Solving Last-Mile Delivery Challenges is Critical to Increase COVID-19 Vaccine Uptake: A Cluster Randomized Controlled Trial

Ahmed Mushfiq Mobarak (✉ ahmed.mobarak@yale.edu)

  Department of Economics and School of Management, Yale University   https://orcid.org/0000-0002-1916-3438

Niccolò Meriggi

  International Growth Centre   https://orcid.org/0000-0002-6757-1284

Maarten Voors

  Wageningen University & Research   https://orcid.org/0000-0001-5907-3253

Madison Levine

  University of Illinois

Vasudha Ramakrishna

  Yale University

Desmond Maada Kangbai

  EPI Program, Ministry of Health & Sanitation

Michael Rozelle

  Wageningen University and Research

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Niccolò F. Meriggi[1]   Maarten Voors[2]   Madison Levine[3]

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Michael Rozelle[2]   Ella Tyler[2]   Sarah Cundy[6]

Ahmed Mushfiq Mobarak[4*]

[1]International Growth Centre,

[2]Wageningen University & Research

[3]University of Illinois,

[4]Yale University and Y-RISE,

[5]Director of EPI Program, Ministry of Health & Sanitation, Sierra Leone

[6]Concern Worldwide

[*]Corresponding author. E-mail: ahmed.mobarak@yale.edu.

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Abstract

In the first six months of COVID-19 vaccine distribution, over 90% of all doses were given to residents of high and upper middle income nations. Less than 30% of Africans were vaccinated with at least one dose even 18 months after vaccine development. This has led to an explosion of scholarly and policy interest on vaccine hesitancy and ways to overcome it. We argue instead that the limiting factor for many rural Africans is lack of access to convenient vaccine services, and implemented an intervention designed to overcome the logistical challenges of last mile service delivery. The cluster randomized controlled trial in 150 remote rural communities shows that simply bringing vaccines to villages using mobile vaccination teams increases the community vaccination rate by 20 percentage points within just 48-72 hours. Moreover, auxiliary populations visited our community vaccination points to receive shots, which lowers the cost of this intervention to US$ 32 per person vaccinated. This is more cost-effective than most vaccination strategies investigated via trials.

1. Introduction

By March 10th, 2022, over a year after COVID-19 vaccines arrived on the market, 80% of the populations living in high-income countries (HICs) had received at least one dose compared to only 15% of the people in low-income countries (Ritchie et al., 2020). Why was there such massive global inequity? As of August 6, 2022, the vaccination rate in sub-Saharan Africa had risen to just 29% of the population. Why do vaccination rates continue to lag in low-income countries, and how can we address this? Not only does this require an immediate policy response, but understanding this might help us design policies and strategies to better control future pandemics.

Two frequently cited explanations for disparities in vaccine coverage are global supply chain failures and vaccine hesitancy (Reza et al., 2022). As a result, there has been a proliferation of research on hesitancy and ways to counter it. Search terms "vaccine hesitancy AND Covid" in August 2022 produces 24,200 results on Google Scholar, and 2,241 articles indexed on PubMed. This literature has examined levels and correlates of hesitancy (e.g. Lazarus et al., 2021; Loomba et al., 2021); ways to counter it (e.g. Bidani et al., 2022; Loomba et al., 2021); trusted sources of information (e.g. Johnson et al., 2020); and whether messaging interventions (e.g. Dai et al., 2021; Rabb et al., 2022) or financial incentives (e.g. Milkman, Gandhi, Ellis, et al., 2022; Thirumurthy et al., 2022) can help overcome vaccine hesitancy. Much less discussed is the mundane problem of access, which could be the key limiting factor in remote, rural areas where the majority of sub-Saharan Africans live.

We designed an intervention to enhance access to vaccines in rural Sierra Leone, inspired by data we collected in November 2021 which showed that the average Sierra Leonean would need to travel three and a half hours each way to the nearest vaccination center, at a cost that exceeds one week of wages (Mobarak et al., 2022). The centerpiece of our intervention was to simply mobilize vaccines to remote, rural communities in March/April 2022, in partnership with the Expanded Programme on Immunization at the Sierra Leonean Ministry of Health and Sanitation and the international NGO Concern Worldwide. Our cluster randomized controlled trial (RCT) reveals that the number of people vaccinated *per community* increases from 4 people pre-intervention to 36-37 people within the intervention period of 2-3 days – an eight-fold increase – at a cost of US$ 32 per person vaccinated. The vaccination rate in treatment villages rises by about 20 percentage points, and in addition, large numbers from neighboring communities also show up to receive vaccines at our temporary clinics.

These results suggest that many un-vaccinated people living in rural Africa were not actually deeply hesitant, and simply providing access was a cost-effective way to increase vaccination coverage quickly. And yet, a PubMed search on August 4 2022 on "vaccine access AND covid" produces only 158 results and "vaccine supply AND covid" returned only 165 results, a small fraction of the several thousand research papers written on COVID-19 vaccine hesitancy. And even within that smaller set, only a handful of studies discuss the

challenges of "internal distribution," almost all in high-income contexts.

All of this implies that we may need to re-balance our analytical approach to increase vaccinations in large scale, but unfortunately this imbalance favoring demand-focused approaches appears set to continue. For example, a large institutional funder allocated over US$ 20 million in research funding in July 2022 to *"interventions in the United States, Africa...to increase uptake of COVID-19 vaccines and other recommended public health measures by countering mis- and disinformation.*" ("The Mercury Project", 2022) Why this massive research and policy attention on demand-side issues like hesitancy, almost to the exclusion of supply and internal distribution challenges? One possibility is that once supply chain issues are addressed in high income countries, disinformation and hesitancy issues loom large in the effort to vaccinate the last 20-25% of the population stubbornly holding out. In contrast, in remote parts of Africa where vaccination rates remain in single digits, vaccinating the first 50% of the population requires solving a fundamentally different problem of access. Vaccine hesitancy is also generally more pronounced in the United States than it is in Africa (Solıs Arce et al., 2021).

This imbalance is emblematic of a wider debate on the relative importance of individual-specific behavioral factors versus systemic deficiencies, in limiting the diffusion of welfare-improving technologies among poor populations (Mobarak and Saldanha, 2022). Prominent behavioral scientists have recently acknowledged our excessive focus on individual behavioral peculiafrities ("i-frame") at the expense of systemic solutions ("s-frame") (Chater and Loewenstein, 2022). In our setting, overcoming the systemic logistical challenges of vaccine delivery proves to be the obvious "low-hanging fruit" for increasing vaccination coverage in remote areas, and no clever behavioral nudge was required. This is consistent with the prior literature on childhood immunizations, where conducting reliable immunization camps in remote Indian villages increased vaccination rates by 12 percentage points or over 200% (Banerjee et al., 2010). In contrast, countering misinformation through nudges and messaging often produce small effects (Dai et al., 2021; Patel et al., 2022; Rabb et al., 2022). But this is not an "either-or" in that community mobilization and messaging are necessary complements to our approach of bringing vaccines to remote villages. We also need to design the messaging component of our strategy well to ensure that effects don't dissipate in the field (DellaVigna & Linos, 2022; Maier et al., 2022; Szaszi et al., 2022).

We conducted our RCT in communities that were outside the reach of Sierra Leone's network of *Peripheral Health Units* (PHUs). These are the most remote rural areas where 59% of the Sierra Leone population resides. So our results serve as a proof-of-concept that it is possible to cost-effectively vaccinate residents of the most remote places. This is an important lesson for policymakers in donor countries and for international pharmaceutical executives, who have cited cases of unused vaccines reaching the expiration dates in Africa (IFPMA, 2021) in response to public health experts' complaints that poor countries were

not receiving adequate supplies of vaccine doses (Ramachandran et al., 2021; Ye et al., 2022).

The lesson is important to highlight because global supply chain frictions can themselves compound the last-mile delivery problem. Our implementation efforts taught us that overcoming logistical challenges requires the Sierra Leone Ministry of Health (MoHS) to engage in "learning by doing", and to experiment with new, innovative distribution systems. Experimentation and innovations are only possible if there is a steady supply of vaccine doses available. Our demonstration of a cost-effective and scalable method of quickly increasing vaccination coverage should hopefully spur renewed energy and attention to the tasks of ensuring a reliable supply of vaccine doses in low-income nations in Africa. Those recipient nations will also have an important role to play: our approach developed in partnership with Sierra Leone's MoHS indicates that it is possible for resource-constrained health ministries to set up partnerships that creatively address logistical challenges and devise context-relevant solutions that improve vaccine access.

2.   Context and Research Design

We conducted a pre-registered cluster randomized controlled trial in 150 rural villages in Sierra Leone. We first mapped all PHUs where the Ministry of Health and Sanitation (MoHS) was offering COVID-19 vaccines, plus the "catchment areas" of a PHU defined (by MoHS) as the 5-mile radius around each PHU. We then compiled a list of all communities situated *outside* these catchment areas, and randomly selected 150 communities from this list. 100 communities were randomly assigned to receive the intervention and the other 50 were assigned to the control group. During March and April 2022, a research team first visited all communities to conduct a village population listing and a baseline survey. Immediately afterwards, mobile vaccination teams coordinated by MoHS visited the 100 treated villages for two to three days per village (see Consort Diagram in Supplementary Figure A.1).

On the first day of intervention, a "social mobilization team" – trained and supervised by MoHS – organized a conversation with all village leaders, including the Town Chief, Mammy Queen, Town Elders, the Youth Leaders and Religious Leaders, and any other important stakeholders including the Paramount and Section Chiefs if they were available (Step 1 in Figure 1). The team explained the purpose of the visit, answered questions about the available vaccines, and asked leaders for their cooperation in encouraging eligible community members to take the COVID-19 vaccine.

Social mobilizers then asked leaders to convene a community meeting that same evening (when people return home from farms) to allow mobilizers to talk directly with all village residents about vaccine efficacy and safety, the importance of getting vaccinated, and to

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address villagers' questions and concerns. This "Step 2" ended with social mobilizers explaining the location and timing of the mobile vaccination site that they were about to set up.

Vaccine doses, nurses to administer vaccines, and MoHS staff to register the vaccinated were brought into the community either the same evening or early the next morning (Step 3). The vaccine doses and staff often traveled in on motorbikes or on boats, given the difficult terrain they had to traverse to reach these remote communities. Once the team was in place, the temporary vaccination site started operating in a central location in the village (Step 4 in figure 1). The vaccination site remained operational from sunrise to sunset over the next two days. Nurses and registration staff remained stationed at the temporary clinic, while the mobilizers continued to provide vaccine information to various community members (Step 5).

We randomized the nature of these additional Step 5 mobilization activities. Half the treatment villages were randomized into an individualized "Door to Door" campaign (Step 5A), where social mobilizers went to 20 randomly selected structures to privately discuss any concerns about that vaccine that the household residents had, and to encourage them to visit the vaccination site. The other 50 treatment communities were randomized into "Small Group" outreach (Step 5B), where mobilizers targeted social groups who gathered at fixed spots in and around the villages (e.g., groups of farmers in fields, mosque attendees, women collecting water). Social mobilizers engaged the group to have joint conversations about the vaccines. There was equipoise about whether individualized or small-group outreach would be more successful in persuading people to get vaccinated, so we tested both strategies.

Figure 1: Vaccination Team Visits Procedure

Step 1:
Meet with the Community Leaders

Step 2:
Organise community meeting

Step 3:
Bring vaccines and nurses to these
remote communities

Step 4:
Set up a temporary clinic for the
next two days

Step 5A: Treatment 1:
Door-to-Door Mobilisation

Step 5B: Treatment 2:
Small Group Mobilisation

3. Results

Our intervention offered vaccines to all adults, so our primary outcome is "verified" vaccine uptake amongst adults. This is measured using a respondent-level question on whether the person took a COVID-19 vaccine of any type, checked against their vaccination card (if consented). This provides us with a site level count of vaccine doses administered.

To estimate a village level vaccination *rate*, we had to first enumerate the adult population in all 150 treatment and control villages. Such community census lists typically do not exist in Sierra Leone. Our research team therefore walked to all structures in every village to tally the number of households (53 on average, SD = 27, see Supplementary Table A1), and the number of individuals living in those households (10133 individuals across the 100 towns, or about 101 people per village). Respondent characteristics are well balanced across the treatment arms (see Supplementary Table A1).[1]

Many of the people who attended our temporary clinics to receive a vaccine were not enumerated during the community census. These additional people fall into one of three categories: residents of other nearby villages (who heard about the clinic and were interested to take advantage of the easy access to a vaccine); recent migrant returnees who were not present during the village listing; and any village resident missed during the census. For these auxiliary populations, we do not have a denominator and can thus not estimate a vaccination *rate*. We therefore begin by providing a clean Intent-To-Treat (ITT) estimate of the total count of people vaccinated relative to the control group (see Figure 2). We report effects from pre-registered linear regression specifications standard in the program evaluation literature in economics. Section 5 provides methodological details.

Figure 2 shows that there were on average about five people aged 12 and older vaccinated in each control or treatment village at baseline. After our intervention is implemented over the next 2-3 days, the number of vaccinated individuals jumps to about 43-44 people per treatment site, an 8 to 9 fold increase. This is the full impact of our mobile vaccination drive, including both people listed at baseline as well as others who attended the clinics. When we divide the additional unlisted people who received a vaccine, 68% (17 people) were short-term, circular commuters or migrant returnees who were not present on the day of the census and could not be matched to our listing records, and the remaining 32% (8 people) were visitors who came in from nearby villages to get vaccinated.[2] The corresponding regression estimates with standard errors are shown in Supplementary Table A2. There are no statistical differences apparent between the "Door to Door" sub-treatment where 43 people received shots on average versus the "small group mobilization" sub-treatment where 44 people did.

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[1]The population of these villages was on average 22.5 years old, 24% of households were female-headed with a household size of 6 people, of which 2.6 were adults (>18). Just 19% had any form of formal schooling and about 90% was primarily engaged in farming.

[2]In total the teams vaccinated 4771 people aged 12 or above.

Figure 2: **Count of People Vaccinated per Site After Mobile Vaccination Program**
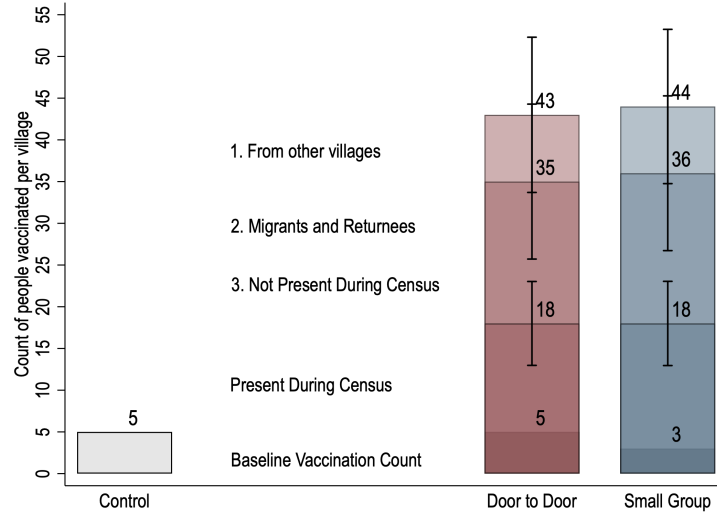
Notes: The figure shows the number of the people (12 years and older) vaccinated by the end of the study. In the control group 5 people were vaccinated on average. For the Door to Door treatment, the average treatment effect is 13 people for the people in the census group, and 30 people when we add people not part of the census within the village (i.e. migrants, returnees) and 37 when we add people from nearby villages. For for the Small Group treatment the average treatment effect is 15, 31 and 39 respectively for each of the sub-groups. Error bars represent 95% confidence intervals of treatment estimates. Refer to Supplementary Table A2, Columns 2, 4 and 6 for the regression estimates underlying the figure.

To study treatment effects on the *vaccination rate*, we now focus on the first of these three groups – *people who were present during the census* – because we know the denominator (i.e. population size) for only this sub-group in both treatment and control villages. Figure 3 (and the associated regression in Supplementary Table A3) show that vaccination rates increase by 19 percentage points (standard error = 0.020, P < 0.01) in treatment villages overall, relative to control. Both Door to Door (ITT = 21 percentage points, standard error = 0.024, P < 0.01) and Small Group outreach (ITT = 19 percentage points, standard error = 0.022, P < 0.01) produce similar effects. Supplementary Table A3 displays p-values of t-tests of differences between these two sub-treatments, and they are not significantly different from each other. Results remain similar when controls for respondent characteristics are added (e.g. previous COVID-19 vaccine, gender, age, education), or if we aggregate the data up to the village level.

Figure 3: **Intent-To-Treat Estimates of Vaccination *Rate* Amongst Adults Enumerated During Census**
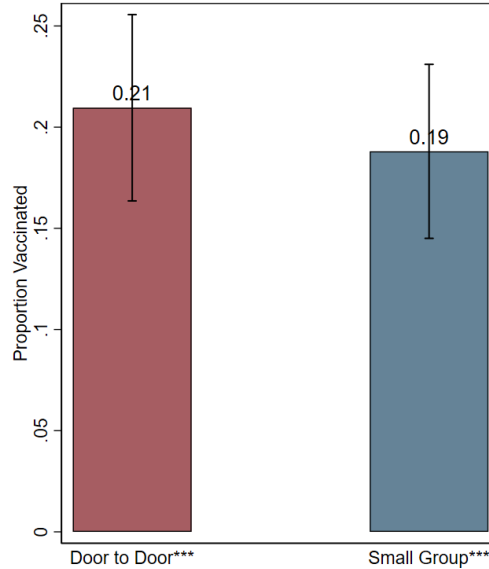
Notes: The figure shows the Intent-To-Treat estimates, the proportion of adults enumerated during the census and vaccinated by the end of the study. The analysis includes the 10133 people (18+) in 150 villages. In the control group 6.5% of the people included in the census were vaccinated. The Intent-To-Treat treatment effect is 19 percentage points for the Door to Door treatment arm and 21 percentage points and for the Small Group treatment arm. Error bars represent 95% confidence intervals of treatment estimates. Refer to Supplementary Table A3, Column 3 for the regression estimates underlying the figure.

The 19-21 percentage point increase is an underestimate of the total number of vaccines administered over those 2-3 days because this analysis only focuses on the subset of adults who were listed in the census, and ignores vaccines given to migrant returnees and others from nearby villages. The average uptake also masks considerable heterogeneity between villages. In four out of the 100 treatment villages there was zero increase in vaccinations because the mobile team did not receive permission from village authorities, and the intervention essentially failed in Step 1 depicted in Figure 1. On the other hand, the full distribution of vaccination rates displayed in Supplementary Figure A.2 shows that in eight villages, over 50% of the community was vaccinated. A similar large degree of variation is evident from the total count of shots set per village, see Figure A.3.

3.1 Effects of Knocking on Doors

In the "Door-to-Door" mobilization sub-treatment, the specific doors that we knocked on were randomly selected. In most cases, this was not literally a door-knock, but a visit to 20 randomly selected structures in each of those 50 communities, and having a private or

semi-private conversation with residents of that structure about the vaccine and encouraging them to visit the temporary clinic. The random selection of structures allows us to report experimental results on the effects of receiving this extra nudge on the propensity to receive a vaccine. We interpret this activity as a "demand-side treatment", in that the visit and conversation gives that resident an opportunity to discuss their concerns or questions about vaccines in private, which could be useful to overcome potential hesitancy.

Table 1 shows that this extra effort did not generate additional demand, beyond the effect of our "supply side" activities to enhance vaccine access. The increase in vaccination rate among those who received the extra door-knock by mobilizers was 19 percentage points, but for those residing in the same communities who did not receive the extra nudge experienced a statistically indistinguishable increase of 20 percentage points.

Table 1: **Intent-To-Treat Effect of Individual Door Knock Among Adults Enumerated During Census**

	(1) Vaccinated
Assigned to the Knock	-0.014
	(0.019)
Observations	3094
Mean in Control	0.20
No. of Structures	1060
R squared	0.17

Notes: The table presents Intent-To-Treat estimates of the individual Door to Door campaign where 20 structured were randomly assigned to be visited by the social mobilisation team. Dependent variable is the vaccination status at the end of the study of adults enumerated during the census. The regression includes baseline vaccination rates and randomization block (village) fixed effects, with standard errors clustered at the structure (hut, house) level. The sample is restricted to the villages assigned to the Door to Door treatment arm, n = 50 villages, and non-peripheral structures within these villages. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

We do not have an equivalent analysis of the individual effect of the Small Group treatment since that was not randomized within villages, and the enumerators were not able to exactly match which households participated in the Small Group sessions.

3.2 Mechanisms

While our vaccine access intervention significantly raises the vaccination rate, it is also clear that after those 48-72 hours of activities, we remain far short of reaching the WHO goal of near universal uptake. We collected individual-level data in all treatment villages after the intervention from both vaccine takers and non-takers. These data can shed some light on why and how our access intervention was more or less successful for certain people.

Meeting Attendance: "Step 2" of our intervention (see Figure 1) was to organize a community-wide meeting to inform all village residents about the vaccine clinic. The field team registered which community members attended that meeting, and overall, 48% of households participated in these meetings. The data show a very strong correlation, in which 86% of those who chose to attend the meeting subsequently chose to get vaccinated. One cannot impose any causal interpretation to this correlation: people who were already interested in getting vaccinated may have been the ones who chose to attend the meeting.

We can make a slightly stronger inference by examining the subset of people who stated in our baseline survey that they were *unwilling* to get a vaccine (see Supplementary Table A7). Within this sub-group, 46% of those who chose to attend meetings ultimately took the vaccine, while the vaccination rate was only 9.5% amongst those who chose not to attend. Even within the converse sub-group (those who stated at baseline that they were willing to take the vaccine), meeting attendance was strongly predictive of subsequent vaccine uptake: 52% vaccination rate among attendees and 16% among non-attendees.

These are not causal, but the strength of these correlation suggests that the information shared in the meeting, and the answers we provided to the community's questions, are unlikely to have dissuaded people from getting vaccinated. These correlations – combined with our implementation experience – suggests that holding these meetings was helpful and is a necessary part of any access intervention. Encouraging greater attendance in meetings in any future replications would probably be a good idea.

Vaccination Knowledge: We collected data on another intermediate outcome in a subset of 45 villages: people's knowledge and attitudes regarding the COVID-19 vaccine. Figure 4 shows that the treatment improved people's knowledge about and trust in vaccines: an increase of 13 percentage points in people who know about the vaccine, and an increase of 0.13 points ($p<0.1$) in the 5-point Likert scale about trust in vaccines. The change in trust implies that our intervention was not solely about improving access: the community interactions and the information we shared were also relevant parts of the intervention package. People's beliefs about vaccine efficacy does not change due to treatment (the magnitude is 0.10 points with $p=0.18$). Table A4 provides the associated regression estimates. The treatments do not change what source people trust the most for receiving health information.
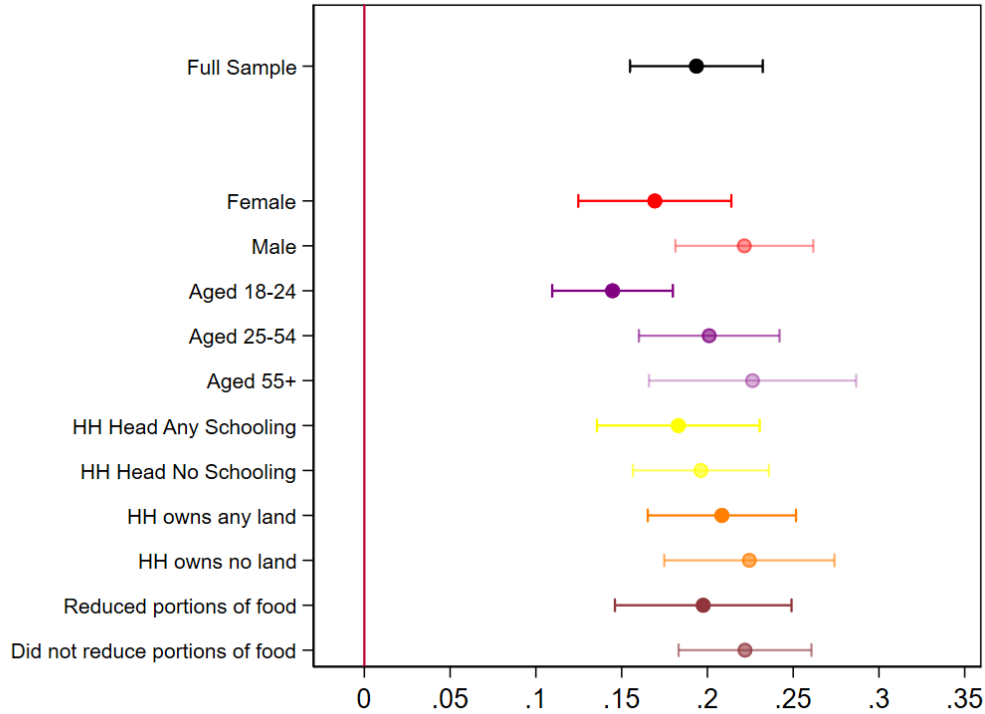
Figure 4: Effect of Pooled Treatment on Knowledge and Attitudes Among Adults Enumerated During Census
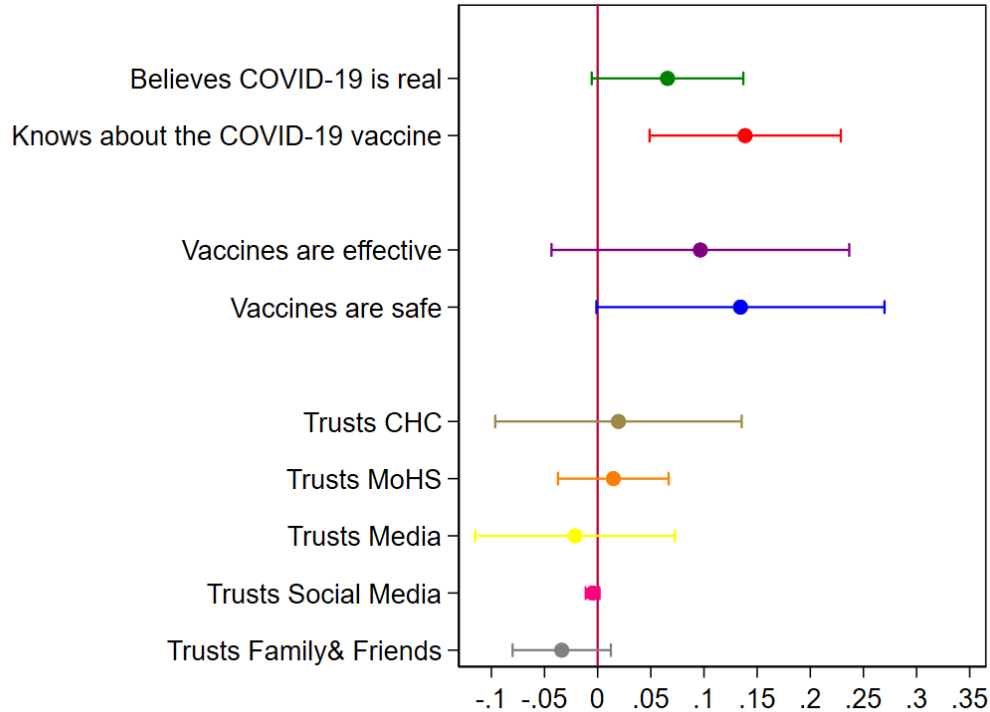
Notes: The Figure shows Intent-To-Treat estimates of vaccination rate of the pooled treatment arms for each subgroup listed on the Y-axis. Error bars represent 95% confidence intervals of treatment estimates. The sample is restricted to 45 villages and 878 households surveyed at endline. Data is missing for other villages. Associated regression results are included in Table A4 and Table A5. The survey measures for the "Beliefs COVID-19 is real" comes from a survey question: "Do you believe that COVID-19 exists in the world?" [Yes/No]. "Knows about COVID-19 Vaccination" comes from a survey question:" Do you know about the COVID-19 vaccine/marklate?" [Yes/No], "Vaccines are Effective" comes from a survey question: How much do you agree with this statement: Vaccines are effective." [Completely disagree (1) - Completely Agree (5)], "Vaccines are safe" comes from a survey question "How much do you agree with this statement: Vaccines are safe." [Completely disagree (1) - Completely Agree (5)], trust in sources of information fro from a multiple select question "Who do you most trust getting information about COVID-19?" [CHC, MoHS, Media (News, TV), Social Media (Facebook etc), Family/Friends, etc]

Heterogeneity Across Demographic Groups: Figure 5 summarizes the results of our investigation on heterogeneity in treatment effects across population sub-groups. Table A6 provides the associated regression results. We find that the vaccines access treatment was 5 points more effective for men than for women (p<.05). The treatment increased the adult male vaccination rate by 22 percentage points, but only 17 percentage points for adult women. The treatment was also more effective among the elderly. The treatment effect was 3-5 percentage points smaller for people aged 18-54 than those aged 55 and above. There is no difference in treatment effects across education and income status.

Figure 5: **Effect of Pooled Treatment by Respondent Characteristics Among those Enumerated During Census**

Notes: The Figure shows Intent-To-Treat estimates of vaccination rate of the pooled treatment arms for each subgroup listed on the Y-axis. Error bars represent 95% confidence intervals of treatment estimates. The dependent variable is constructed using the vaccination status of adults at the end of the study enumerated during the census. Gender, age and schooling data come from the census. Land ownership and food insecurity come from the baseline sample. Associated treatment estimates and exact sample size for each subgroup are included in Supplementary Table A6. The indicator for "HH Head Any Schooling" indicates if the household head had schooling above the primary level; "HH owns any land" indicates of the household owns land; "Reduced portions of food" indicates if any household member had reduced portions in the past week.

4.   Discussion

4.1   Comparing Our Effect Size to Other Vaccination Efforts

Our simple intervention to solve last-mile challenges in vaccine delivery increases vaccination rates by 800% within 48-72 hours. While that percentage increase appears dramatic, this is the gain off a very low base rate: just 6% were vaccinated at baseline. Another relevant benchmark is our *percentage point* effect size relative to other vaccination campaigns evaluated in the literature. Table 2 summarizes percentage point effect sizes of recent studies. Many of the vaccination campaigns evaluated are nudges via text messages, telephones or

mailings. Others visit parents to educate them about the benefits of childhood immunization, or send community health workers. Yet others offer direct financial incentives against a verified vaccination.

The mean effect size of the change in vaccination rate reported across these studies is just under 12 percentage points (SD 9.7), smaller than our intent-to-treat estimate (which itself is a very conservative estimate, given that the majority of people we vaccinated were not present in the village during the village census, and therefore not included in our vaccination rate calculation). Overall, the table indicates that simple nudge strategies like text or phone-based reminders produce small effects (single digit percentage point changes).

Of special interest are the very recent studies that attempted to promote COVID-19 vaccinations in the United States, Sweden and Italy. Campos-Mercade et al. (2021) offered monetary rewards of US$24 to get a COVID-19 vaccine in Sweden, and this increases the vaccination rate by an extra 4 percentage points, from 72% to 76%. A financial incentive of US$10-50 combined with other nudges in the United States did not produce any effect (Chang et al., 2021). City and state-wide lotteries offering financial rewards in the United States (e.g. Lang et al., 2022; Milkman, Gandhi, Ellis, et al., 2022) produced very small or negative effects. Text-based reminders in the U.S. (Dai et al., 2021; Rabb et al., 2022) and defaulting people into a vaccination appointment in Italy (so that they are forced to opt out, see Tentori et al., 2021) increase vaccination rates between 0 and 3.5 percentage points.

Table 2: Comparing Vaccination Rates

Intervention Type	Year	Author	Country	Vaccine	Effect Size in Percentage Points
Education: Community Meetings	2007	Pandey et al.	India	Tetanus	24
	2009	Andersson et al.	Pakistan	Infant	26
				Measles	20
				DPT3	28.5
	2018	Pramanik et al.	India	Full immunization	0
Education: Maternal Education	2010	Usman et al.	Pakistan	DPT3	27
				DPT3	22
				DPT3	28
	2011	Owais et al.	Pakistan	DPT3/Hepatitis B	20.4
	2018	Powell-Jackson et al.	India	DPT3	15
Education: Maternal Education; Text Message Nudge	2018	Yeung et al.	Hong Kong	Influenza	26
Education: Community Leaders	2021	Oyo-Ita et al.	Nigeria	Partial	12.6
				Pentavalent 1	16.5
				Pentavalent 3	5.3
				Measles	16.6
Improve Planning; Community Health Worker Programs	2014	Carnell et al.	Ethiopia	Measles	11.5
				DPT3	14.4
Telephone Nudge	2007	Winston et al.	USA	Pneumococcal (elderly)	9
				Pneumococcal (chronic disease)	10
Mailing Nudge	2011	Milkman et al.	USA	Influenza	4.2
				Influenza	1.5
	2018	Yokum et al.	USA	Influenza	0.9
Text Message Nudge	2014	Stockwell et al.	USA	Influenza	2.7
	2015	O'Leary et al.	USA	All needed vaccinations	3.1
				Any vaccination	5.2
	2015	Bangure et al.	Zimbabwe	OPV1, Penta1 and PCV1	20
	2016	Uddin et al.	Bangladesh	BCG, Penta and MR	21.6
	2017	Regan et al.	Australia	Influenza	3
	2021	Dai et al.	USA	COVID-19 (1st reminder)	3.57
				COVID-19 (2nd reminder)	1.06
	2021	Milkman et al.	USA	Influenza	2.1
	2022	Milkman, Gandhi, Patel, et al.	USA	Influenza	2
	2022	Rabb et al.	USA	COVID-19	0.2

Table 2 (continued)

Intervention Type	Year	Author	Country	Vaccine	Effect Size in Percentage Points
Text Message Nudge; Financial Incentive	2021	Kagucia et al.	Kenya	Measles	10
Financial Incentive	2010	Banerjee et al.	India	Full immunization	12
				Full immunization	33
	2021	Campos-Mercade et al.	Sweden	COVID-19	4.2
	2021	Chang et al.	USA	COVID-19	<1
Lottery	2021	Milkman, Gandhi, Ellis, et al.	USA	COVID-19	3.5
	2022	Lang et al.	USA	COVID-19 (first dose)	-0.38
Opt In	2010	Chapman et al., 2010	USA	Influenza	12
	2021	Tentori et al.	Italy	COVID-19	3.2
Social signaling	2021	Karing	Sierra Leone	Childhood immunizations	14
School Based Vaccination	2015	Yoo et al.	USA	Influenza	12

Notes: This table reports the intervention types, locations, vaccines administered, and effect sizes in percentage points for RCTs testing interventions used to increase the uptake of vaccines. The reported studies were conducted across a variety of countries, use various intervention types, and different types of vaccines are included. These studies were found through searching databases, reviewing prior systematic reviews, and reviewing the references of related studies. Across these studies, the mean effect size of the reported change in vaccination rate is around 12 percentage points (SD 9.7). FIC here refers to "fully immunized child", or a child who has received one dose of BCG vaccine, three doses of DPT vaccine, three doses of oral polio vaccine, and one dose of the measles vaccine.

4.2 Cost-effectiveness Relative to Other Strategies

Sending text message reminders or running city-wide lotteries are relatively cheap to implement, while delivering vaccines in remote areas is costly. Moreover, we chose to work in the most remote areas not covered by the Sierra Leone MoHS vaccination programs, because they are too far away even from Peripheral Health Units. It is useful to compare not just percentage point effect sizes, but also the cost of administering various programs *per vaccinated individual*. We collected detailed cost data on our program to compute this metric, and compare it to other studies that provide such cost information.

The total costs of our intervention to reach 100 villages was US\$ 152,892, or approximately US\$ 1529 per village. This includes all travel, administration and management and supervision costs, but excludes the cost of the vaccine doses, which were provided to Sierra Leone by the COVAX program for free. This translates to a cost per dose administered of about US\$ 32.

Appendix Table A8 provides a detailed breakdown of the fixed and variable components of our implementation costs. Of the US\$ 32, around 27% (US\$ 9) were fixed costs of training

project staff. 73% (US$ 23) were variable costs. The most expensive category (37% or US$ 11.50) is transportation to these remote villages, which includes the cost of renting vehicles and fuel. Salaries and subsistence allowances for the social mobilization and vaccination teams account for another quarter of the total costs.

To conduct this intervention again at larger scale, the variable costs would need to be repeated, but not the fixed costs of training. At scale, the cost of this intervention would thus approach about US$23 per person vaccinated.

Figure 6 provides the "cost per vaccinated person" for the subset of studies in Table 2 that reported detailed enough cost information for us to be able to compute this metric. Most other vaccination campaigns exceed the US$ 32 benchmark. The mean value in Figure 6 is US$ 120 (SD = 82.2), even after top-coding the most expensive approaches.

Of particular interest is the cost-effectiveness of alternative Covid-19 vaccine strategies. The Milkman, Gandhi, Ellis, et al. (2022) Philadelphia lottery was very costly (US$4485 per person vaccinated) because $63,000 worth of lottery prizes produced a very small increase in vaccinations. The other COVID-19 studies do not provide cost information.[3]

In Figure 6, Banerjee et al. (2010) pursues a similar strategy to ours by setting up measles vaccination clinics in rural Rajasthan. That treatment costs US$ 75 (in 2022 dollars) per vaccine administered, but adding an incentive for the parents to bring their children to the clinic lowers the cost to US$ 38 per child vaccinated.

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[3]Campos-Mercade et al. (2021) – which offered US$24 as financial incentives to get vaccinated in Sweden – comes closest to providing the necessary information, but costs on many program elements are missing such as information on the cost of administering the incentive program, such as verifying individual-specific vaccination information in the administrative records, sending two text message reminders, etc.

Figure 6: **Cost Per Person Vaccinated Compared to Other Studies**
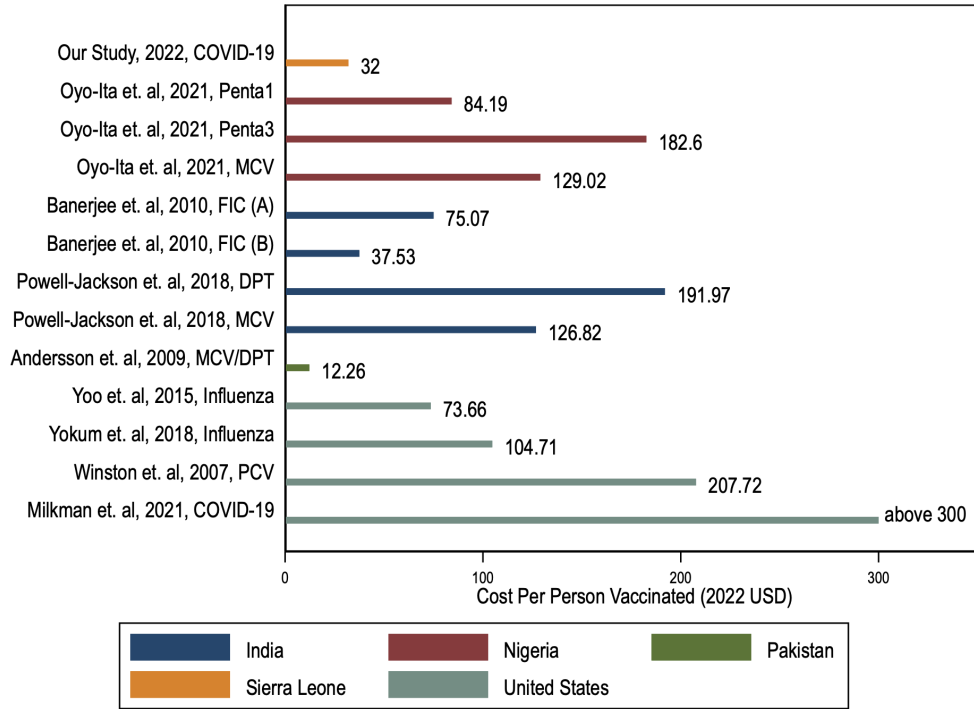
Note: The Figure includes the cost per person vaccinated (in 2022 USD). We use studies from in Table 2 that provide information about the cost per person vaccinated. The color of each bar indicates the country in which that the study was conducted. The cost per person vaccinated in our study is approximately US$ 32. We top-coded the most expensive approaches and the mean value in this figure is US$ 120 (SD = 82.2).

4.3   Policy Implications

Vaccine equity remains an important policy goal (Ye et al., 2022). Vaccination rates are severely lagging among rural Africans, so achieving equity requires us to devise an effective strategy to reach this population. Our study provides clear guidance that an important component of such a strategy is to improve access by addressing last-mile delivery challenges.

The most immediate and direct implication of our results is for the government of Sierra Leone to replicate and expand this cost-effective program to reach the 59% of the country's population who reside in similar remote, rural areas outside of PHU coverage. At US$ 23 per person at scale, reaching that population will require a total budget of US$ 112 million to achieve universal coverage. An investment of US$ 50 million would likely address access constraints for all Sierra Leoneans living in remote communities eager to take the vaccine. This is expensive for a resource-constrained MoHS, and Sierra Leone's international development partners must provide support.

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The other direct implication is to replicate this program in neighboring countries with similar last-mile delivery challenges. The majority of sub-Saharan Africans reside in rural areas, so overcoming access challenges through such initiatives holds enormous potential for both achieving vaccine equity and maximizing global coverage.

It is reasonable to wonder whether COVID-19 vaccine distribution is a high-priority investment, given the low incidence of COVID-19 in Africa. But as the Indian experience from April 2021 shows, new COVID-19 variants have the capability to devastate public health systems in developing countries. Health infrastructure in the typical African nation is even more fragile than it is in India. Moreover, setting up the infrastructure for last-mile delivery can be useful to cost-effectively reach remote populations with other necessary health technologies including childhood immunizations and pre-natal care.

Our study shows that low-income countries need to experiment with creative ideas to overcome stubborn logistical challenges, such as setting up temporary clinics and sending both doses and nurses to remote locations on motorcycles. A broader implication for international development partners and pharmaceutical companies is that they need to facilitate and underwrite such experimentation by making vaccine doses and budgets readily available to allow ministries of health to learn what approaches work best in a given context. Local institutions need to engage in "learning by doing", which is impossible without a reliable supply of vaccines, and per-diems to induce staff to spend time tinkering with novel, innovative ideas.

An even broader implication is that researchers developing strategies to increase the take-up of vaccines and other health technologies should pay greater attention to systemic issues like access failures and logistical challenges with supply, in addition to individual-specific barriers like psychological hesitancy. PubMed searches reveal that research interests and funding have shifted heavily in favor of individual behavioral issues, and some re-balancing towards addressing systemic barriers may generate greater marginal returns for our collective interest in improving human health and welfare.

4.4   Study Limitations

The intervention we implemented had two important limitations. The US$ 32 cost (per person vaccinated) varies substantially across villages because the number of individuals per village that we managed to vaccinate varies. Village leaders did not allow us to conduct the intervention *at all* in 4 of the 100 treatment villages, which inflates the overall average cost of our intervention. Any replication should try to identify early the villages where such refusals might occur, and find ways to avoid having the entire vaccination team travel to such villages.

Second, we observe large cross-team variation in performance. Supplementary Figure A.4 shows that some of our teams administered over twice as many vaccines as other teams on

average. Some of the these differences could be due to differences in village characteristics, but our implementation experience suggests that team effort also played a role. Providing good performance incentives to teams could improve the cost-effectiveness of this effort. Given that a large portion of the cost of the intervention is the cost of traveling to the remote village, we should spend more effort figuring out how to maximize the vaccination rate within the 48-72 hour window once we get there. The additional demand-side nudges we tried, such as knocking on individual doors, did not produce any marginal gains.

5. Methods

5.1 Ethics Approval

We received Institutional Review Board (IRB) approval from the Sierra Leone Ethics and Scientific Review Committee (SLERC 20220210), Yale University (2000031541) and Wageningen University (WUR 20220222). The research protocol was pre-registered at ISRCTN (study SRCTN 17878735, see https://doi.org/10.1186/ISRCTN17878735). All study participants completed informed consent.

The study was implemented in close collaboration between the researchers, the Government of Sierra Leone's Expanded Programme on Immunization (EPI) at the Ministry of Health and Sanitation (MoHS), their National COVID-19 Emergency Response Centre, and Concern Worldwide an international organization who had partnered with MoHS. This collaboration came together because all partners had the joint goal of addressing barriers to vaccine adoption in rural Sierra Leone. While all partners are responsible for the research design, only the Ministry of Health team was responsible for actually distributing and administering vaccines. We had a memorandum of understanding in place to govern this collaboration.

5.2 Village Study sample

We collaborated with the MoHS to select the study sample of 150 villages. As a starting point we used the 2015 Sierra Leone Census which contains data on 20,659 communities in 166 Chiefdoms across 16 Districts. We selected 7 largely rural districts (Koinadugu, Falaba, Karene, Kambia, Tonkolili, Bombali, Port Loko), limiting the sample to 8,784 communities in 54 Chiefdoms. We then restrict the sample to communities that had no health clinic within 5-miles of the community center, the standard PHU catchment area (according to our data the actual distance to the nearest PHU was slightly smaller at about 3.5 miles, see Table A1), resulting in 1,849 communities. From this list we excluded very small communities of below 19 structures and for which latitude and longitude was missing. The final sampling frame

of 420 communities were located in 49 Chiefdoms and 7 Districts. Within each District, we then use matching to assign villages to triplets of similar villages, using data on community level measures that are good predictors of vaccine uptake including childhood immunization, age, literacy. This resulted in 106 triplets in total. We then randomly selected 50 triplets using district as a blocking variable. The final list included: 9 triplets each for Koinadugu and Falaba District, 8 triplets for Karene District and 6 triplets each for Port Loko, Tonkolili, Kambia and Bombali District.

5.3 Randomization

Randomization to Vaccine Access Treatments: Within each of the 50 triplets, we randomized villages into control, Door to Door and Small Group treatment arms. This results in 50 villages assigned to control, 50 to Door to Door, and 50 to Small Group, see Figure A.1. The sample is well balanced on observable characteristics, the F statistic at the bottom of A1 is small and not significant.

Household-level Random Assignment to Door to Door Treatment: Within the villages randomly assigned to the "Door to Door treatment" arm, we randomly selected 20 residential structures from the community census list to receive a visit from the social mobilisation team.

5.4 Data Collection

Community Census Listing and Baseline: Before any intervention activities took place, in all 150 villages, the research team implemented a community census with all households. The research team went door to door to each residential structure and asked how many households resided in the structure. They then interviewed each household head to create a roster of those who "eat from the same pot; and reside under the same roof for at least the past 9 months (aside from newborn babies)." For each household member enumerators asked about the gender, ages and vaccination status. The total census includes N=29,608 people. Migrant household members who were temporarily away on the day of the visit would have been missed from this listing.

Next, the research team randomly selected a sample of 20 households per village from the households listed in the census to conduct a short (baseline) survey with the household head, to record household characteristics (age, gender and education), access to land and food security. If the village happened to have less than 20 structures, there were fewer respondents sampled giving the total baseline sample to include N=2,240 respondents.

Exit and Endline Surveys: After the interventions were implemented, the research team conducted an exit survey of those who took a vaccine at each mobile vaccination clinic. The

survey recorded the vaccination status verified using the vaccination card, as well as age and gender.

In a sub-sample, the research team conducted a follow-up survey with the same households that we interviewed at baseline. Due to a coding error, the survey was implemented a subset of 104 villages (N = 1688), of these 45 are within complete triplets and are used in the analysis, N = 878. The survey included questions on vaccine knowledge and attitudes. The endline survey was conducted one day after intervention activities were completed. We limited this survey to the treatment villages to avoid further burdening control group households. Since only 4 days had elapsed after the baseline survey, we did not expect vaccination rates to have meaningfully changed in the control villages. We verified that there was no large vaccination drives being conducted by MoHS or any other non-governmental entities in these remote areas within that 5-day period of interventions and data collection that could have meaningfully change the rate of vaccination in control villages.

Research assistants were blinded with respect to treatment arm and study hypothesis.

5.5   Intervention Details

Timeline of Activities: The research team collaborated closely with the Ministry of Health vaccination team. Within each village the teams followed several steps, see also a consort diagram in Figure A.1.

- Day 1, 2 – Research team implemented census listing and baseline surveys described above.

- Day 3–5 – Mobilizing team engaged in Small Group and Door to Door mobilisation; Vaccination Drive by MoHS; Exit Survey by Research team in treatment villages

- Day 6 – Research Team implemented endline for sub-sample of households in 45 villages

Social mobilisation: MoHS trained community mobilizers on COVID-19 vaccine safety and efficacy, vaccine availability and types. All mobilizers were trained on how to respond to questions and misinformation about COVID-19. They were also trained on WHO-recommended safe practices relating to COVID-19, and were instructed to maintain social distance and wear masks when social distance could not be guaranteed. Additional masks were available for free for community members.

Community social mobilizers arrived at the village before the mobile vaccination teams. The community mobilizer engaged with local community leaders including the Town Chief/Section Chief/Paramount Chief, Mammy Queen, Town Elders, Youth leaders, CHOs, Imams, and

any other relevant authorities to seek permission to organise a village information session. The information session took place at a central location, often the community centre or any other convenient location amenable to safe COVID-19 practices.

At the information session, the mobilizer informed community members about COVID-19, available vaccines and evidence about the safety and efficacy of vaccines in preventing transmission and severe illness. People were also informed about the mobile vaccination team and operating procedures during the vaccination drive. They encouraged participants to spread this message to other members of the community not present during the meeting.

In four treatment villages the MoHS vaccination team did not receive permission from village authorities to conduct the vaccination drive.

Door to Door Campaign: In 50 of the 100 villages randomly selected for treatment, community mobilizers approached 20 structures randomly selected by the research team from the census list, after the group information session was completed. Due to logistical complexities and costs, in some communities mobilizers did not include very remote village structures (more than 15 minutes walk from the village center. This excluded a total of 12 structures (including 39 people aged 12 and above). Social mobilizers met in private with residents and delivered the same information as was presented at the community meeting. In addition, they addressed people's concerns in private. If the individuals were convinced to get vaccinated immediately afterwards, the social mobilizer would guide them to the vaccination site before moving on to the next household.

Small Group Mobilization: In the other 50 treatment villages, after the group information session, social mobilizers searched for small groups of people around the village to converse with. Such groups included women washing clothes around in the river, individuals gathered at the ataya (tea) shops, residents playing a game of drafts, groups of people around the mosque or church, or residents nearby the Town Chief's house. Social mobilizers repeated the same information presented during the community information session. If people inside the small group had already taken the vaccine before this second session, they were invited to talk about their experience. After the session, if residents wanted to take the vaccine, the social mobilizer would guide them to the vaccination site before moving on.

Mobile Vaccination Drive: Vaccines were transported in approved cool boxes or vaccine carriers appropriate for transportation to remote locations. In each treatment village, the MoHS Mobile Vaccination teams worked with community leaders to select a suitable venue for the vaccination drive. The venue had to be able to accommodate a waiting area (with some shelter); an arrival and check-in area – where patient information can be gathered maintaining confidentiality; space for clinical assessment and vaccine administration, including vaccine preparation, maintaining patient confidentiality, privacy and social distancing;

area and system for post-administration observation of patients. Vaccination exclusion criteria included being below 12 years old. MoHS teams determined on site if populations deemed at risk (pregnant or suffering from severe disease) would be excluded also. After the vaccine is administered, recipients remained in close proximity to the vaccination team for a minimum of 15 minutes, so that health professionals would be present in the event of any unexpected side-effect.

Vaccine teams were compliant with MoHS requirements for the storage, preparation, administration and disposal of the vaccine and associated consumables; they followed Infection Prevention and Controls (IPC); and checked the eligibility of people to be vaccinated using the patient checklist.

Mobile teams adhered to MoHS guidelines on informed consent to receive COVID-19 vaccination, ensuring it was taken freely, voluntarily, and without coercion by people with the mental capacity to consent to the administration of the vaccines. Participants were allowed to withdraw consent at any time.

All vaccine teams received training on vaccinations including the management of Adverse events following immunization (AEFI)s. All AEFIs had to be reported using national reporting systems to the MoHS.

5.6   Statistical Analysis

For Figure 2 and Supplementary Table A2, we estimate a *village-level* intent-to-treat effect using the following specification:

$$Y_j = \alpha_k + \beta_{1,j}T_{DoortoDoor} + \beta_{2,j}T_{SmallGroup} + \epsilon_j \tag{1}$$

where Y_j is the number of people vaccinated in village j, $T_{DoortoDoor}$ and $T_{SmallGroup}$ are the village assignment to the Door to Door and Small Group treatment arms. α_k is a vector of randomization block fixed effects (i.e. the triplet described above). We also estimate equation (1) pooling across the treatment arms where T_{pooled} is the village assignment to either Door-to-Door or Small-Group treatment arm.

For Figure 3 and Supplementary Table A3, we estimate intent-to-treat effects using the following specification on individual-level data:

$$Y_{i,j} = \alpha_k + \beta_{1,j}T_{DoortoDoor} + \beta_{2,j}T_{SmallGroup} + \epsilon_{i,j} \tag{2}$$

here $Y_{i,j}$ is the vaccination status of individual i, in village j, $T_{DoortoDoor}$ and $T_{SmallGroup}$ are the village assignment to the Door to Door and Small Group treatment arms. α_k is a vector of randomization block fixed effects (ie triplet) and $\epsilon_{i,j}$ is the standard error clustered at the village level. To increase precision, in some specifications we also add $Y_{i,j,bl}$ the

baseline vaccination status, and $X_{i,j}$ a vector of individual controls including age, gender and education. We also estimate (2) at the village level, as well as pooling across the treatment arms where T_{pooled} is the village assignment to either Door-to-Door or Small-Group treatment arm.

To assess the individual level effect of the Door to Door campaign, we restrict our sample to the 50 villages assigned to the Door to Door campaign (ie $T_{DoortoDoor}$ =1), and we estimate:

$$Y_{i,s} = \alpha_j + \delta_i T_{DoortoDoor} + \mu_{i,s} \tag{3}$$

where $Y_{i,s}$ is the vaccination status of individual i in structure (hut or house) s, $T_{DoortoDoor}$ the individual level assignment to receive a visit by the social mobilisation team to a structure, $\mu_{i,s}$ is the standard error clustered at the structure level.

For the survey based outcomes on COVID-19 vaccine knowledge, attitudes and trust, we estimate equation (2), replacing the dependent variable with the survey responses described above, using the sub-sample of 45 villages where this data was collected.

5.7 Deviations from Pre-registered Hypotheses

We pre-registered our research protocol and hypotheses at ISRCTN (study SRCTN 17878735, see https://doi.org/10.1186/ISRCTN17878735).

We report on our main hypothesis in Figure 3 and Table A3. In addition to reporting on our main pre-registered outcome (adult vaccination rate) we also report on the total shots given per vaccination site, because many more people showed up to our temporary clinics from neighboring villages or were not present during the pre-intervention census, and we had not anticipated this. Figure 2 and Table A2 therefore report on the count of all individuals (aged 12 and above) who visited our clinics to take a shot. This metric is necessary to compute cost-effectiveness correctly.

Since we do not find meaningful differences in vaccine uptake between the Door to Door and Small Group treatment arms, we do not investigate further the specifics underlying any such differences, as we had pre-registered as Hypothesis 2.

5.8 Data Availability

All of the data generated and analyzed in this study can be made available to the editors and referees upon request during the review process. All replication files (de-identified data and code) will be deposited in Harvard Dataverse upon publication.

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A.   Supplementary Material

A.1   Consort Diagram
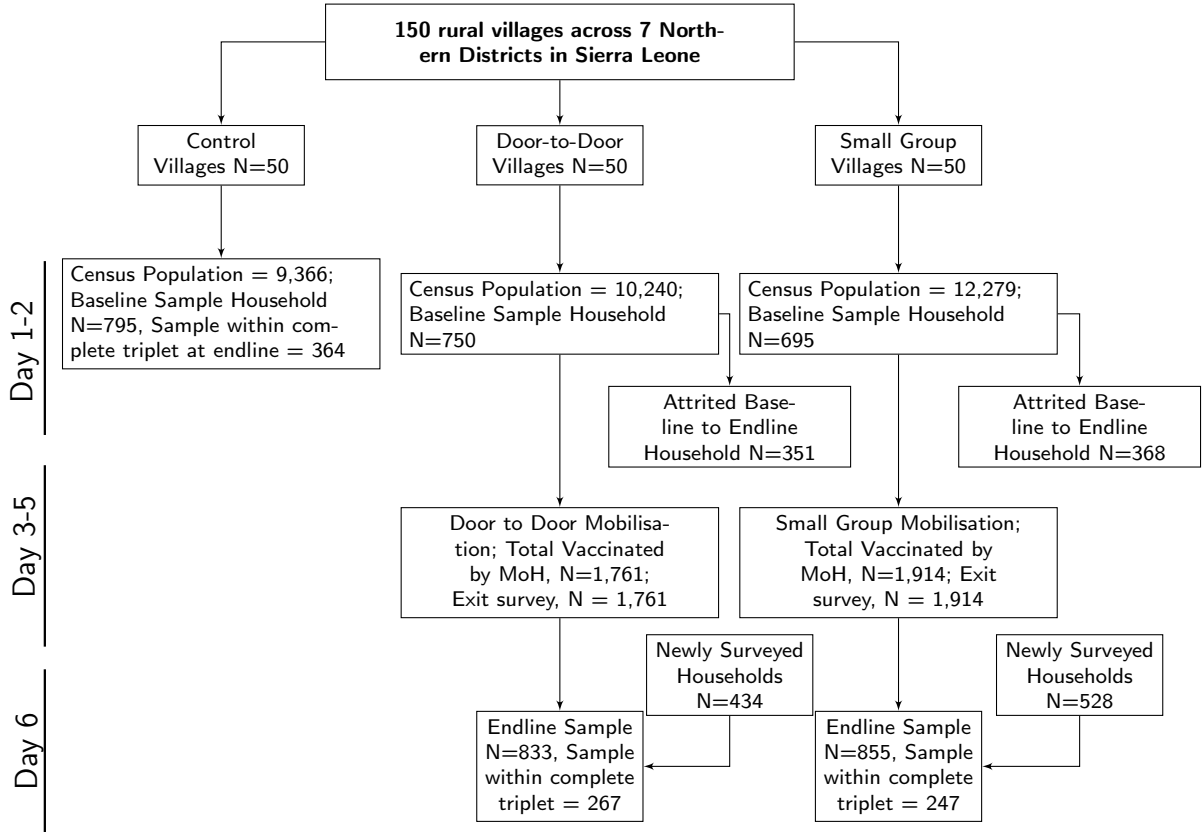
Figure A.1: Consort Diagram

Table A1: Baseline Descriptive Statistics and Statistical Balance

	Control Mean (SD) (1)	Control-Door to Door Diff (SE) (2)	Control-Small Group Diff (SE) (3)	Door to Door- Small Group Diff (SE) (4)	N (5)
Stratification Variables					
Proportion of infants in the community fully immunized	0.502 (0.300)	0.015 (0.03)	−0.016 (0.03)	0.031 (0.03)	150
Proportion of community that is Literate	0.284 (0.206)	−0.028 (0.02)	−0.016 (0.03)	−0.013 (0.03)	150
Average age	21.483 (2.366)	−0.118 (0.32)	0.053 (0.31)	−0.171 (0.34)	150
Proportion of community that lives beyond five miles of a Clinic	0.960 (0.196)	0.022 (0.02)	−0.000 (0.01)	0.022 (0.02)	150
Community Characteristics from Cencus 2015					
Current Population estimated from 2015 census	242.998 (131.400)	0.888 (21.83)	16.733 (25.19)	−15.844 (24.06)	150
Proportion of community that is Christian	0.119 (0.249)	−0.005 (0.04)	0.027 (0.04)	−0.032 (0.04)	150
Proportion of community that is Muslim	0.867 (0.261)	0.010 (0.04)	−0.014 (0.05)	0.024 (0.04)	150
Proportion of community born in the same chiefdom	0.931 (0.115)	−0.020 (0.02)	0.008 (0.02)	−0.028 (0.02)	150
Proportion of community employed in agriculture	0.937 (0.078)	−0.076** (0.03)	−0.052* (0.03)	−0.024 (0.03)	150
Proportion of community with access to internet	0.027 (0.073)	−0.010 (0.01)	−0.016 (0.01)	0.007 (0.01)	150
Proportion of community living in formal strcutures	0.795 (0.354)	0.046 (0.06)	0.003 (0.06)	0.043 (0.06)	150
Proportion of community who own land	0.989 (0.023)	−0.022 (0.02)	−0.023 (0.02)	0.001 (0.02)	150
Proportion of community that lives within five miles of a Primary School	0.616 (0.478)	−0.117 (0.08)	−0.019 (0.08)	−0.098 (0.08)	150
Proportion of community that lives within five miles of a Water Source	0.942 (0.211)	−0.041 (0.05)	−0.047 (0.05)	0.006 (0.05)	150
Proportion of community that owns a radio	0.508 (0.293)	−0.105* (0.05)	−0.080 (0.05)	−0.024 (0.05)	150
Proportion of community that owns a Cellphone	0.315 (0.249)	−0.026 (0.05)	−0.020 (0.05)	−0.005 (0.05)	150
Proportion of community with a formal roof	0.546 (0.365)	0.055 (0.05)	0.060 (0.06)	−0.005 (0.06)	150
Average number of assets	1.704 (0.699)	−0.112 (0.16)	−0.063 (0.15)	−0.049 (0.15)	150
Distance to nearest clinic in miles	3.761 (2.209)	−0.231 (0.32)	−0.058 (0.30)	−0.172 (0.32)	150
Community Characteristics from Cencus					
Household Size	5.917 (1.107)	−0.057 (0.21)	0.149 (0.21)	−0.206 (0.20)	150
Has recieved atleast one dose of covid vaccine	0.065 (0.099)	0.076*** (0.03)	0.037 (0.02)	0.039 (0.03)	150
Fully Vaccinated at baseline	0.035 (0.064)	0.041** (0.02)	0.014 (0.02)	0.027 (0.02)	150
HH head has had any formal schooling	0.185 (0.106)	−0.016 (0.02)	0.020 (0.02)	−0.036* (0.02)	150
HH head has secondary schooling or higher	0.094 (0.080)	0.016 (0.02)	0.048*** (0.02)	−0.032* (0.02)	150
HH head is a farmer	0.883 (0.147)	−0.018 (0.03)	−0.047 (0.03)	0.029 (0.03)	150
HH head is Muslim	0.892 (0.241)	0.010 (0.04)	−0.035 (0.05)	0.045 (0.04)	150
Age	22.517 (2.899)	1.637*** (0.53)	1.387*** (0.46)	0.250 (0.51)	150
Average age for those above 18	39.392 (4.405)	−0.642 (0.62)	−0.144 (0.63)	−0.498 (0.59)	150
Females above the age 18	0.441 (0.099)	0.023 (0.02)	0.003 (0.02)	0.020 (0.02)	150
HH head is female	0.249 (0.123)	0.028 (0.02)	0.004 (0.02)	0.023 (0.03)	150
Is breastfeeding	0.119 (0.065)	0.017 (0.01)	0.020* (0.01)	−0.003 (0.01)	150
Is pregnant	0.052 (0.088)	−0.023* (0.01)	−0.016 (0.01)	−0.007 (0.01)	150
P-val from Joint Orthogonality Test		0.203	0.506	0.943	

Notes: This table presents baseline balance data for the 150 sampled communities using 2015 census data. Column (1) shows the mean and standard deviation for the control group at baseline. Columns (2) and (3) indicate the regression coefficients and standard errors of the Door to Door and Small Group treatment arms compared to the control group. Column (4) compares the two treatment arms. The regressions include fixed effects at the triplet level with clustering at the community level. All the measures are constructed from household level variables from the 2015 Sierra Leone Census, and collapsed at the community level. The measures in the first panel were used to stratify communities into triplets. The last row shows p-values from Joint Orthogonality tests. We estimate a multinomial logit with the treatment indicator being the dependent variable, regressed on all the variables in the table. .***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Table A2: Intent-To-Treat estimates of the Count of People Vaccinated per Site After Mobile Vaccination Program

|	In Census		+Not in Census & Migrants		+ Other Villages	
	(1)	(2)	(3)	(4)	(5)	(6)
Any Treatment	14.192***		31.550***		39.630***	
	(2.214)		(4.077)		(4.077)	
Door to Door		13.472***		30.163***		37.868***
		(2.565)		(4.737)		(4.747)
Small Group		14.923***		32.930***		41.348***
		(2.574)		(4.732)		(4.716)
Observations	150	150	150	150	150	150
Mean in Control	4.50	4.50	4.50	4.50	4.50	4.50
R squared	0.48	0.48	0.52	0.52	0.61	0.61
P val						
Door to Door = Small Group		0.58		0.56		0.47

Notes: This table presents Intent-To-Treat estimates corresponding to Figure 2. The dependent variable is vaccine uptake (any vaccine dose) i.e the count of people (12 years and older) vaccinated by the end of the study. In columns (1) and (2) we restrict our sample to those enumerated during the census. In columns (3) and (4) we add in people who were not enumerated during the census and come from nearby communities, are migrants or returnees, or were missing for other reasons. In columns (5) and (6) we add people from nearby villages. The last row reports the P-value from a two-sided t-test across the Door to Door and Small Group treatment arms. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Table A3: Intent-to-treat Estimates of Vaccination Rate of People Enumerated During Census

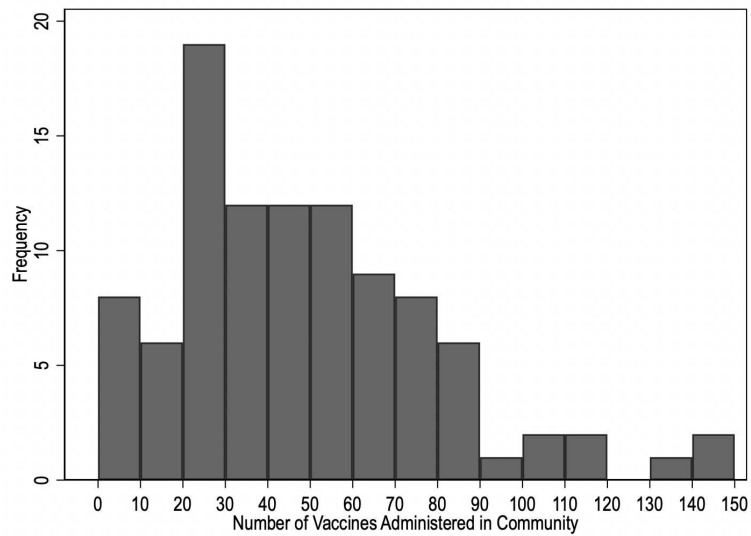|	(1)	(2)	(3)	(4)
Any Treatment	0.194***			
	(0.020)			
Door to Door		0.210***	0.210***	0.218***
		(0.024)	(0.023)	(0.029)
Small Group		0.179***	0.188***	0.191***
		(0.023)	(0.022)	(0.029)
Has recieved one dose at baseline			0.427***	0.210
			(0.067)	(0.145)
Observations	10135	10135	10135	150
Mean in Control	0.06	0.06	0.06	0.07
No. of Villages	150	150	150	
R squared	0.11	0.11	0.17	0.54
P val Door to Door= Small Group		0.22	0.42	0.37

Notes: This table presents Intent-To-Treat estimates corresponding to Figure 3. Dependent variable is the vaccination status at the end of the study of adults enumerated during the census. The dependent variable in Column (1)-(3) is the individual level vaccination status at endline, with standard errors clustered at the community level. Column (4) estimates the vaccination rate at the village level. The regression includes randomization fixed effects (ie for each triplet). In columns (3) and (4) we control for baseline vaccination status. The last row reports the P-value from a two-sided t-test across the treatment arms. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Figure A.2: Variation in Endline Vaccination Rate
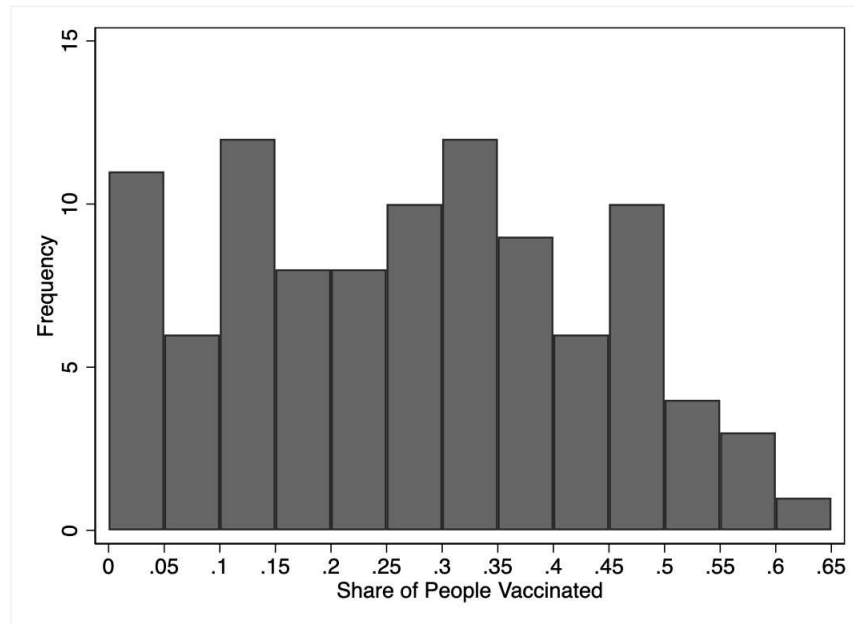
Notes: This figure provides a histogram of the vaccination rate (i.e share of adults that took the vaccine at the end of the study, from those enumerated during the census) of the 100 treatment villages.

Figure A.3: Variation in Number of People Vaccinated in Each Community

Notes: This figure provides a histogram of the number of vaccines administered (for those 12 and older) in the 100 treatment villages.

Table A4: Intent-To-Treat estimates for Knowledge and Attitudes Towards Vaccines in Sub-sample

	(1) Believes COVID-19 is real	(2) Knows about the COVID-19 vaccine	(3) Vaccines are effective	(4) Vaccines are safe
Any Treatment	0.066*	0.139***	0.097	0.134*
	(0.036)	(0.046)	(0.071)	(0.069)
Observations	878	878	746	746
Mean in Control	0.87	0.77	0.26	0.24
No. of Villages	45	45	45	45
R squared	0.11	0.14	0.13	0.13

Notes: This table presents Intent-To-Treat estimates of the pooled treatment. The dependent variables are indicators for which source respondents trust for information relating to COVID-19, included in 4. Regressions include randomization fixed effects (ie triplets), with standard errors clustered at the village level. Trust indicators are constructed from the household level endline. Sample is restricted to 45 villages and 878 households surveyed at endline. Data is missing for other villages. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Table A5: Intent-To-Treat estimates for Which Source People Trust Most for Information on COVID-19 in Sub-sample

	(1) Community Health Clinic	(2) Ministry of Health and Sanitation	(3) Media	(4) Social Media	(5) Family and Friends
Any Treatment	0.020	0.015	-0.021	-0.005	-0.034
	(0.059)	(0.027)	(0.048)	(0.003)	(0.024)
Observations	878	878	878	878	878
Mean in Control	0.21	0.06	0.29	0.01	0.07
No. of Villages	45	45	45	45	45
R squared	0.08	0.13	0.26	0.05	0.08

Notes: This table presents Intent-To-Treat estimates of the pooled treatment. The dependent variables are indicators for which source respondents trust for information relating to COVID-19, included in 4. Regressions include randomization fixed effects (ie triplets), with standard errors clustered at the village level. Trust indicators are constructed from the household level endline. Sample is restricted to 45 villages and 878 households surveyed at endline. Data is missing for other villages. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Table A6: Intent-To-Treat Estimates and Interactions With Demographic Variables

|	(1)	(2)	(3)	(4)	(5)
Any Treatment	0.219***	0.195***	0.196***	0.224***	0.221***
	(0.021)	(0.019)	(0.020)	(0.025)	(0.020)
Female	-0.012				
	(0.009)				
Female X Treat	-0.050**				
	(0.017)				
Aged 18-25		-0.085***			
		(0.018)			
Treatment X 18-25		-0.035*			
		(0.015)			
Aged 25-54		-0.010			
		(0.014)			
Treatment X 25-54		-0.046***			
		(0.011)			
HH head has had any formal schooling			0.007		
			(0.014)		
Any schooling X Treat			-0.013		
			(0.019)		
HH owns any land				0.037*	
				(0.016)	
Own any Land X Treat				-0.016	
				(0.025)	
Reduced portions of food in the past week					0.039*
					(0.016)
Reduced portions of food X Treat					-0.026
					(0.022)
Observations	10135	10059	10135	5691	5694
Mean in Control	0.06	0.06	0.06	0.06	0.06
No. of Villages	150	150	150	149	149
R squared	0.11	0.12	0.11	0.11	0.11

Notes: This table presents Intent-To-Treat estimates of the pooled treatment and interactions with demographic variables included in 5. Dependent variable is the vaccination status at the end of the study of adults enumerated during the census. Regressions include randomization fixed effects (ie triplets) as well as baseline vaccination status, with standard errors clustered at the village level. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.
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Table A7: Proportion Vaccinated by Baseline Willingness to Take Vaccines and Meeting Attendance

	Attended N=1,846	Not Attended N=10,781
Would take COVID Vaccine if offered N=4,209	51.58	16.38
Would not take COVID Vaccine if offered N=781	46.09	9.46

Notes: Each of cell indicates the vaccination rate for adults by whether they attended the village meeting crossed by whether they indicated if they were willing to take the COVID-19 vaccine at before the intervention or not.

Figure A.4: Number of Vaccines Administered per Community by Vaccination Team
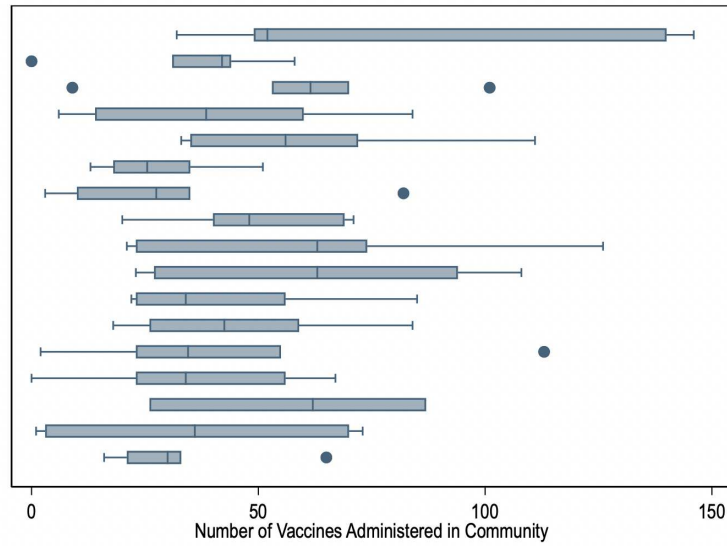
Notes: The box plots in this figure each represent the distribution of the number of vaccines administered in different communities by one COVID-19 vaccination team. The center line of each box plot represents the median number of vaccines that each team administered in a community. The top of each box represents the 75th percentile of the number of vaccines each team administered in a community, while the bottom of the box represents the 25th percentile of the number of vaccines each team administered in a community. The whiskers extend to the upper adjacent value and the lower adjacent value, as defined by Tukey, 1977. The dots represent outside values.

Table A8: Cost-Effectiveness Analysis

	Cost Type	Total Cost	Cost Per Vaccination	N
Training Costs				
Training venue	Fixed Cost	14610.6	3.1	4771
DSA for trainees (76 team members + 7 DOOs)	Fixed Cost	14094.8	3.0	4771
Debriefing				
Training venue	Fixed Cost	5844.3	1.2	4771
DSA for trainees (76 team members + 7 DOOs)	Fixed Cost	7047.4	1.5	4771
Materials				
Printing of Vaccination cards	Variable Cost	6809.1	1.4	4771
Printing of screening forms	Variable Cost	8511.4	1.8	4771
Transport/Communication				
Vehicle hire + Fuel	Variable Cost	47401.5	9.9	4771
Fuel for DOOs	Variable Cost	7507.0	1.6	4771
Mobile phone top up (per team)	Variable Cost	289.4	0.1	4771
Salaries Vaccination Teams				
Daily rate for vaccinators	Variable Cost	13661.8	2.9	4771
DSA for vaccinators	Variable Cost	25615.8	5.4	4771
Total		151393.0	$31.7 \approx 32$	4771

Author contributions

N.M, A.M.M., M.V, S.C and D.K conceptualized the project; V.R and M.L curated the data; V.R. and M.V. undertook formal analyses; N.M, A.M.M. and M.V acquired funding; N.M, M.L, M.R. and S.C. performed the investigations; N.M,A.M.M.,M.V,V.R and M.L designed the methodology; M.V administrated the project; M.L, V.R and M.R. supervised the work; all authors validated the findings; V.R and E.T. visualized the data; A.M.M. and M.V. wrote the first draft, with all other authors contributing to writing, and all authors contributed to the review and editing of the paper.

Competing interests

The authors declare no competing interests. The authors did not receive financial or non-financial benefits from the donors, NWO, Weiss Asset Management and the IGC, or any other partners related to any of the interventions presented here.