 50 are targeted. What would happen if vaccination rates were high for over 50s and low for under 50s.

## 2.2 Audience for this HTA

The main audience for this work consists of key policymakers and stakeholders in Ethiopia. EPHI will work with the Federal Ministry of Health and its agencies, NGOs, civil associations, and other key decision makers and stakeholders in this space to inform Ethiopia procurement.

As part of this outreach we hosted a dissemination event on April 11th and 12th 2022 as part of another project relating to the role of HTA more generally in Ethiopia. The dissemination will help the Ethiopian government—including the Vaccine Taskforce and Federal Ministry of Health—to understand how to strengthen HTA in Ethiopia and how to use this information to inform important up-and-coming decisions about COVID-19 vaccines.

## 2.3 Contribution of the HTA

We undertook this study to inform the Ethiopian health system about COVID-19 vaccines. Throughout this project, EPHI has worked closely with the Federal Ministry of Health to ensure that the right questions are being asked and that the ministry is aware of the research. We have also worked to identify other key partners in the health space in Ethiopia.

This HTA will give insight to the COVID-19 vaccine way forward by looking at cost-effectiveness, target population prioritization, and age and delivery modes.

## 2.4 Assessment Questions and PICO Statements

Taking into account the broad policy questions described above, it was agreed that for the de novo cost-effectiveness analysis (see section 4 of this report), the focus would be on the following analytically suitable questions:

- Which COVID-19 vaccines should be bought, and how much of each vaccine? What is the maximum price to pay?
- Which is the best way to deliver each/all vaccines?
- What is the cost and cost-effectiveness of vaccinating different target groups?

These were further expanded into the context-specific decision problems set out in Table 4.

**Table 4. Summary of the decision problem(s) modelled in this analysis**

| | |
|---|---|
| Intervention | COVID-19 vaccination, specifically the use of the following vaccines:<br>• Viral vector vaccines similar to Oxford/AZ and J&J<br>• mRNA vaccine similar to Pfizer-BioNTech and inactivated-virus vaccine similar to Sinopharm |
| Comparator | No vaccination scenario |
| Perspective | Health system |
| Delivery mechanisms | • Fixed posts<br>• Vaccination campaigns<br>• Outreach posts |
| Age groups | All adults, 50+, 18- to 49-year-olds |
| Coverage | 25% to 100% |

## 2.5 Evidence of Vaccine Effectiveness

Vaccines have three main functions. Not all vaccines will achieve all three, but most aim to reduce

1. the probability that an exposed person will become sick,
2. the severity of illness for those who are infected, and
3. the transmissibility of the disease from people who are infected to those who are susceptible.

The first two of these have benefits that accrue directly to the individual who is vaccinated, whilst the first and last benefit society at large by reducing the chance that viruses will spread through the population.

Table 5 (sourced from the International Decision Support Initiative [iDSI] Toolkit to support vaccine procurement decisions (Chi et al., 2021)) summarizes information about vaccine efficacy for the selected vaccines to be considered in the assessment, looking at the reduction in chance of becoming sick that a person receives from getting vaccinated (note that the definition of "sick" slightly differs between trials). There is a range of efficacy for vaccines, with Moderna and Pfizer-BioNTech achieving 95 percent efficacy while Oxford/AZ achieves 67 percent. For reference, the World Health Organization (WHO) set a 50 percent threshold for COVID vaccines in 2020, so all considered options are above that threshold.

Vaccines' efficacy will vary against different variants of COVID-19, and while most function well against current variants of concern, not all do (and there is no guarantee they will function against future variants). There is evidence that Novavax does not function well against the Beta variant. Evidence form Israel released in July 2021 suggests that the Pfizer vaccine is less effective against the Delta variant of COVID compared with the original strain, reducing symptomatic COVID infections by 62 percent and hospitalisation by 93 percent. This is down from May estimates of a 95 percent reduction in symptoms from those vaccinated in Israel. It is likely that there will continue to be new variants of COVID, and it's important that vaccine efficacy against these variants continue to be tracked.

**Table 5. Summary of vaccine characteristics**

| Vaccine | Mean Average price per dose | Efficacy (%) symptomatic illness (primary outcome) Efficacy secondary outcome | Status (November 2021) | Doses manufactured by 31st of October, 2021 (millions) |
|---|---|---|---|---|
| J&J | $9.50 ($8.50–$10.00) | Moderate to severe/critical centrally confirmed COVID-19 with onset at least 12 days after vaccination among seronegative and SARS-CoV-2 negative participants in the per-protocol population: 66.9%<br>Severe Disease: 76.7% | Granted emergency use approval by the WHO on 12th of March 2021<br>25 countries reporting use | 110 |
| Oxford/AZ | $3.72 ($2.19–$5.00) | COVID-19 with at least one qualifying symptom (fever, cough, shortness of breath, anosmia, or ageusia) in seronegative participants confirmed via nucleic acid test-positive swab >12 days after second dose: 66.7%<br>Severe Disease: 100% | 183 countries reporting use | 1,905 |
| Pfizer/ BioNTech | $13.37 ($6.75–$19.50) | Efficacy of the vaccine 7 days after second dose against laboratory-confirmed COVID-19: 95%<br>Severe Disease: 100% | 112 countries reporting use | 1,883 |
| Sinopharm | $30.00 ($18.00–$36.00) | Efficacy of the vaccine 7 days after second dose against laboratory-confirmed COVID-19: 78.1%<br>Severe Disease: 100% | Approved in 68 countries | 1,772 |

**Source:** Adapted from a table in the iDSI Toolkit for collecting evidence to inform COVID-19 vaccine procurement decisions. That table was updated in August 2021 with manufacturing data. For this report we added Sinopharm data using the same methodology, based on data from the same period.

In addition to the direct health benefits to those inoculated, there are indirect impacts of vaccination on transmission (Mallapaty 2021), thereby reducing cases and the size of the epidemic. This is for two reasons. First, vaccinated people may be less likely to transmit SARS-CoV-2; a large-scale study in England found, though, that the likelihood of household transmission was reduced by 20–50 percent from individuals diagnosed with COVID-19 after vaccination, for both AZ's and Pfizer/BioNtech's vaccines. Second, vaccinated people are less likely to become infected in the first place (Pritchard et al. 2021).

We did not model adverse events in this study. However, most health agencies believe the benefits of adults' taking the AZ and J&J vaccines greatly outweigh the risks, although a different vaccine may be recommended for younger populations. As of August 2021, this vaccine has been approved for 172 countries including 26 African countries. The US Centers for Disease Control and Prevention issued a similar recommendation about the use of J&J's vaccine, which has been licenced by 78 countries.

### 2.6 Evidence on Cost-Effectiveness

Cost-effectiveness analysis is a key component of HTA, and it provides a framework to explore the value for money of alternative policy choices (including vaccine procurement) and the implications for service delivery and affordability. It can help identify optimal subgroups to target. For example, a key challenge usually encountered in the design and deployment of vaccination strategies during disease outbreaks, including the COVID-19 pandemic, even in developed countries, is deciding which classes of the population will be vaccinated, taking into account their vulnerability as well as the number of available vaccines (Area and Nieto 2021).

Cost-effectiveness analysis typically uses modelling techniques to integrate information from a variety of sources on costs, benefits, and future outcomes. Mathematical models (epidemiological and economic) can provide a rational basis to inform approaches to how, where, and when to control an infectious disease. Mathematical models can be used to explore policy questions that are otherwise difficult to assess in the field (Mushayabasa, Ngarakana-Gwasira, and Mushanyu 2020).

No published studies that we are aware of have been identified evaluating the cost-effectiveness of vaccination against COVID-19 in Ethiopia, nor the benefit of vaccination.

## 3. METHODOLOGY

### 3.1 EPHI–London School of Hygiene & Tropical Medicine–Center for Global Development Analysis

To inform this HTA, a bespoke analysis was undertaken to explore the cost-effectiveness of vaccination in the Ethiopia setting, in line with the decision problems set out in section 2.1.

Cost-effectiveness analysis evaluates the effectiveness of two or more interventions (or technologies) relative to their cost. The interventions being analysed here are vaccines being deployed in the Ethiopian context, and their value is being compared to a no-vaccination strategy. Such an approach allows the estimation of so-called ICERs, which are calculated as follows and are used to give an indication of value for money when compared to a cost-effectiveness threshold.

$$\text{Incremental cost-effectiveness ratio (ICER)} = \frac{\text{cost}_{\text{new}} - \text{cost}_{\text{current}}}{\text{health gain}_{\text{new}} - \text{health gain}_{\text{current}}}$$

where "new" in this instance is the selected vaccines being evaluated and "current" is a no-vaccination strategy. Health gains are expressed through DALYs averted (see below).

### Epidemiological Model

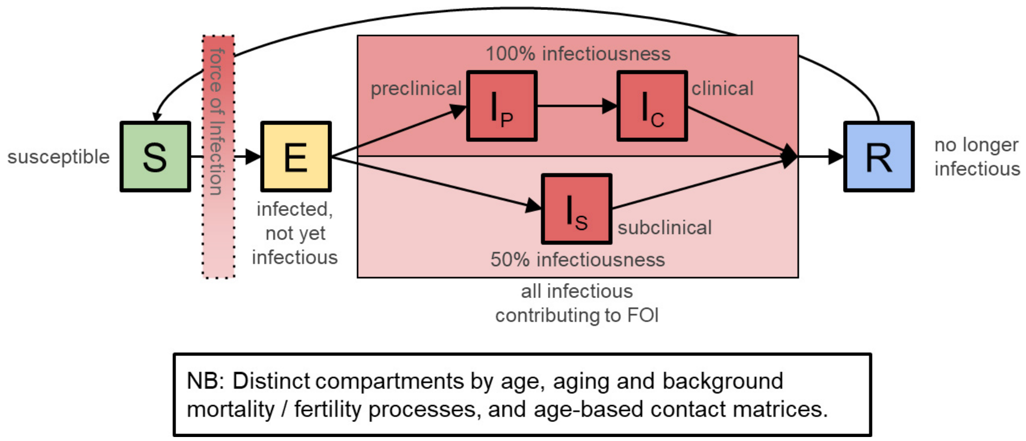
To capture the natural history and transmission of SARS-CoV-2, a previously published compartmental model was used (Davies et al. 2020) that was tailored to the population of Ethiopia using data from WorldPop (2019). Further details about model design can be found in the publication by Pearson et al. (2021), including its supplementary materials.

The model compartments (see Figures 2A and 2B) are an extended SEIRS+V (*S*usceptible, *E*xposed, *I*nfectious with multiple sub-compartments, *R*ecovered and/or *V*accinated, potentially converting either to Susceptible or if in the combined state to only Recovered or Vaccinated) system with births, deaths, and age structure. For all compartments other than Recovered and/or Vaccinated, event-time distributions were derived from global observations. For Recovered and/or Vaccinated, it was assumed that there would be no waning of infection- or vaccine-derived protection, but birth-death demographic turnover was taken into account.

In the model, vaccination operates through preventing infection (and thus disease, but with no impact on breakthrough disease) or disease (with no impact on infection, but with reduced onward transmission due to shifting symptomatic to asymptomatic cases). In the analysis, the benefits of vaccination are bounded by considering all benefits from protection due to either prevention of infection (same direct benefit, maximum indirect benefit) or prevention of disease (same direct benefit, but with minimum indirect benefit).

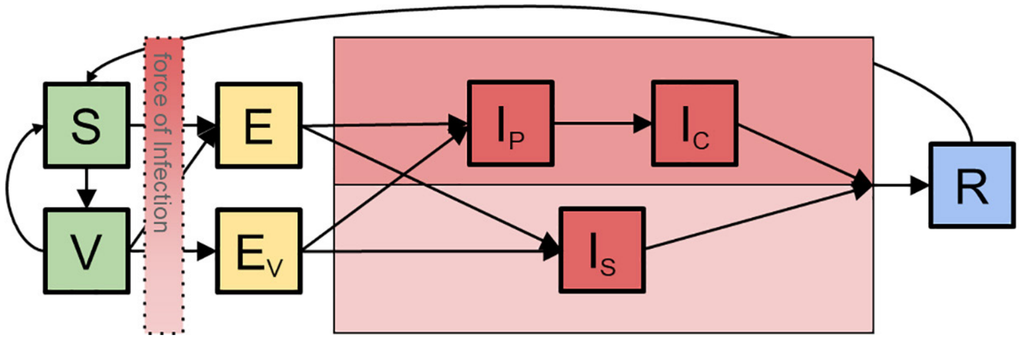
To reflect on the real-world effectiveness of vaccines and recognise the regularly changing evidence base behind individual vaccines, the modelling sought to analyse vaccine types that link with the target vaccines of interest to Ethiopian policy makers. Vaccine effectiveness was estimated for viral vector vaccines (AZ- or J&J-like), an inactivated virus vaccine (Sinopharm-like), and mRNA vaccines (Pfizer-BioNTech–like). The vaccine estimates used in the cost-effectiveness analysis should therefore not be interpreted as specifically linked to an individual vaccine product but rather as broadly reflective of a vaccine with similar characteristics. It is also important to highlight that there remains a lack of data, particularly in low- to-middle-income country contexts, on the real-world effectiveness of COVID-19 vaccines.

**Figure 2A. Model diagram**




**Note:** FOI = force of infection.

**Figure 2B. Introducing vaccination**




We used early case incidence (the number of cases during approximately the first 60 days after the first reported cases in a country) to determine pre-pandemic effective reproduction number, Rt, for the urban population (21.23 percent or 24,941,348 individuals; *Urban Population* 2022). We used early deaths to determine infections, and then we projected the pandemic in the urban population only, using this underlying multiplier as well as changes in mobility indices. A behaviour-modification parameter (i.e., how much people further lower their susceptibility and onward transmission in response to the observed cases) was subsequently fitted to match the trajectory going forward. The timing of the new variants was identified by examining the start of each distinct wave in the observed data, and then multipliers were fitted for those new variants for projection beyond those points.

Since Ethiopia does not have Google mobility data available to estimate contact patterns, we used the Kenyan Google mobility values, shifted based on the policy timing difference with the Oxford stringency index (as defined in the context of the Oxford COVID-19 Government Response Tracker). The impact of nonpharmaceutical interventions (e.g., lockdowns) was estimated using the Oxford Tracker.

A summary of the epidemiological, vaccine, and economic parameters used in the base case and scenario analysis is available in Table 6.

**Table 6. Summary of the epidemiological parameters (including vaccine efficacy) used in the analyses**

| Parameter | Base case value | Source |
|---|---|---|
| Latent period | Gamma (mean = 2.5, k = 5) | Davies et al. (2020) |
| Contact rates | Age-dependent synthetic contact matrix for Ethiopia | Prem et al. (2021) |
| Proportion asymptomatic | Age specific | Posterior from the CMMID C-19 working group |
| Duration of infectiousness | Gamma (mean = 5, k = 4) | |
| Duration of natural immunity | 1 year (average; exponentially distributed) | Assumed |
| Duration of vaccine immunity | 1 year (average; exponentially distributed) | Assumed |
| Vaccine efficacy/ effectiveness | Viral vector 1: 75% (AZ-like) | Barnard et al. (2021)<br><br>Table 1. "Pre-alpha/alpha" two-dose estimates for the prevention of infection |
| | Viral vector 2: 66% (J&J-like) | Bekker et al. (2021)<br><br>Prevention of hospitalisation as *upper* bound on the prevention of infection |
| | mRNA vaccine: 90% (Pfizer-BioNTech–like) | Barnard et al. (2021)<br><br>Table 1. "Pre-alpha/alpha" two-dose estimates for the prevention of infection |
| | Inactivated virus vaccine: 51% (Sinopharm-like) | *Evidence Assessment* (2021)<br><br>Brazilian data, was used as an approximate estimate for inactivated-virus vaccines |

### Vaccination Programme

For the vaccine scenarios, it was assumed that the vaccine is infection blocking and that protection is complete for some individuals and absent in others (i.e., all-or-nothing protection). Disease-only blocking vaccination scenarios also were analysed. Vaccine doses are distributed among individuals in the Susceptible and Recovered compartments; Susceptible individuals become Vaccinated, and Recovered individuals become Recovered and Vaccinated.

Different vaccine efficacies were modelled taking into account the available options in Ethiopia (see section 2.5).

We assumed that vaccination would be carried out over 12 months and only during working days.

### COVID-19 Transmission

To capture the natural history and transmission of SARS-CoV-2, a previously published compartmental model was used (Davies et al. 2020) and was tailored to the population of Ethiopia using data from WorldPop (*CRAN—Package Wpp2019* 2020). Further details about model design can be found in the publication by Pearson (Pearson et al. 2021), including its supplementary materials.

## 3.2 Heath and Economic Outcomes

The analysis modelled the impact of COVID-19 vaccination on cases, deaths, and DALYs compared to counterfactual scenarios with no vaccination over a 10-year time horizon. For different vaccination scenarios, the averted DALYs were combined with the costs of the vaccination program and any reduction in COVID-19 case management costs from vaccination to calculate ICERs. The analysis followed the Consolidated Health Economic Evaluation Reporting Standards (see supplementary materials in Pearson et al. 2021) and adhered to the iDSI Reference Case (Wilkinson et al. 2016).

Base case model parameters are listed in Table 8.

### DALYs

For each scenario, the analysis modelled the health burden in DALYs for symptomatic cases, nonfatal hospitalisations, nonfatal admissions to critical care, and premature death due to COVID-19.

### Costs of COVID-19 Vaccine Delivery

In line with best practices in economic evaluation, all consequential costs were modelled. In other words, we included both the costs of vaccination and the costs of care and treatment of COVID-19. All costs were estimated in 2020 US dollars. The costing was carried out from a health system perspective using a normative, bottom-up, ingredients-based approach.

It was assumed that vaccine doses would be delivered through three modes: health facilities, vaccination campaigns, and outreach posts. We modelled costs of delivering the four vaccines across the three delivery modes.

We report a unit cost per dose per vaccine type per delivery mode in 2020 US dollars (see Table 8).

Our costing covered 12 vaccination sub activities necessary for the planning, rollout, and delivery of vaccines as well as the cost of the dose itself. These are planning and coordination, technical assistance, training, social mobilisation, vaccine transport, cold chain, personal protective equipment, hand hygiene, vaccine delivery, vaccination certificates, waste management, and pharmacovigilance. The decision to include these 12 sub activities was based on a model of the costs of delivering COVID-19 vaccine in the 92 COVAX Facility countries developed by UNICEF. Costs were calculated and separated into five input categories: staff salaries, staff per diems, supplies, equipment, and vehicles and buildings.

Resource use was estimated through an iterative process. A literature review, encompassing both peer-reviewed literature and grey literature, was conducted. This description was shared with public health experts in-country who, through several rounds of validation exercises, arrived at a final resource use description for each sub activity, including quantities and frequencies of activities at both the national and the subnational level for each of the delivery modalities.

A similar process was followed to determine prices of inputs. An initial list of prices was compiled using the literature and was updated to 2020 US dollars. This list was then reviewed and validated by in-country experts.

The base cost of the vaccine doses are outlined in Table 7, these were then augmented by additional costs due to freight charges, vaccine wastage, and the maintenance of a buffer stock. We assumed an additional 10 percent freight charge for receiving the vaccine doses in-country from external senders. Domestic transportation costs are accounted for under the category of vaccine transport. We consulted with vaccine costing experts to discuss uncertainties surrounding an appropriate wastage factor and proportion of buffer stock. We have assumed 15 percent wastage represented by the factor $1.18 = 1/(1 - 0.15)$ and have assumed the need for a 10 percent buffer stock, with the cost of these additional doses annuitized over 10 years.

**Table 7. Cost of vaccines, in US dollars[a]**

| | Base | Sensitivity analysis high | Sensitivity analysis low |
|---|---|---|---|
| AZ-like | 3 | 5 | 2 |
| J&J-like | 10 | 10 | 8 |
| Pfizer-like | 17 | 17 | 17 |
| Sinopharm-like | 30 | 36 | 18 |

[a] Based on discussion with policymakers and the prices listed by UNICEF.

### Costs of COVID-19 Diagnosis and Treatment

The economic impact of COVID-19 on the health system includes diagnosis and clinical management. Unit costs of outputs, such as bed days or outpatient visits, were sourced from a range of primary published and unpublished sources in Ethiopia. These estimates represent the economic cost of all resources required to deliver health services, including staff time, capital and equipment, drugs, supplies, and overhead costs. Quantities of resources used were defined following WHO and Ethiopian guidelines.

### Other Inputs

Table 8 outlines the main inputs that went into the model, with a discount rate of 3 percent used and vaccines rolled out at health facilities, vaccination campaigns, and outreach posts being at 200, 150, and 100 doses per day, respectively. The faster base case scenario assumes everyone will be vaccinated in two years, while the slower one spreads vaccination out over three.

**Table 8. Main modelling assumptions**

| Model | Main assumptions | Input |
|---|---|---|
| Both base cases | Discount rate | 3% |
| Both base cases | Health facility coverage (doses per day per facility) | 200 doses per facility per day |
| Both base cases | Campaign coverage (doses per day per campaign) | 150 doses per team per day |
| Both base cases | Outreach posts (doses per day per mobile/outreach) | 100 doses per facility per day |
| Both base cases | Age targeting | Older than 65 first, then 18–64 |
| Faster base case | Rollout timeline | 20% of adults vaccinated by end of year 1, 100% by end of year 2 |
| Slower base case | Rollout timeline | 10% of Ethiopians will be vaccinated by the end of 2021, 50% vaccinated by the end of 2022, and 80% vaccinated by the end of 2023 |

## Sensitivity Analysis Inputs

As well as the two base case scenarios, we used analysis to understand the importance of different inputs on our analysis. This varied the discount rate, the productivity rates of different distribution mechanisms, different age-targeting approaches, and different prices for the vaccines. The nine scenario analyses are outlined in Table 9. All other sensitivity analysis inputs come from the faster base case unless otherwise stated.

**Table 9. Sensitivity analysis inputs for COVID-HTA vaccine model**

| Scenario | Sensitivity/scenario analysis type | Baseline input | New input |
|---|---|---|---|
| 1 | Low discount rate | 3% discount rate | 0% discount rate |
| 2 | High discount rate | 3% discount rate | 6% discount rate |
| 3 | Facility coverage very low | 50 doses per health facility per day | 20 doses per health facility per day |
| 4 | Facility coverage very high | | 200 doses per health facility per day |
| 5 | Campaign rate low | 150 per campaign group | 100 per campaign group |
| 6 | Age targeting: 50-year-olds+ | 100% coverage for over 18s | 100% coverage for over 50s, no vaccines for under 50s |
| 7 | Age targeting: 50-year-olds+ (70%); 18- to 49-year-olds (25%) | | 70% coverage for those age 50 and older; 25% coverage for those age 18–49 |
| 8 | High-cost vaccines | AZ-like: $3, J&J-like: $10, Pfizer-like: $17, Sinopharm-like: $30 | AZ-like: $5, J&J-like: $10, Pfizer-like: $17, Sinopharm-like: $36 |
| 9 | Low-cost vaccines | | AZ-like: $2, J&J-like: $8, Pfizer-like: $17, Sinopharm-like: $18 |

# 4. RESULTS

## 4.1 Epidemiological Modelling

The model-fitting procedure found that the simulated data matched closely on available seroprevalence information but somewhat less well on reported cases and deaths. However, what is key to acceptable vaccine projections is the fit to the seroprevalence data, which was found to be good.

Note that in the modelling, vaccination was set to begin on the 1st of September 2021. Therefore, year 1 covers a vaccination period between the 1st of September 2021, and the 1st September 2022. All vaccination is completed by 1st September 2022 in the analysis, and impact is projected until September 2026. The figures presented in the Appendix show data wherein vaccine is uniformly distributed by age and infection is assumed to be totally immunizing.

## 4.2 Economic Findings

Results are presented on cost-effectiveness from a health system perspective. The analysis does not consider wider societal benefits, although these could be substantial. The aim is to examine likely impacts on the key budget holder and reflect as far as possible on the trade-offs given existing spending. To that end, the estimates of cost-effectiveness were compared against supply-side thresholds estimated for Ethiopia (Ochalek, Lomas, and Claxton 2018). In addition, a threshold of 1 × GDP per capita was used, although this is still regarded as aspirational and not reflective of the actual budget constraint. It can best be regarded as an upper limit in the present analysis. It is important to highlight that the WHO does not recommend the use of GDP-based thresholds (ranges of 1 to 3 times GDP per capita typically have been used in the past for many economic evaluations undertaken for low- and middle-income country (LMIC) contexts) (Kazibwe et al. 2022), although practical alternatives are needed when direct country-specific data and analyses are unavailable.

The first area we assessed was which COVID-19 vaccine Ethiopia should purchase. We looked at four hypothetical vaccines that are similar to those being considered by the Federal Ministry of Health, under two base case scenarios. This work is backward focused and based on modelling variants that were common in September 2021. However, we believe the analysis offers generalisable lessons that are useful for policymaking going forward.

## 4.3 Overall DALYs Averted

While all vaccines offer large protection against COVID-19, the benefit varies by both the scenario and the vaccine chosen. As shown in Table 10, vaccinating people more quickly averts more DALYs.

**Table 10. DALYs averted for each of the vaccination alternatives under two rollout scenarios (fast vs. slow) and different vaccine impact mechanisms (disease only vs. infection)**

| Vaccine | Cost per course (excluding delivery, in US dollars) | Disease slower scenario | Infection slower scenario | Disease faster scenario | Infection faster scenario |
|---|---|---|---|---|---|
| AZ-like | 6 | 179,521 | 347,821 | 255,038 | 433,989 |
| J&J-like | 10 | 216,561 | 350,917 | 272,180 | 439,578 |
| Sinopharm-like | 60 | 123,106 | 251,203 | 169,222 | 317,690 |
| Pfizer-like | 32 | 229,367 | 414,209 | 319,263 | 537,226 |

An mRNA vaccine as modelled here offered the greatest health benefit of the alternatives analysed. Depending on the scenario, it prevented between 19 and 27 percent more DALYs than the AZ-like alternative, but at almost six times the purchase price, this meant it was less cost-effective. In all scenarios, the J&J-like vaccine also averted more DALYs than did the AZ-like alternative, averting up to 21 percent more DALYs, but the difference was much smaller in the infection model. An inactivated-virus vaccine like Sinopharm averts a little more than two-thirds as many DALYs as in each scenario.

To compare the cost-effectiveness, we thus can use ICERs. These compare the total cost of a treatment to the health system against the total benefit and assign a cost per DALY averted as outlined in Table 11.

**Table 11. ICERs per vaccine when given by health facilities, in US dollars**

| Vaccine | Disease slower scenario | Infection fast scenario | Disease faster scenario | Infection faster scenario |
|---|---|---|---|---|
| AZ-like | 330.28 | –125.19 | –38.85 | –322.62 |
| J&J-like | 306.26 | –83.72 | 90.35 | –231.07 |
| Sinopharm-like | 5,811.83 | 2,698.29 | 2,972.60 | 2,279.25 |
| Pfizer-like | 1,581.70 | 580.22 | 1,192.09 | 212.57 |

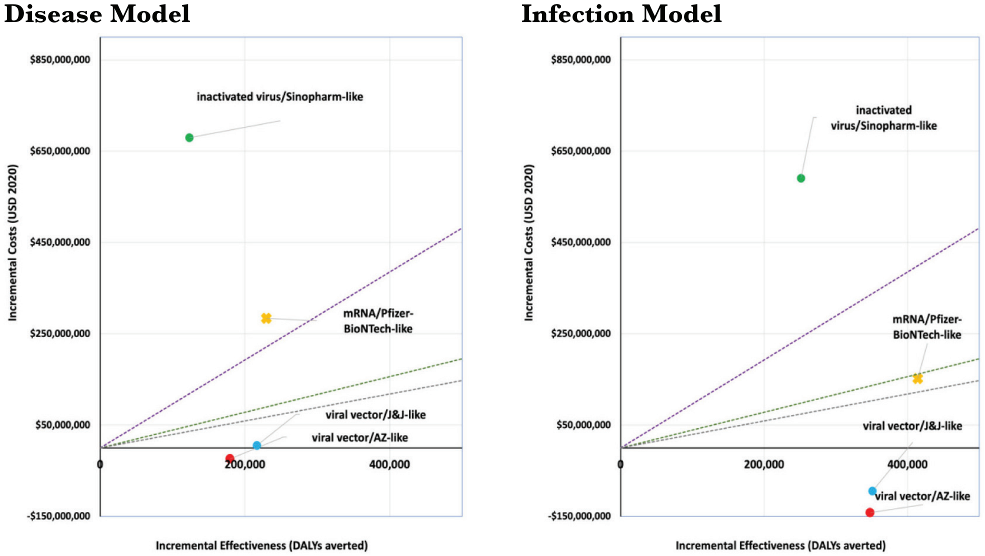
These figures reflect some of those shown in the graphs above. It is worth emphasising that viral vector vaccines could save money for the Ethiopian health system and generally appear cost-effective even when applying the opportunity cost–based thresholds derived from Ochalek, Lomas, and Claxton (2018).

## 4.4 Policy Question 1: Which Vaccines Should Ethiopia Purchase?

### Slower Scenario

Of Ethiopians, 10 percent will be vaccinated by the end of 2021, 50 percent by the end of 2022, and 80 percent by the end of 2023 these results are shown in Figure 3, and Table 12.

Figure 3. Distribution assumptions: health facilities at 20 percent, campaigns at 20 percent, outreach posts at 20 percent

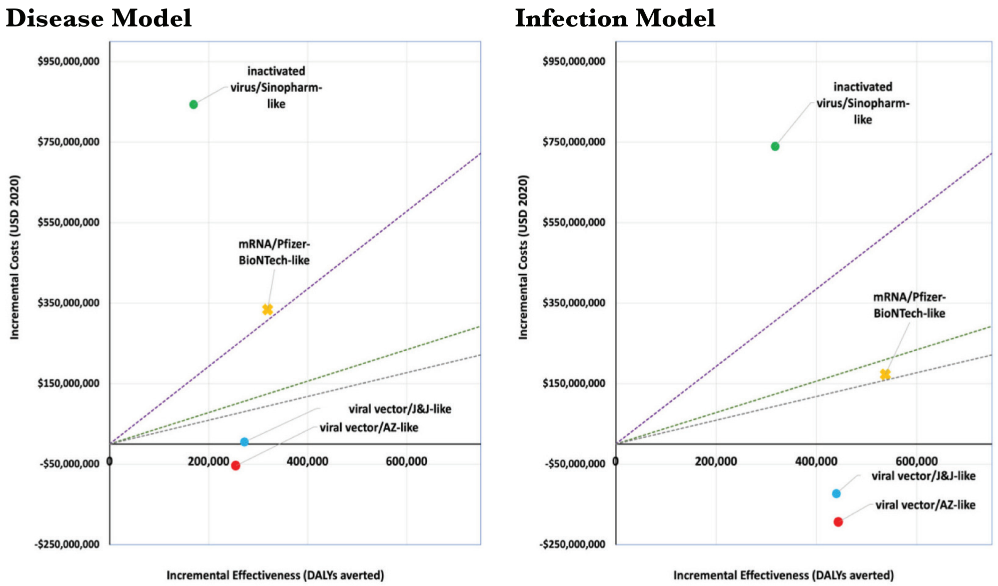



**Note:** Cost-effectiveness threshold: 1 × GDP (US$963), Ochalek high (US$390), Ochalek low (US$295).

### Faster Scenario

Of Ethiopians, 20 percent will be vaccinated by the end of 2021 and 80 percent by the end of 2022 these results are shown in Figure 4, and Table 12.

Figure 4. Distribution assumptions: health facilities at 20 percent, campaigns at 20 percent, outreach posts at 20 percent




**Note:** Cost-effectiveness threshold: 1 × GDP (US$963), Ochalek high (US$390), Ochalek low (US$295).

**Table 12. Results from the two base case scenarios, averaging delivery method**

| Base case scenario | Vaccine mechanism | Vaccine type | Total cost (US$1,000 in 2020 US dollars) | Total DALYs | ICER |
|---|---|---|---|---|---|
| Slower | Disease | AZ-like | –25,728,719 | 179,521 | –$158 |
| Slower | Disease | J&J-like | 4,979,730 | 216,561 | $4 |
| Slower | Disease | Sinopharm-like | 677,968,110 | 123,106 | $5,129 |
| Slower | Disease | Pfizer-like | 282,395,322 | 229,367 | $1,199 |
| Slower | Infection | AZ-like | –143,393,921 | 347,821 | –$419 |
| Slower | Infection | J&J-like | –94,895,777 | 350,917 | –$270 |
| Slower | Infection | Sinopharm-like | 589,242,028 | 251,403 | $2,340 |
| Slower | Infection | Pfizer-like | 150,339,348 | 414,209 | $363 |
| Faster | Disease | AZ-like | –56,260,106 | 255,038 | –$235 |
| Faster | Disease | J&J-like | 4,179,909 | 272,180 | $12 |
| Faster | Disease | Sinopharm-like | 840,989,492 | 169,442 | $4,691 |
| Faster | Disease | Pfizer-like | 331,565,869 | 319,263 | $1,036 |
| Faster | Infection | AZ-like | –196,304,943 | 443,989 | –$442 |
| Faster | Infection | J&J-like | –123,892,809 | 439,578 | –$281 |
| Faster | Infection | Sinopharm-like | 737,200,239 | 317,690 | $2,321 |
| Faster | Infection | Pfizer-like | 170,585,664 | 537,246 | $319 |

In the faster scenario, the cost-effectiveness is improved because there are greater potential benefits in giving vaccines more quickly. However, supply and capacity issues make this difficult. The cost per dose may be higher if vaccines are distributed more quickly, but this difference is not captured in our model.

In both base cases, the model shows that an inactivated-virus vaccine similar to Sinopharm would not be cost-effective by any threshold applied in this analysis. An mRNA vaccine similar to Pfizer is usually not cost-effective either, but in some scenarios it is. In all the cases, the two viral vector vaccines modelled appear highly cost-effective. In the slower scenario, they are approximately at the Ochalek-low threshold of $295 per DALY averted (in the disease-only vaccine model), suggesting that these vaccines were just cost-effective by this conservative threshold but highly cost-effective relative to other thresholds used. When it is assumed that vaccines also will impact transmission (the infection model), rollout with viral vector vaccines could reduce total costs over five years. Under these vaccine impact assumptions, the mRNA vaccine modelled was cost-effective when applying a 1 × GDP per capita threshold and was cost-effective within the Ochalek-high threshold under the faster rollout scenario. However, the comparator for all of these is no vaccination; the two less cost-effective vaccines would be much less cost-effective if they were compared to a viral vector vaccine as the alternative, as discussed later.

All of the vaccines are more cost-effective in the faster scenario; this difference varies a lot by vaccine, but the faster scenario is usually more than $200 more cost-effective per vaccine.

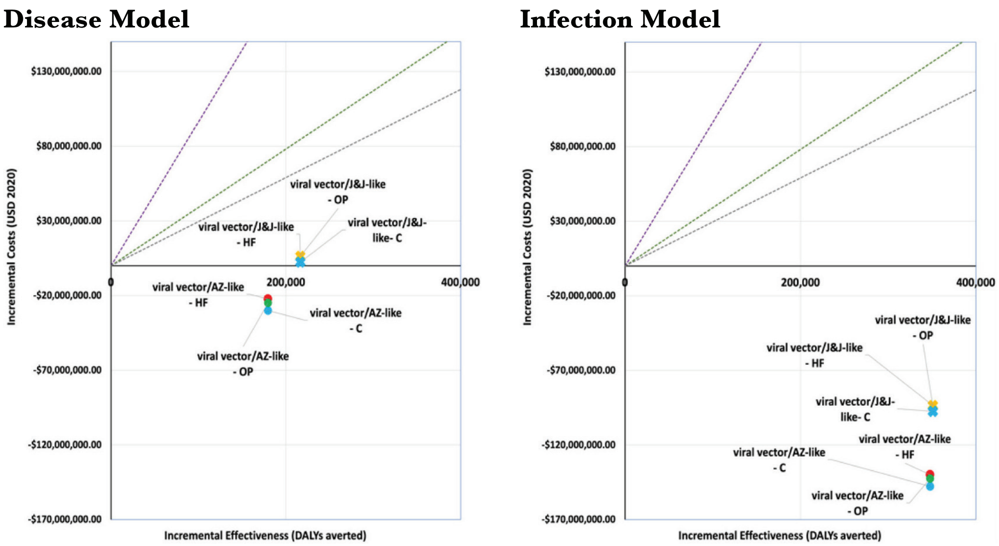
## 4.5 Policy Question 2: How Should These Vaccines Be Distributed?

As outlined in section 2.1, Ethiopia is considering three ways of delivering vaccines: health facilities or other fixed posts, vaccination campaigns, and outreach posts. We found that each of these matters far less than the choice of vaccine and the speed of rollout. For this reason, we have focused on just the two viral vector vaccines shown in Figures 5 and 6, but the analysis was done on all four vaccines.

### Slower Scenario

Of Ethiopians, 10 percent will be vaccinated by the end of 2021, 50 percent by the end of 2022, and 80 percent by the end of 2023.

**Figure 5. Cost planes by vaccine delivery method in slower sceanrio**

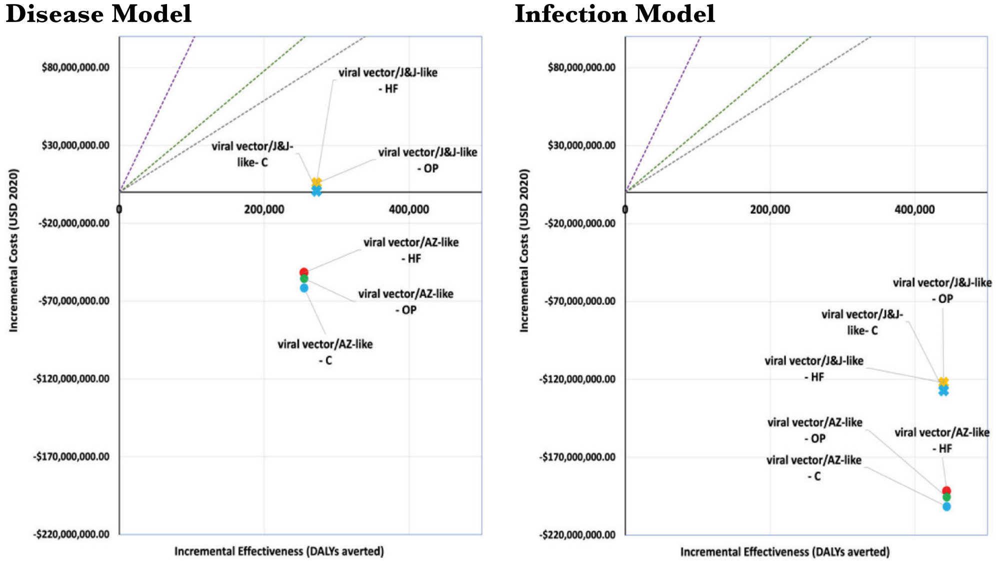



**Note:** C = campaigns; HF = health facilities; OP = outreach posts. Cost-effectiveness threshold: 1 × GDP (US$963), Ochalek high (US$390), Ochalek low (US$295).

### Faster Scenario

Of Ethiopians, 20 percent will be vaccinated by the end of 2021 and 80 percent by the end of 2022. Results for different delivery methods are outlined in Figure 6, and Table 13.

**Figure 6. Cost planes by vaccine delivery method in faster sceanrio**




**Note:** C = campaigns; HF = health facilities; OP = outreach posts. Cost-effectiveness threshold: 1 × GDP (US$963), Ochalek high (US$390), Ochalek low (US$295).

**Table 13. Results for delivering the viral vector vaccines by different delivery modes**

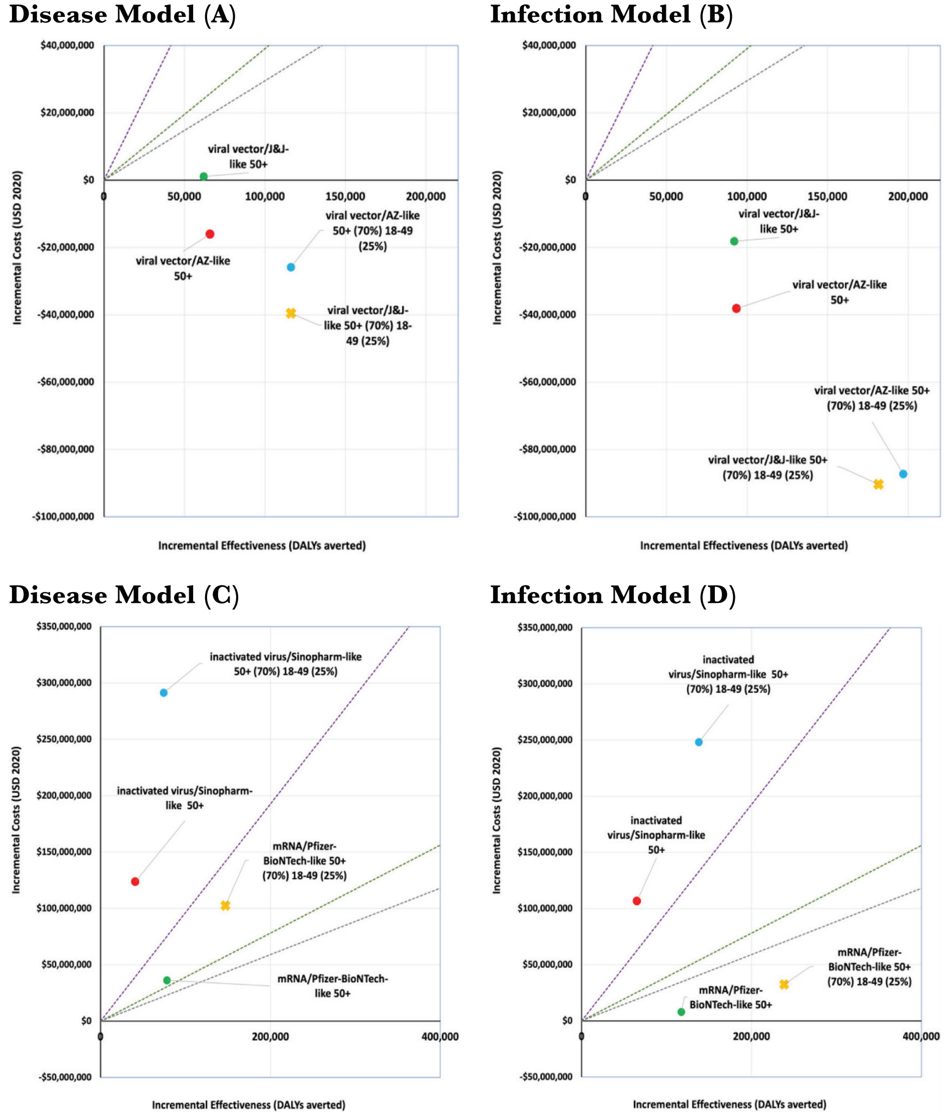
| Base case scenario | Vaccine mechanism | Vaccine type | Delivery mode | Total cost (US$1,000 in 2020 US dollars) | Total DALYs | ICER |
|---|---|---|---|---|---|---|
| Slower | Infection | AZ-like | Health facility | –$139,964 | 347,821 | –$408 |
| Slower | Infection | AZ-like | Campaign | –$147,729 | 347,821 | –$432 |
| Slower | Infection | AZ-like | Outreach post | –$142,489 | 347,821 | –$416 |
| Slower | Infection | J&J-like | Health facility | –$93,504 | 350,917 | –$266 |
| Slower | Infection | J&J-like | Campaign | –$97,519 | 350,917 | –$278 |
| Slower | Infection | J&J-like | Outreach post | –$93,665 | 350,917 | –$267 |
| Slower | Disease | AZ-like | Health facility | –$22,299 | 179,521 | –$141 |
| Slower | Disease | AZ-like | Campaign | –$30,063 | 179,521 | –$180 |
| Slower | Disease | AZ-like | Outreach post | –$24,824 | 179,521 | –$154 |
| Slower | Disease | J&J-like | Health facility | $6,372 | 216,561 | $10 |
| Slower | Disease | J&J-like | Campaign | $2,357 | 216,561 | –$8 |
| Slower | Disease | J&J-like | Outreach post | $6,210 | 216,561 | $10 |

This research suggests that vaccination campaigns offer the best value for money (although the differences between delivery methods were small). However, rarely does delivery mechanism affect whether something is cost-effective, and it is probable that the best mechanism is the one that can get vaccines out to people most easily or most quickly.

## 4.6 Policy Question 3: Which Age Groups Should Be Targeted?

We examined two age scenarios; one was vaccinating just people older than 50, and the second was vaccinating 75 percent of people older than 50 and 25 percent of 18- to 29-year-olds. To make it easier to follow the graphs, we have separated the viral vector vaccine from the other two analyses. Figure 7 and Table 14 show the results from the faster scenario.

**Figure 7. Cost planes for different vaccine targeting approaches**




**Note:** Cost-effectiveness threshold: 1 × GDP (US$963), Ochalek high (US$390), Ochalek low (US$295).

Table 14. ICERs for age-targeting approaches

| Scenario | Age targeting: over 50s | | Age targeting: over 50s (70%), 18- to 49-year-olds (25%) | | 20% of population in year 1, 100% by end of year 2 | |
|---|---|---|---|---|---|---|
| Model | Disease model | Infection model | Disease model | Infection model | Disease model | Infection model |
| AZ-like | –$240 | –$415 | –$240 | –$450 | –$218 | –$432 |
| J&J-like | $16 | –$213 | –$393 | –$518 | $18 | –$277 |
| Sinopharm-like | $3,096 | $1,668 | $3,928 | $1,804 | $4,717 | $2,335 |
| Pfizer-like | $480 | $69 | $647 | $140 | $1,050 | $327 |

Comparing these results to inoculating the whole population, we find that there is very little difference between the ICER of treating just over 50s and that of treating everyone, when using the viral vector vaccines, with an average difference of just $22. However, when looking at mRNA or inactivated-virus vaccine, inoculating over 50s first is far more cost-effective, with an average ICER difference of $770. The small difference for the viral vector vaccines is partially driven by lower costs per vaccine for the whole population due to economies of scale in distribution, against a lower effectiveness per dose. The optimal approach varies by vaccine. Table 14 gives ICERs showing the cost-effectiveness of the four vaccines with these three age-targeting approaches. All are modelled using inputs from health facilities, but results are similar to what we would have shown with other distribution mechanisms.

## When Multiple Vaccines are Available

In all cases above, the cost-effectiveness of these vaccines was assessed against no vaccine. If the comparator changes from no vaccine to a viral vector vaccine similar to AZ, Sinopharm is both more expensive and less efficacious than the AZ-like vaccine and would be marked as inadequate; using an incremental analysis would not be possible. This approach can be used to compare a Pfizer-like mRNA vaccine to an AZ-like comparator. In this case, the Pfizer-like vaccine has a very high incremental cost and does not appear to be a good value for money as shown in Table 15.

**Table 15. Comparison of the mRNA vaccine modelled against a viral vaccine comparator (AZ-like)**

| Scenario | DALYs averted | Cost ($1,000) | Incremental DALYs averted | Incremental cost ($1,000) | ICER |
|---|---|---|---|---|---|
| Slower—disease comparator (AZ-like) | 179,521 | –$25,729 | x | x | x |
| Slower—disease treatment (Pfizer-like) | 229,367 | $282,395 | 49,846 | $308,124 | $6,182 |
| Slower—infection comparator (AZ-like) | 347,821 | –$143,394 | x | x | x |
| Slower—infection treatment (Pfizer-like) | 414,209 | $150,339 | 66,388 | $293,733 | $4,424 |
| Faster—disease comparator (AZ-like) | 255,038 | –$56,260 | x | x | x |
| Faster—disease treatment (Pfizer-like) | 319,263 | $331,566 | 64,225 | $387,826 | $6,039 |
| Faster—infection comparator (AZ-like) | 433,989 | –$196,305 | x | x | x |
| Faster—infection treatment (Pfizer-like) | 537,226 | $170,586 | 103,237 | $366,891 | $3,554 |

## 4.7 Sensitivity Analysis

Table 16 outlines the main results from the sensitivity analysis; all of these results are based on health facility distribution. Improving the productivity of health facilities by an order of magnitude improves the ICER for each vaccine by about $100 when given by a health facility, but it does not impact vaccination campaigns. Similarly, a decrease in the productivity of vaccination campaigns makes this less cost-effective. As previously stated, the cost of vaccines is the biggest driver behind this analysis, highlighted by the fact that even small changes in the vaccine price have a large impact on the ICER.

**Table 16. Main results from the sensitivity analysis**

| Scenario | Description | Vaccine | ICER for health facilities | | ICER for campaigns | |
|---|---|---|---|---|---|---|
| | | | Disease model | Infection model | Disease model | Infection model |
| Facility coverage very low | 20 doses per health facility per day | AZ | –$104 | –$364 | –$254 | –$454 |
| Facility coverage very low | | J&J | $74 | –$242 | $0 | –$288 |
| Facility coverage very low | | Sinopharm | $4,887 | $2,430 | $4,661 | $2,304 |
| Facility coverage very low | | Pfizer | $1,145 | $383 | $1,019 | $309 |
| Facility coverage very high | 200 doses per health facility per day | AZ | –$275 | –$466 | –$255 | –$455 |
| Facility coverage very high | | J&J | –$10 | –$294 | –$1 | –$288 |
| Facility coverage very high | | Sinopharm | $4,632 | $2,288 | $4,661 | $2,304 |
| Facility coverage very high | | Pfizer | $1,003 | $299 | $1,019 | $309 |
| Campaign rate low | 100 per campaign group | AZ | –217 | –$432 | –$235 | –$442 |
| Campaign rate low | | J&J | $19 | –$276 | $10 | –$282 |
| Campaign rate low | | Sinopharm | $4,717 | $2,335 | $4,690 | $2,320 |
| Campaign rate low | | Pfizer | $1,050 | $327 | $1,035 | $318 |
| High-cost vaccines | AZ-like: $5 | AZ | $16 | –$292 | –$21 | –$314 |
| High-cost vaccines | J&J-like: $10 | J&J | $18 | –$277 | $0 | –$288 |
| High-cost vaccines | Pfizer-like: $17 | Sinopharm | $7,168 | $3,707 | $7,112 | $3,675 |
| High-cost vaccines | Sinopharm-like: $36 | Pfizer | $1,050 | $327 | $1,019 | $309 |
| Low-cost vaccines | AZ-like: $2 | AZ | –$334 | –$499 | –$371 | –$521 |
| Low-cost vaccines | J&J-like: $8 | J&J | –$98 | –$349 | –$117 | –$360 |
| Low-cost vaccines | Pfizer-like: $17 | Sinopharm | $2,616 | $1,160 | $2,560 | $1,128 |
| Low-cost vaccines | Sinopharm-like: $18 | Pfizer | $1,050 | $327 | $1,019 | $309 |

## 4.8 Key Limitations

It is important to highlight a number of limitations to the de novo modelling undertaken for this HTA:

- There is a lack of evidence on immunization's waning, either from natural infection or vaccination. Waning was not accounted for in the model, and therefore cost-effectiveness may be overestimated.

- The model does not take into account the rapid emergence of new variants (such as Omicron).
- The model does not account for future changes in the technologies available for the prevention or management of disease nor other changes that may affect the epidemiology and the impact on outcomes.
- Analyses take a health system perspective only, and therefore cost-effectiveness may be underestimated (but see section 5).
- The approach to costing care and treatment involved cross-country extrapolation and may not fully reflect resources on the ground in Ethiopia.
- The study does not take into account health system constraints on the delivery of the vaccine, nor does it include the displacement of services that could result from the health system. This may result in cost-effectiveness' being overestimated.
- We did not adjust costs of delivery (e.g., social mobilization costs) as coverage increases; more intense activities need to be undertaken to address hesitancy and vaccinate the remaining population.
- The study does not take account of the wide economic benefits outside of health.

## 5. DISCUSSION

In this study we modelled four vaccines to emulate existing vaccines on the market. We looked at these under a number of different scenarios and assumptions to understand which vaccines are likely to be optimal to administer, how best to administer them, and whether it made sense to target vaccines by age.

Of the four vaccines, the inactivated-virus alternative (Sinopharm-like) is the most expensive and the least efficacious; the analysis indicates that it is not cost-effective relative to the other vaccines considered. Even if it were the only vaccine available, our modelling suggests the Ethiopian government would likely pay between US$2,280 and US$5,700 per DALY averted with a Sinopharm-like vaccine. This is between 2.6 and 6 times Ethiopia's GDP per capita. If the threshold estimates provided by Ochalek, Lomas, and Claxton (2018) reflect the possible health opportunity costs that could be forgone, the analysis suggests that Ethiopia could avert between 6.3 and 20 times as many DALYs by spending this money elsewhere in its health system. The Sinopharm-like inactivated-virus vaccine does not appear to offer good value for money.

Of the remaining three vaccines, the two viral vector vaccines are similar on both efficacy and price. The mRNA vaccine we modelled is the most efficacious and the most expensive of these three. Its price is quite a lot higher (relative to the viral vector vaccines), making the cost per DALY averted at least US$600 more than the other two vaccines. If there were no other vaccines available, it plausibly would be a good value for money to use an mRNA vaccine similar to the one modelled here in certain circumstances, for example, if officials believed it would greatly reduce transmission, or if it were targeted at vulnerable groups like the elderly.

However, most of our modelling outputs suggest that at least relative to viral vector vaccine alternatives, it would not offer good value for money.

The comparator in this study is a no-vaccine scenario. If the mRNA or inactivated-virus vaccines were compared to a viral vector vaccine, then these would become even less cost-effective. The Sinopharm-like vaccine that was modelled was observed to be more expensive and less efficacious than any of the other three vaccines analysed and would seemingly offer very poor value for money. While the mRNA vaccine can avert the most DALYs of the alternatives compared in this analysis, relative to the viral vector vaccines, it is likely to offer poor value for money.

## 6. WIDER CONSIDERATIONS

The de novo analyses presented here relate to four hypothetical vaccines modelled against the then prevalent Delta variant in urban and peri-urban regions of Ethiopia. It found that the biggest driver by far of cost-effectiveness was the price of the vaccine, which was much more important than targeting the vaccine at particular groups. All of the vaccines we looked at were efficacious at well over the 50 percent minimum threshold the WHO set (*Understanding the Spectrum* 2021). The degree to which they were efficacious seemed to matter much less than the price.

While this study was done on the Delta variant, it is currently not clear how prevalent the Omicron variant will become in Ethiopia, nor is there good information about how well current vaccines work against this variant. However, the broad findings of this analysis are likely still relevant, highlighting the importance of cost per dose and the value of vaccinating people quickly. However, it is not clear whether that threshold is still met with Omicron.

Areas to explore (this is not an exhaustive list):

- **Equity/access—**Our model has looked only at urban and peri-urban areas and suggests that there are no major equity issues; vaccinating all groups appears to be cost-effective in Ethiopian urban areas. Further research is needed to examine rural areas.
- **Vaccine hesitancy—**Vaccine hesitancy remains a serious global threat to achieving herd immunity. Studies done in Ethiopia showed that people had low acceptance of vaccines against COVID-19. A study done in Northwest Ethiopia showed that 26 percent of the studied population would refuse COVID-19 vaccines, and similarly, a study conducted in Addis Ababa stated that one out of five (19.1 percent) participants were not willing to get vaccinated once vaccines were available (Castillo et al. 2021a; Dereje et al. 2021).

  Currently, COVID-19 vaccine hesitancy is a challenge that is faced by the Ethiopian health system. Thus, it is critical to investigate feasible interventions to find applicable solutions. Cognizant of this, the current analysis answers key questions about vaccine type selection, target group prioritization, and delivery mode. Having responses to these questions allows focus to move to the next key question of exploring and applying strategies against vaccine hesitancy and paves the way for implementation studies on vaccine hesitancy (e.g., what are the implications of the present analysis for strategies to address hesitancy, etc.).

- **Budget impact—**The total budget impact of COVID-19 vaccines could be cost saving as they will greatly reduce the strain on the Ethiopian health system by reducing pressure on primary care facilities and hospitals. However, there might still be a large financial impact on certain parts of the Ethiopian health system that funds the vaccines or on primary care overall.
- **Implementation issues—**Our modelling suggests that the faster the vaccine is rolled out, the better will be the benefits and the greater will be the value for money. However, this does not take into account resource constraints in the system, and it is possible that a shortage of volunteers to administer the vaccines, or strains put on supply chains for delivering the vaccines, might have negative consequences elsewhere in the system that are not captured by this analysis.
- **State capacity shortages—**All countries have constraints on what they can do as there are limited resources at their disposal; these constraints are greater in low-income countries. There is a risk that the vaccinators, refrigerators, facilities, and other resources used to inoculate people against COVID-19 will crowed out different health programs.

### Wider Benefits and Harms

The benefits of vaccinating against COVID-19 are bigger than just health. 2020 saw a huge shock to the world economy, with more than 80 percent of countries going into recession. As previously outlined, while Ethiopia's economy survived better than most in 2020, growth rates for 2021 were much lower than expected before COVID-19. This financial shock can be reduced by inoculation. Some estimates of the global value to the economy by increasing vaccine supply are as large as US$5,800 per course, or US$576 to US$989 for speeding up vaccination by four months (Castillo et al. 2021b). This greatly dwarfs the global price.

However, a large part of the economic benefits arising from these estimates is based on the removal of nonpharmaceutical interventions such as lockdowns; these have for the most part been removed in Ethiopia. The country also is looking at things from a global perspective and so taking into account international as well as domestic components around vaccination as outlined in section 1.2. The financial benefits will be higher in high-income countries both because these have tended to see greater economic consequences from COVID-19 and because a similar uptick in a high-income economies is much greater in absolute terms. Finally, most of the benefits come from vaccinating the most vulnerable people in society and allowing a return to greater trade practices.

There are not sufficient research papers on the macro-economic impact of COVID-19 vaccines in low-income countries to know what these benefits would be for Ethiopia. If the vaccination allowed Ethiopia to return to IMF-forecast growth rates of 7 percent for 2021 instead of 2 percent, the difference would be US$27 per capita, far less than the cost of inoculation. However, as previously outlined, these costs have many causes, most of which will not be overcome by vaccinations in Ethiopia. Ethiopia is projected to return to high growth in 2022, reducing the scope for vaccine-induced economic growth.

## 7. FURTHER RESEARCH

Ethiopia lacks Google mobility data; more information about how often people meet each other and how the disease spreads in the country would be useful.

In this research, we focused on urban and peri-urban areas. Information from other countries suggests that these are likely the most important places to vaccinate, but further studying of rural areas in Ethiopia would be useful.

Future modelling work should look at the advantages of booster doses and when to give them as well as vaccination of children ages 12 to 17. All work should be updated when a new variant substantially changes the nature of the disease. In the short term, the most likely variant to do so is Omicron.

## 8. NEXT STEPS

An earlier draft of this report was shared with policymakers in Ethiopia both informally and through a dissemination event that took place on April 11–12, 2022. We will write a blog outlining the research, present findings to the African Union, and continue to work with the Federal Ministry of Health and vaccine task force to inform any future decisions.

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## 10. APPENDICES

- Protocol(s) and related materials
- Detailed London School of Hygiene & Tropical Medicine modelling information
- Epidemiological modelling outputs