The effect of regional under-age-5 campaigns on the SARS-CoV2 outbreak in LMIC

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Original report, results as of May 19th, 2020. Updated report, with results as of June 30th, 2020

What do we already know?

The global SARS-CoV2 pandemic is spreading through many countries in Sub-Saharan Africa and South Asia and low availability of laboratory testing means that there is much uncertainty as to where the disease is currently. In response to concerns over further propelling the virus forward, some countries have chosen to delay their previously planned health campaigns, such as measles supplementary immunization activities (SIAs). In low- and middle-income countries, these campaigns provide essential health services to the most vulnerable and so there may be substantial health impacts from delays.

What does this report add?

We estimate the impact of fixed-post and door-to-door campaigns targeting children under age 5 on the transmission of SARS-CoV2 in an Ethiopia-like setting. We examine the effect of personal protective equipment (PPE) on both the community outbreak and on healthcare worker infection.

What are the implications for public health practice?

These findings can be used to support decisions around when and how to resume campaign-based health efforts targeting children, such as measles and polio vaccination activities.

Executive summary

- **Purpose:** To inform policy makers about the possible impact of campaigns targeted to children under age five (e.g. for measles vaccination) on COVID transmission.
- **Geography:** Anywhere there are health-oriented campaigns. Modeling was done based on Ethiopia's demographics and urbanization level.
- **Background:** In light of the COVID epidemic, on March 26th 2020, the WHO issued interim guidance stating that countries should suspend all planned vaccination campaigns, citing the risk of further transmission during such an event and other global institutions have followed suit. The question remains of how and when to resume activities.

- **Primary Results:**
- We find that both fixed post and door-to-door campaigns targeting children under age 5 have temporary impacts on transmission of SARS-CoV2 and tend to result in a minor increase in total infections.
- In places with ongoing community-based SARS-CoV2 transmission, the total effect is small relative to the inherent variability in transmission. As much as possible, avoiding campaigns during the local peak of SARS-CoV2 transmission is key to reducing the effect size.
- The primary risk of vaccination campaigns is the potential introduction of SARS-CoV2 to communities not previously exposed to the virus.
- Use of personal protective equipment (PPE) can mitigate the increased transmission due to campaign, if implemented well. In the cases of limited PPE availability, prioritization should be given to healthcare workers who are coming from geographies with high levels of SARS-CoV2 transmission and working with communities with little evidence of SARS-CoV2 spread.

Introduction

The novel coronavirus SARS-CoV-2 emerged in Wuhan, China, in late Nov or early Dec 2019. After initial emergence in China, travel associated cases started to appear in other parts of the world with strong travel connections to Wuhan. The first case of COVID-19 introduction into sub-Saharan Africa was reported in Nigeria on February 27, 2020; since then confirmed cases have risen across the continent (Johns Hopkins dashboard). Early importations were primarily found in travelers returning from abroad but now community transmission has begun to occur and many countries have instituted strict lockdowns to prevent expansion of the outbreak.

On March 26th, the WHO issued interim guidance that health-oriented campaigns be reconsidered in light of the risks of COVID transmission, and as a result many countries have postponed or cancelled planned services. By April 24th 2020, measles vaccination campaigns had been postponed in 24 countries, including some with large and vulnerable populations such as Bangladesh, Ethiopia, Nigeria, and the DRC. Gavi, the global Vaccine Alliance, has announced delays in implementation of campaigns against polio, measles, cholera, HPV, yellow fever and meningitis and at least four national routine vaccine introductions. Similar actions have been taken by the GPEI, suspending many polio campaigns until the public health situation allows.

The risk of COVID transmission during campaigns does exist, as there are reports of many healthcare workers becoming ill with the virus, for example in Liberia, Djibouti, and South Africa. These healthcare workers could potentially be able to transmit to otherwise healthy individuals during a campaign or may become ill themselves after contracting COVID during a campaign.

This delay is being driven by concerns over risks of COVID transmission via campaigns, but there are also health risks, particularly to vulnerable populations, of campaign delay. For example, there is an ongoing measles outbreak in DRC, which killed 6,000 children in 2019. In Kathmandu, a measles-rubella vaccination campaign scheduled for February was suspended, and communities are now experiencing outbreaks. Diphtheria and cholera are both making a comeback in several countries and putting particularly vulnerable populations such as refugees at high risk for outbreaks, at least in part due to delays in campaigns and diversion of healthcare providers. In addition, health systems weakened by the COVID pandemic are unable to keep up with day-to-day healthcare needs, which may leave those who are affected by non-COVID illness more vulnerable to morbidity and mortality.

As a result, some countries are now reconsidering their earlier choices to postpone campaigns and it is likely that at least some campaigns will be rescheduled and will occur in 2020. The COVID risks need to be balanced with the benefits of the campaign itself.

Methods: transmission modeling

Burden forecasts were generated using EMOD, an individual-based disease modeling platform. Additional details have been included in Appendix 1: Detailed Methods for the Epidemiological Model.

Simulations were intended to represent SARS-CoV-2 progression in an LMIC context and used parameter values appropriate to Ethiopia. Many assumptions were needed to make this comparison; one of the most significant assumptions being that importations of virus began in late-February to early-March. Infection trajectories based on this start date imply the beginnings of community transmission in late-March to early-April.

We used EMOD to simulate the social structure of the population, with each agent assigned to an age cohort. Their contact rates with other agents within the model are stratified across four routes (school, home, work, and community) and by age based on published data from K. Prem et al (2017). School contacts are 23% of the total, due to the young age pyramid in Ethiopia. Community-based contacts are the largest portion at 46%, which includes activities like religious contacts, markets, and informal employment. The remainder are 20% at home and 11% at work.

The baseline scenario is representative of the Ethiopian government's March 15th, 2020 order to close schools, ban large public gatherings, and work from home if possible. To reflect this, our social distancing measures include a 50% reduction in work contacts and 10% in community contacts and 100% in school contacts. Twenty percent of the work and school contacts that were reduced were redistributed to the home route. We also assume that 10% of individuals with symptoms persisting for more than 1 day begin to self-isolate. This self-enforced isolation is assumed to achieve an 80% reduction in transmission during the period of self-enforced isolation.

We also examine the implications of a partial re-opening of the economy by varying a change in contact rates on May 15th, 2020. This was done because the extent of reopening will be different depending on countries' policies and this approach provides a sensitivity analysis on the results. We consider a revision to the contact rates as follows, where 1.0 is equal to the normal pre-COVID level of contacts.

Policy change	Home	School	Work	Community
Variant A	1.00	0.00	0.25	0.90
Variant B	1.00	0.00	0.50	0.70
Variant C	1.00	0.00	0.50	0.50

Table 1. Social distancing policy scenarios. Used for comparison purposes to test robustness of the results. These do not represent actual or recommended social distancing policies.

Reduced susceptibility among children is a significant unknown. Several recent publications (citation, citation, citation) suggest that the under-15 year old cohort acquires and transmits SARS-CoV2 infections at a lower rate than the general population. This age-based modification has a substantial impact on transmission in an LMIC context like Ethiopia where about 45% of the population is under-15 years old, reducing the total burden and slowing the speed of the outbreak. (See Figure 1.)

Note that outcomes depicted in Figure 1 (and throughout) are ***trajectories of mean behavior*** based on ensembles of 500 simulations, filtered to remove simulated outcomes not resulting in an outbreak. The stochastic uncertainty of the models is shown later in the results section in Figure 7.

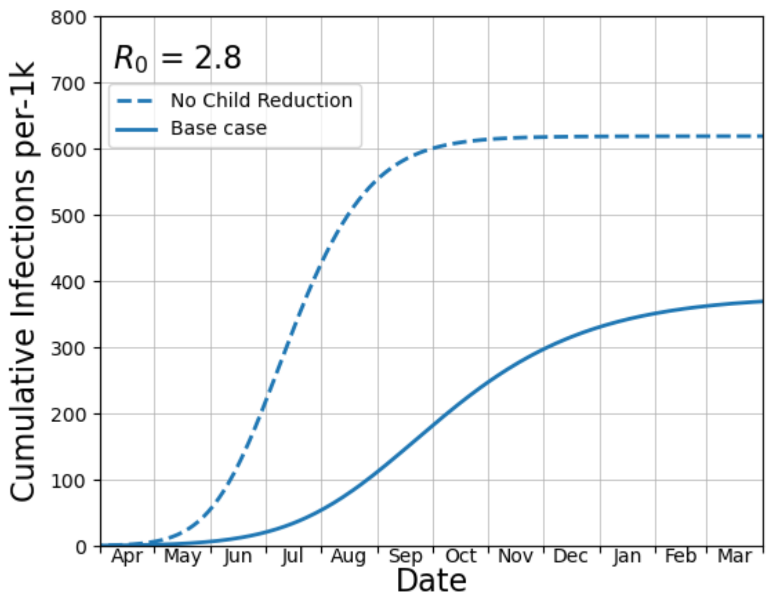


Figure 1. Cumulative infection trajectories for SARS-CoV2 in an urban environment when varying the level of susceptibility in the under-15-year-old cohort. The base case incorporates a reduction in childhood susceptibility of about 25%, with respect to both acquisition and transmission.

Connectivity and migration between city centers, peri-urban and rural communities is also poorly documented. We assume an exponential distribution of city sizes, with 30% of the population in the largest city, in alignment with Ethiopia's urban/rural distribution, and migration patterns relative to the distance between population centers. Modeling the SARS-CoV2 outbreak using this distributed community connectivity results in a slower growth and extended outbreak. (See Figure 2.)

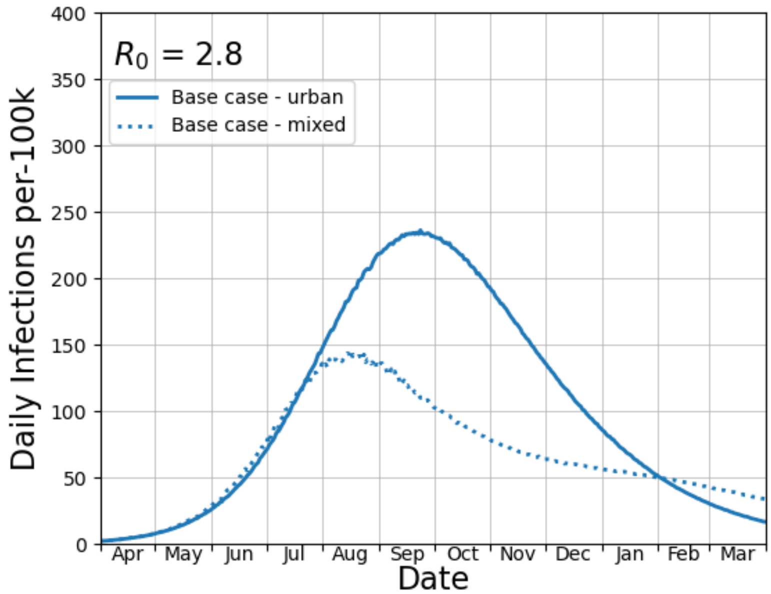


Figure 2. Daily infection trajectories per 100,000 population, for an urban-only and for a mixed-connectivity population.

Methods: scenarios and sensitivity analysis

We ran modeling scenarios for both fixed-post campaigns and door-to-door campaigns. Both sets of assumptions were modeled on vaccination campaigns for measles and polio respectively and targeted all children under the age of five.

Fixed post campaigns were reflected in the model by adjusting the contact rates among different age cohorts for seven days, to reflect the community coming together to a central location and having some level of social interaction as well as travel. This was represented by a 50% increase in contacts within the under-5 cohort (children), a 50% increase in contacts among individuals in the 20-35-year-old cohort (their caregivers), and a 200% increase in contacts between the two groups.

Door-to-door campaigns were reflected in the model by adjusting the interaction rates between healthcare workers and the general population, but no changes were made to general community contacts rates with each other. This reflects the process of a door-to-door campaign, where a vaccinator stops at each household in the community to provide vaccination, but the children and their caregivers remain in their homes, abiding by social distancing practices.

We conducted three sensitivity analyses. The first varied the timing of the one-week fixed-post campaign across four dates: June 15, July 15, August 15, and September 15. The second was to test personal protective equipment at a 50% and a 95% effectiveness level, where the healthcare worker is partially protected from acquisition and the community is protected from transmission of SARS-CoV2 at the given rate. The third was to examine the impact of running multiple campaigns in the same year, to assess the relative impact of considering an integrated campaign strategy.

Results

Fixed-post urban SIA

A fixed post SIA in an urban center already experiencing community transmission had a small, transient effect (< 5%) on the number of daily infections during the period of the SIA. The effect was largest when the SIA occurred around the time of peak transmission. Outcomes are depicted in Figure 3. The SIA also tended to result in a minor increase in infections for a period of about a month following the SIA, although given the variance in the infection process this secondary increase was not meaningfully different from the from the no-SIA scenarios.

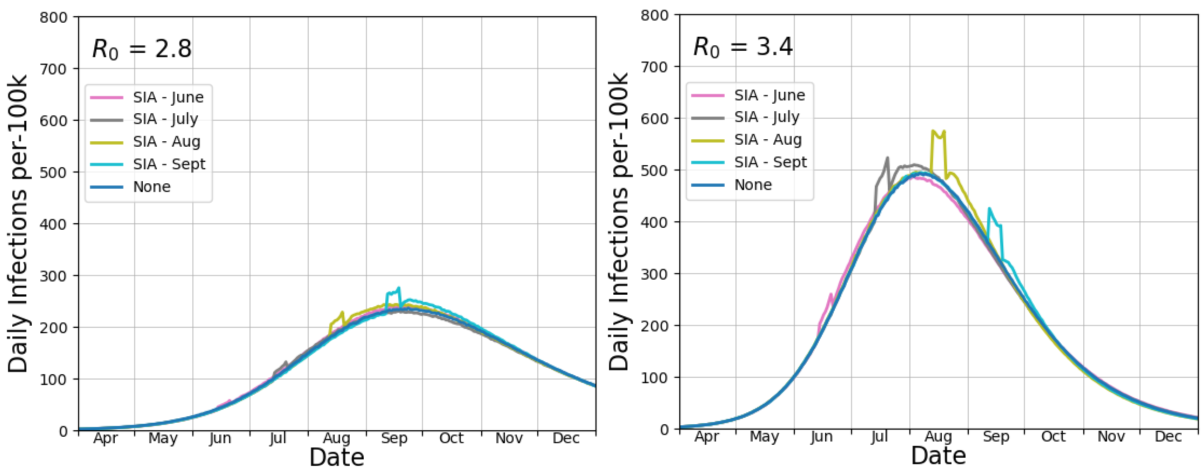


Figure 3. Expected daily infections per 100k individuals for two infectivity scenarios: R_0 = 2.8 and R_0 = 3.4. In each scenario, a fixed-post SIA with 7-day duration was implemented once in either June, July, August, September, or not at all.

The SIA effects in these scenarios had no long-term impact on the course of the epidemic trajectory. Scenarios that included multiple SIAs (four total; one each in June, July, August, and September) reproduced the behaviors from scenarios with a single SIA; there was no evidence that multiple SIAs spaced at one-month intervals would lead to compounding transmission effects beyond what would be expected from the SIAs taken independently. Outcomes depicted in Figure 4 for the 'SIA - All' trajectories are equivalent to the maximum in daily infection outcomes from the four independent SIA trajectories depicted in Figure 3. No outcome from the scenarios in Figure 4 is greater than an outcome depicted in Figure 3.

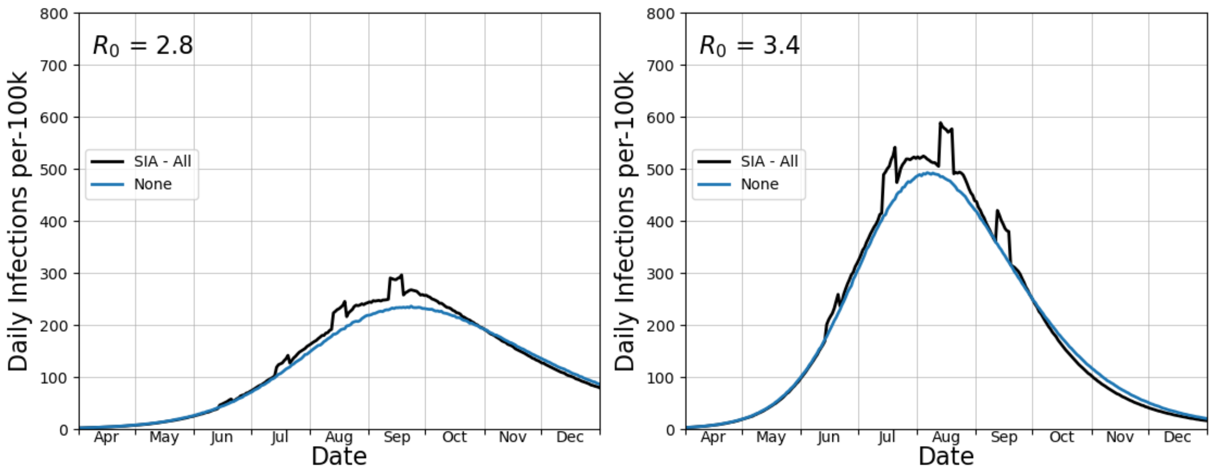


Figure 4. Expected daily infections per 100k individuals for two infectivity scenarios: R_0 = 2.8 and R_0 = 3.4. In each scenario, a fixed-post SIA with 7-day duration was implemented in four consecutive months, June, July, August, September, or not at all.

Fixed post rural SIA

Fixed-post SIAs implemented exclusively in rural settings without additional interaction with the urban centers tend to have lower overall impact per-capita than their corresponding activities in exclusively urban setting. This result is a consequence of the lower overall levels of transmission in rural settings due to their limited connectivity. Outcomes are depicted in Figure 5.

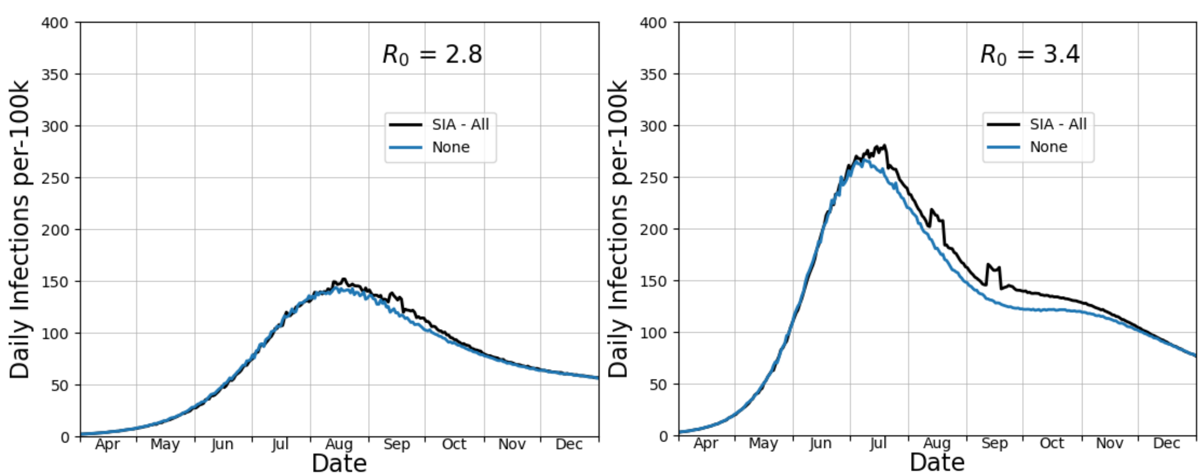


Figure 5. Fixed post SIA effects when implemented exclusively in rural locations in the context of an ongoing epidemic in a mixed urban-rural environment. The marginal increase in burden is lower than for fix-post SIA occurring in exclusively urban settings.

House-to-house urban SIA

Implementing house-to-house SIAs in an urban center already experiencing community transmission did not result in any meaningful change to epidemic trajectory or total number of infections. In these scenarios, a house-to-house SIA was implemented by revising heath care workers (HCW) contact patterns so that 80% of work contacts were with children <5 yrs. Outcomes for the house-to-house SIA scenarios are depicted in Figure 6.

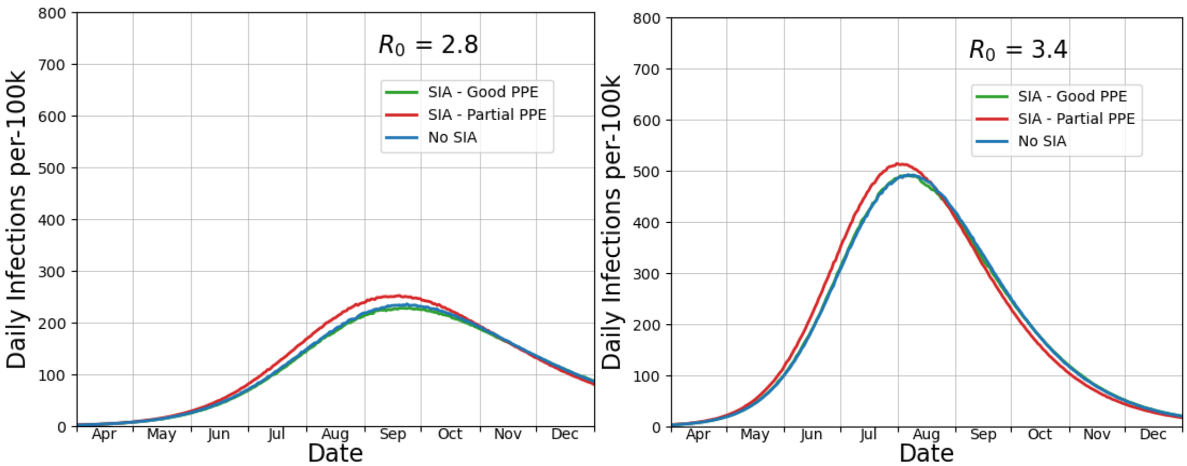


Figure 6. Expected daily infections per 100k individuals for two infectivity scenarios: R_0 = 2.8 and R_0 = 3.4. In each scenario, a house-to-house SIA with 7-day duration was implemented in four consecutive months, June, July, August, September, or not at all. In scenarios including an SIA, heath care workers were provided with either good PPE (95% reduction in acquisition and transmission) or partial PPE (50% reduction in acquisition and transmission).

Providing only partial PPE to HCWs slightly increases the peakedness of the epidemic, although this change is not significantly different from the scenarios with no SIA. In scenarios where HCWs receive good PPE, the attack rate among health care workers is reduced by between 65% and 80%, although HCWs are a small fraction of the total population (0.1%) and this change does not affect the overall course of the epidemic. These simulations are entirely focused on disease transmission, and do not address the morbidity or mortality effects that may arise from a depletion of HCW availability due to disease.

Implementing house-to-house SIAs with good HCW PPE results in a very slight decrease in the peakedness of the epidemic, although this change is not significantly different from the scenarios with no SIAs. Reassigning HCW contacts to focus on the under 5 year age-group has a minor protective effect on the HCW population because that segment of the population has been modeled to have reduced susceptibility and transmission of SARS-CoV2 infection, as described in the methods.

House-to-house rural SIA

Implementing an SIA in rural locations using HCW based in regions with ongoing transmission may introduce the virus to communities that would not otherwise experience an outbreak. When the SIA is poorly timed, total burden in these scenarios increases by 14 – 18%. Figure 7 depicts a month-long SIA targeting rural locations; this SIA is implemented from mid-June to mid-July, around the peak in urban transmission. This timing substantially increases the likelihood that an urban HCW is infectious.

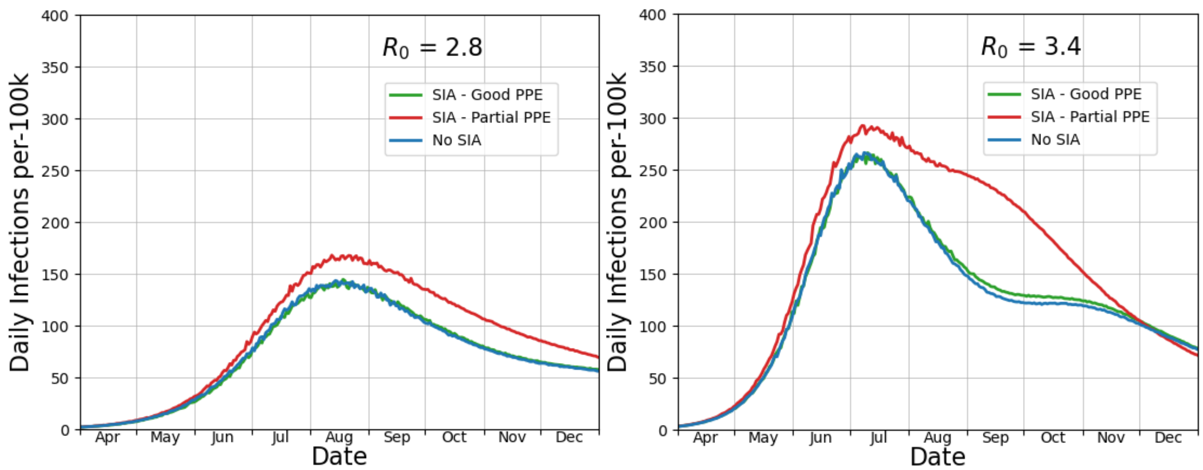


Figure 7. Expected daily infections per 100k individuals for two infectivity scenarios: R_0 = 2.8 and R_0 = 3.4. In each scenario, a rural SIA with 30-day duration was implemented from mid-June to mid-July, or not at all. In scenarios including an SIA, heath care workers were provided with either good PPE (95% reduction in acquisition and transmission) or partial PPE (50% reduction in acquisition and transmission).

The rural SIA was implemented as daily round trips by teams of 5 to 10 HCW from the urban center to rural locations. Rural locations were selected randomly and without respect to distance from the urban center or incorporation of travel time.

Providing good PPE to HCWs largely eliminates the probability of infectious HCWs introducing transmission into communities that do not have circulating virus. As in previous scenarios, good PPE also achieves a substantial reduction in the attack rate among health care workers.

Scenarios where HCWs are provided with only partial PPE have a much higher probability of infection, and travel to COVID-naïve communities sometimes cause extreme outcomes due to introductions that results in transmission in additional populations. The uncertainty of whether there will be an outbreak in many peri-urban and rural communities results in a wide cloud of possible outcomes, since there is not always a larger outbreak but when there is it can be substantial.

Repeating these rural SIA scenarios so that the SIA is timed the urban outbreak off-peak (e.g., an early May or late-September) results in trajectories largely indistinguishable from the ‘No SIA’ base case. In both of those alternate scenarios, the probability of urban HCW infectiousness is low, and new introductions are unlikely even when using only partial PPE. Substantial caution is needed to avoid potential introduction of disease to communities that do not have ongoing transmission.

Impact of Social Distancing Policy

The relative impact of a campaign is also affected by the level of underlying disease transmission, which is partially driven by the degree to which social distancing policies are in place and enforced. We conducted a sensitivity analysis to assess the robustness of the results described above to the degree of social distancing (See table 1).

The overall impact of social distancing in urban locations is depicted in figure 8 (upper panel) and in blue in figure 9. These simulations include no spatial heterogeneity and the shape of the outbreak remain mostly symmetric. Increased social distancing results in an overall lower rate of transmission, flattening the outbreak curve and reducing total burden. At low infectivity and increased social distancing, many simulations do not lead to widespread community transmission.

The same scenarios were run in the mixed urban-rural context and the visibility of the transition between epidemic peaking in urban and rural locations is reduced, with less connected locations experiencing ongoing infections several months after peak incidence. (Figure 8 lower panel)

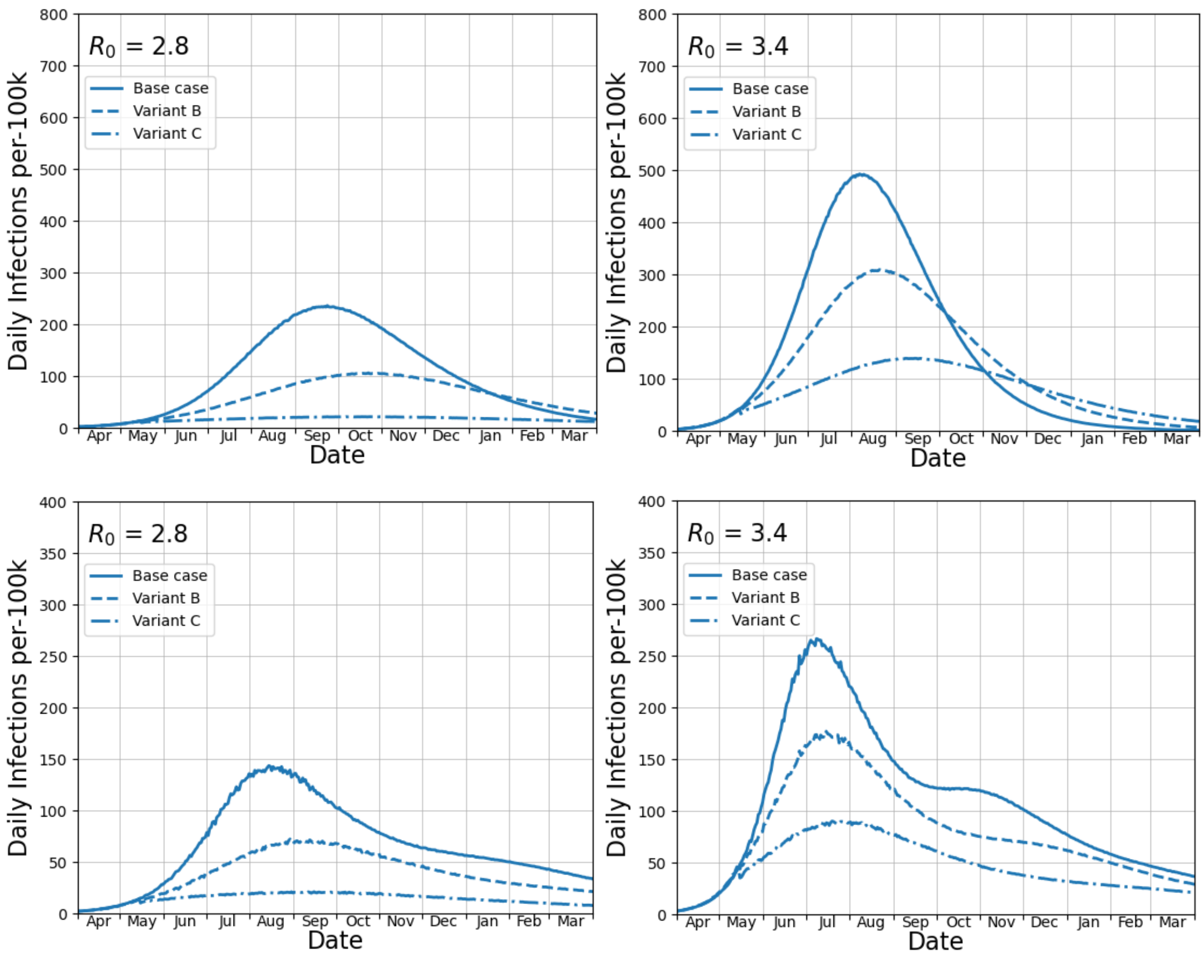


Figure 8. Increased social distancing moderates the severity of outbreaks in urban locations (upper) and in urban-rural mixed populations (lower). Lower levels of overall transmission reduce the distinctiveness of the urban peak. Variants represent alternative social distancing scenarios as defined in Table 1.

Replicating scenarios that included multiple fixed-post urban SIAs at the various levels of social distancing policy yields the expected outcome and is shown in black in figure 9. The magnitude of impact is roughly proportional to the level of ongoing transmission; reduced transmission due to increased social distancing or off-peak timing results in qualitatively similar behavior. Interventions at monthly intervals are almost entirely independent and doe not demonstrate any non-linear behavior in these simulations.

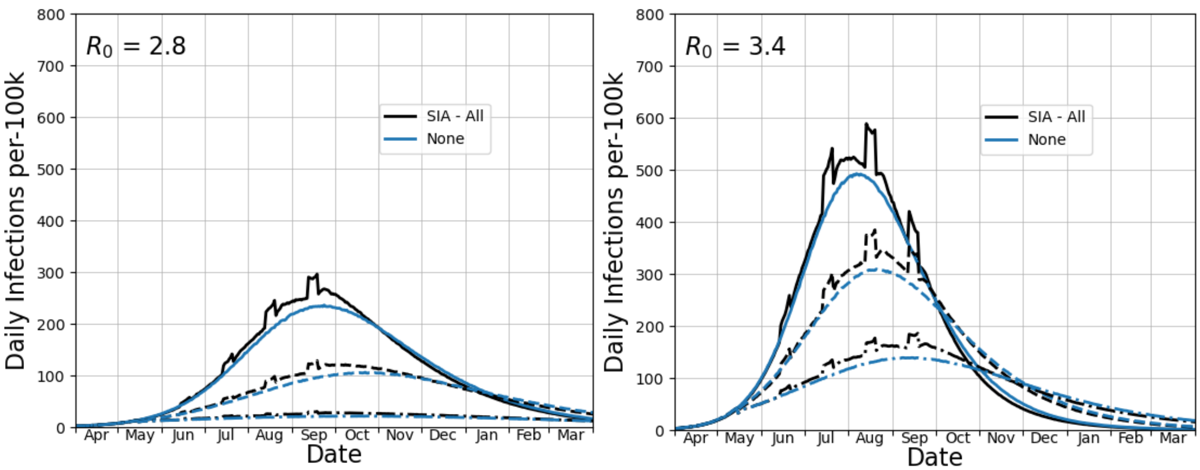


Figure 9. Increased social distancing moderates the severity of outbreaks in both urban locations. Lower levels of overall transmission reduce the distinctiveness of the urban peak. Fixed-post SIAs with 7-day duration implemented in four consecutive months, June, July, August, September, or not at all. Outcomes depicted for three distancing policies.

Uncertainty Quantification

Scenarios that involve discrete stochastic importations of disease have a high variability in outcome; some importations lead to outbreaks, and some do not. Figure 10 below depicts the range of outcomes (50%, 75%, and 95% clouds) based on an ensemble of 500 simulations. Simulations that did not produce an epidemic trajectory in the urban center were excluded.

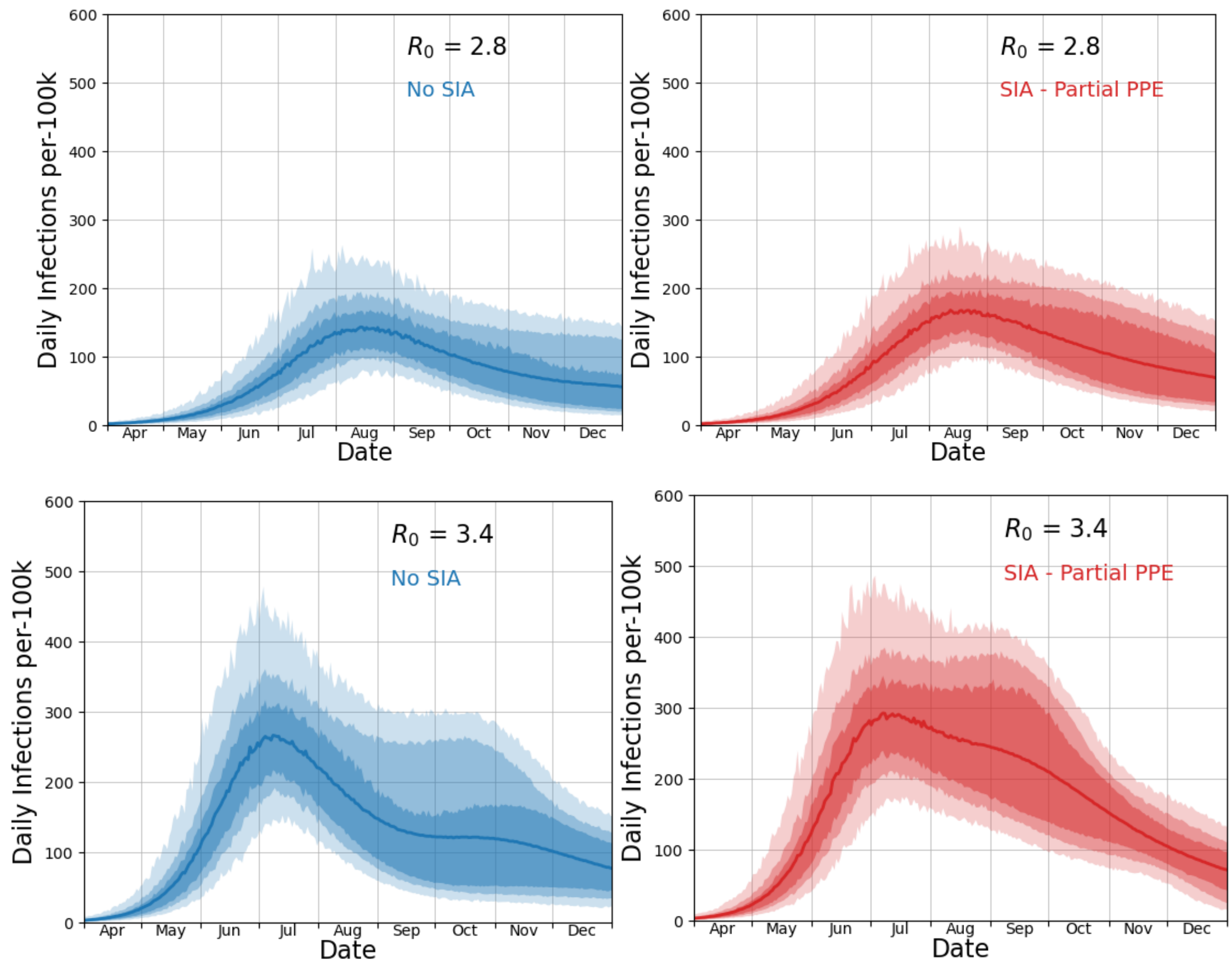


Figure 10. Expected daily infections per 100k individuals for two infectivity scenarios: R_0 = 2.8 and R_0 = 3.4. In each scenario, a rural SIA with 30-day duration was implemented from mid-June to mid-July, or not at all. In scenarios including an SIA, heath care workers were provided with partial PPE (50% reduction in acquisition and transmission). Shaded areas indicate the range of outcomes; (50%, 75%, and 95% of the ensemble).

Tabulated Outcomes

Each scenario that was run impacted the total number of cases, maximum prevalence rates, and age groups differently. These results are summarized in Table 2 below as the mean values from the simulation replications.

Campaign	Setting	Scenario Details	R0	Total Infections per 100k	Max daily Infections per 100k	Incidence per 100k > Age 50	Total % HCW Infected
Baseline	Urban	-	2.8	37,616	236	7,808	16.7
Fixed Post	Urban	June	2.8	38,007	239	7,888	17.1%
Fixed Post	Urban	July	2.8	37,366	231	7,774	16.9%
Fixed Post	Urban	August	2.8	38,024	243	7,900	16.3%
Fixed Post	Urban	Sept.	2.8	38,024	275	7,890	16.0%
Fixed Post	Urban	All 4	2.8	39,239	296	8,154	16.2%
H2H	Urban	Good PPE	2.8	37,147	228	7,697	16.8%
H2H	Urban	Partial PPE	2.8	39,133	252	8,384	80.0%
Baseline*	Rural	-	2.8	27,739	144	5,598	9.4%
Fixed Post*	Rural	Worst timing	2.8	28,008	152	5,664	9.6%
H2H*	Rural	Good PPE	2.8	27,844	145	5,617	9.2%
H2H*	Rural	Partial PPE	2.8	32,196	168	6,873	63.2%
Baseline	Urban	Soc. Dist. B	2.8	34,294	207	6,411	15.5%
Fixed Post	Urban	Soc. Dist. B + All 4	2.8	35,290	255	6,600	15.7%
Baseline	Urban	Soc. Dist. C	2.8	23,161	106	4,451	6.6%
Fixed Post	Urban	Soc. Dist. C + All 4	2.8	24,360	129	4,658	10.2%
Baseline	Urban	-	3.4	54,676	492	13,381	31.4%
Fixed Post	Urban	June	3.4	54,788	486	13,408	31.1%
Fixed Post	Urban	July	3.4	55,194	523	13,507	31.8%
Fixed Post	Urban	August	3.4	55,588	575	13,601	31.3%
Fixed Post	Urban	Sept.	3.4	55,339	494	13,550	31.1%
Fixed Post	Urban	All 4	3.4	56,967	588	13,937	31.9%
H2H	Urban	Good PPE	3.4	54,591	492	13,334	32.7%
H2H	Urban	Partial PPE	3.4	55,710	514	13,949	94.7%
Baseline*	Rural	-	3.4	43,618	266	10,599	22.1%
Fixed Post*	Rural	Worst timing	3.4	45,293	281	11,023	23.2%
H2H*	Rural	Good PPE	3.4	44,129	266	10,753	21.8%
H2H*	Rural	Partial PPE	3.4	50,013	292	12,519	82.9%
Baseline	Urban	Soc. Dist. B	3.4	51,644	452	11,454	28.9%
Fixed Post	Urban	Soc. Dist. B + All 4	3.4	53,961	540	11,952	30.7%
Baseline	Urban	Soc. Dist. C	3.4	44,296	309	10,397	26.1%
Fixed Post	Urban	Soc. Dist. C + All 4	3.4	46,361	384	10,879	25.9%

Table 2. Mean values from simulated COVID outbreaks; confidence intervals are reported in the appendix. HCW = healthcare workers (i.e. vaccinator). R0 = baseline reproductive rate. H2H = house-to-house campaign. In scenarios including an SIA, heath care workers could be provided with either good PPE (95% reduction in acquisition and transmission) or partial PPE (50% reduction in acquisition and transmission). In scenarios with a fixed post campaign, the start date could be in June, July, August, September, or all four. Baseline scenarios had no campaigns. *Rural population only, reported values do not include urban infections.

Conclusions

Results from each of the simulated scenarios shows an increase in SARS-CoV2 cases as a result of a mass campaign targeted at children under age five. While the impact on total cases was modest in most scenarios, campaigns should be expected to generate some excess infections. The degree of impact varies depending on the timing of the campaign, the delivery mode (fixed post or door-to-door), and the level of protection provided to healthcare workers by using PPE.

In the fixed post campaign, the time distance from the peak of the curve was the primary driver of the number of excess cases. The intuitive response to this result may be to "avoid the peak", but this is difficult to do in practice due to 1) logistical constraints related to staffing and supply availability, 2) the difficult of detecting when the peak is occurring until it has substantially passed, and 3) the uncertainty regarding the true infection rate, which makes accurate prediction of a future peak unreliable. Thus, trying to time the campaign to avoid the peak is not a reliable strategy.

Only one scenario generated a fundamentally different shape of the outbreak curve, which was the worst-case scenario of unprotected healthcare workers from a high-transmission setting vaccinating rural communities that were previously naïve to SARS-CoV2. If a country would find itself facing a known outbreak in one area while other parts of the country were not, our results suggest that they should think carefully about whether to delay the campaign, ensure strict adherence to sanitation protocols, and preferentially use local vaccinators wherever possible to reduce the likelihood of importation from other parts of the country.

The health of the vaccinators, usually trained healthcare workers who also provide clinical care during outside of campaigns, is also at risk during a campaign and must be prioritized. The use of highly protective PPE is effective at reducing cases in vaccinators by up to 76% in urban, well-mixed door-to-door campaigns and 87% in the worst case, rural door-to-door campaigns. These measures are straight forward to implement if PPE can be acquired, vaccinators trained properly on use, and the waste safely disposed of after the campaign is over.

Integrated campaigns present one alternative that can enable governments to protect the public and healthcare workers, while also providing services. This strategy would reduce exposures and could also integrate the distribution of soap and other sanitation interventions as well as SARS-CoV2 prevention education, thus further reducing the net impact on cases.

Country decision makers may want to consider different strategies for campaigns planned in the near-term vs. later in the year. For campaigns that are planned to start soon, our results suggest that it may be relatively safe to consider proceeding if strict enforcement of practices to reduce introductions can be put in place. For campaigns that are planned for later in the year, there is a need to closely monitor the outbreak's progression and consider making a go/no go decision just a few weeks in advance, so that as much information about the current state of the outbreak is available. There is a reasonable likelihood that over the next weeks-months, there will be community transmission in many areas, even if they are not officially documented, which while unfortunate would reduce the likelihood of there still being truly naïve populations that a campaign would put at risk. Building in flexibility to the schedule to allow last-minute adjustments at the local level may be useful.

Limitations

The modeling does have limitations, as there are many unknowns about how SARS-CoV2 will spread in the LMIC context. There are a couple of factors that affect the dynamics of the modeled outcomes.

The first is the level of asymptomatic infections in children and the documented reduction in both susceptibility and transmission. We made a conservative assumption based on recent literature but given the high proportion of the population that is under age 15 in many LMIC, the uncertainty that still exists about their infectivity creates a substantial shift in both the shape and size of the curve.

The second is the level interconnectedness across social networks and between communities. The social networks in LMIC are not especially well documented and have likely changed due to social distancing policies currently in place, with unknown consequences. Since transmission in our model is based on the number of contacts between sub-populations, this is a key assumption for which we do not have as robust of data as we would like.

Additionally, we do not make any assumption about the risk level of individuals moving between population centers. It is possible that individuals who are more likely to migrate for work or other purposes may also be at higher risk individuals SARS-Cov2, but there is no evidence to demonstrate whether this relationship exists.

The third is that a moderate social distancing policy is built into our baseline scenario, in alignment with the Ethiopian government's policies put in place as of March 15th, 2020 and ongoing as of this writing. However, it is not clear whether they will be able to sustain this level of distancing over the long term and changes in policy would have direct impacts on the outbreak's progression.

Social distancing has significant societal consequences such as income losses and there are concerns that hunger and malnutrition (UN report) and social unrest is already being seen (news reports) and could rise if significant lockdowns remain in place. While social distancing is effective in reducing transmission, LMICs may not be able to sustain this to the same level as more developed economies and at least some countries have opted to reopen their economies to a large extent (e.g. India). This is driven by factors such as less flexible supply chains, families have less savings to be able to stockpile food and other essentials, and informal sector employment (e.g. estimated in India) is high and leaves many without continued income streams.

The laboratory capacity in many LMIC is also a constraint because it may limit the number of tests that can be performed and may result in under-reporting of cases, making it more difficult to validate the model results with observed outcomes. We have endeavored to parameterize the modeling assumptions based on realistic assumptions but there is the possibility that we have overlooked transmission dynamics or assumed an infectivity that is too high.

Supplement: Thoughts on reducing transmission risk during a campaign

If a campaign is held, some actions could potentially reduce the likelihood of transmission:

- Use of vaccinators from within the local community, reducing importation risk
- High quality PPE available, including hand sanitation systems
- Additional staffing for supervision of PPE use
- Additional staffing (volunteer?) to ensure distancing between families while they wait
- Extended hours or additional days to reduce density of participant attendance
- Co-distribution of multiple interventions, to avoid the need for multiple gatherings
- Careful disposal of waste (sharps, gloves, masks, etc.)
- Checking of temperatures and symptoms screening for participants, possible diversion
- Provision of soap and sanitation, as well as COVID-19 education during the event

Appendix 1: Detailed Methods for the Epidemiological Model

Forward burden projections were constructed using IDM's primary software, Epidemiological MODeling (EMOD), a stochastic agent-based model of disease transmission. The Generic branch of this software is not specific to any disease and was used to represent SARS-CoV-2 by selecting appropriate parameter values.

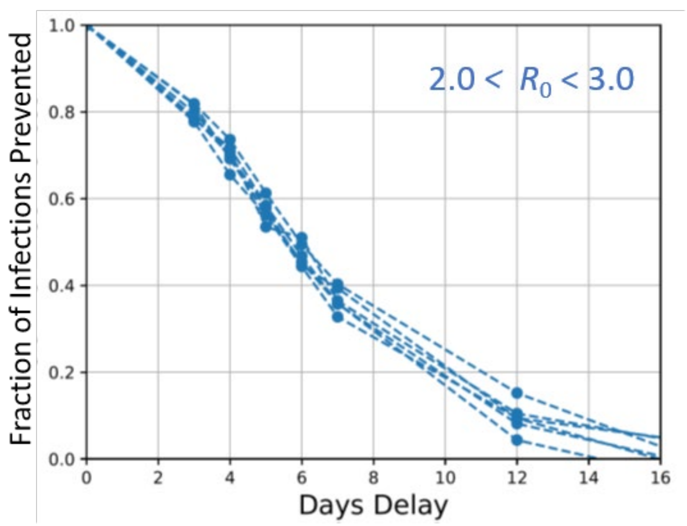
A single EMOD simulation follows a collection of agents through an arbitrary number of discrete time steps. Simulations used a constant length time step constructed to represent one day. Years were approximated as 365 time steps; leap days were neglected. All simulations had a duration of 2 years, which was taken to represent the period from January 2020 to December 2021. Properties that varied on a monthly basis attributed 31 days to January, 28 days to February, etc.

Infection Parameters

Infections were represented by an incubation period followed by an infectious period. The progression of disease within each agent was stochastically variable, dictated by the distributions below. At the end of the infectious period, the agent is given total immunity from subsequent infection. Immunity is assumed to not wane over the course of the simulation.

Latent Period	Gaussian distribution:	mean = 4.0 days;	standard deviation = 1.0 days
Infectious Period	Gamma distribution:	mean = 8.0 days;	standard deviation = 5.7 days
Symptomatic Period	Symptoms begin 2.0 days after latent period ends.		
Infectiousness	Exponential distribution: Adjusted so that R_0 is between 2.0 and 4.0, as specified		

Given these parameters, about 10% of all infected agents were completely asymptomatic (have an infectious period of less than two days). These parameters correspond to a median generation interval of about 6 days. This interval is not specified as an input parameter but is observable given simulation outputs.



The figure above depicts the relative fraction of infection events prevented when individual infectiousness is restricted, as a function of the number of days before that restriction is applied.

Demographics Parameters

Age Distributions

A total population of 1M agents was used for each simulation. Each agent was assigned to one of 16 age groups. Simulations were configured to represent an LMIC context by varying the fraction of agents in each age group. As an example, an age distribution vector appropriate to Ethiopia is indicated below.

Total population age distribution for Ethiopia simulations (% by 5yr-bin):

< 5	*5-10*	*10-15*	*15-20*	*20-25*	*25-30*	*30-35*	*35-40*	*40-45*	*45-50*	*50-55*	*55-60*	*60-65*	*65-70*	*70-75*	*75+*
14.6	*13.3*	*12.1*	*11.3*	*10.2*	*8.4*	*6.5*	*5.5*	*4.3*	*3.6*	*2.8*	*2.2*	*1.8*	*1.4*	*1.0*	*1.0*

Populations and ages were static for the period of the simulation; there were no vital dynamics (i.e., births, non-disease mortality, ageing, etc.). There was no disease mortality included as part of the simulation.

Contact Rates

Contact rates were age-stratified (5-yr age bins) and route-stratified (home, office, school, community) based on contact rates published by K. Prem et al. (citation), and risk-stratified (low, mid, high). Risk stratification was orthogonal to route-stratification; for each age group, 35% of individuals received 60% of the group's mean contact rate (low risk) and 15% of in individuals received 193% of the group's mean contact rate.

Basic Reproductive Number

The overall R_0 of a simulation is equal to the inner product of the age vector and the contact matrix. For a given simulation, the contact matrix was multiplied by the necessary scalar to generate the desired basic reproductive number for that simulation.

Reduced Childhood Susceptibility

Children were assumed to have reduced susceptibility (citation, citation, citation, citation, citation). The magnitude of this reduction is uncertain; it was implemented here as a 25% reduction in the probability of acquisition and a 25% reduction in the probability of transmission.

Reduced Susceptibility (% reduction by 5yr-bin):

< 5	*5-10*	*10-15*	*15-20*	*20+*
31.4	*24.8*	*19.8*	*11.6*	*0.0*

This reduction was applied after the normalization of the contact matrix. Simulations with reduced childhood susceptibility demonstrate a lower initial effective reproductive number than the specified basic reproductive number (i.e., $R_{eff} < R_0$ prior to outbreak start).

All other agents were fully susceptible at initialization.

Healthcare Workers (HCW)

Heathcare workers (HCW) were assigned their own demographic group independent of age and risk stratification. This group was assumed to be 0.1% of the total population. The HCW group was assumed to consist of individuals with ages between 20 yrs and 70 yrs. This age distribution varied by context. An example age distribution vector for HCW in Ethiopia is given below (citation).

HCW Age Distribution: Ethiopia (% by 5yr-bin):

<20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70+
0.0	20.5	23.4	14.7	12.5	8.3	6.9	3.0	2.4	1.5	1.2	0.0

Contacts for the HCW group via the home and community route were calculated based the age distributions above. No school contacts were assigned to the HCW group.

Total work contact rates were calculated using the HCW age distributions and the work contact route. These contact rates were then multiplied by a factor of 20 and re-distributed according to a presumed healthcare contact age structure. This age structure for Ethiopia is given below.

HCW Work Contacts Distribution: Ethiopia (% by 5yr-bin):

< 5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75+
0.1	0.1	6.7	6.7	14.8	14.8	9.5	9.5	9.4	9.4	3.1	3.1	3.1	3.1	3.1	3.1

Within-group contact rates for the HCW were calculated based on the age distribution and unmodified home, work, and community routes. The contact rates for other demographic groups interacting with the HCW group were equal to the age stratified HCW contact rates multiplied by 5/3.

Spatial Structure

The total population was distributed into multiple nodes (i.e., locations). The number of nodes and distribution of agents among nodes was variable between simulation types.

Typical simulations assigned the urban fraction (e.g., 30%) of the total population to the primary node (node with identifier 1). The balance of the population was distributed among 100 to 400 additional nodes (the number of secondary nodes varied randomly between simulations). Populations of these secondary nodes were exponentially distributed; each secondary node had minimum population of 100 individuals. Locations of these nodes were distributed randomly on a two-dimensional grid. Periodic boundary conditions were enforced at the edges of the grid.

Individuals within each node were able to make single day, round-trip transits to any of the 30 closest adjacent nodes. The frequency of transits for each individual was proportional to the population of the destination node, and inversely proportional to the distance to the destination node. The constant of proportionality was an adjustable parameter used to describe connectedness.

For large values of the connectedness parameter, disease transmission outcomes were equivalent to locating all the population within a single node. These scenarios were used to describe urban-like environments.

For intermediate values of the connectedness parameter, disease transmission within the primary node was urban-like, with limited and stochastic importations into the remaining population centers. These scenarios were used to describe urban/rural separations.

In the limit of very low or zero values of the connectedness parameter, disease transmission would only occur in the primary node and all other locations would be isolated with no infections. No scenarios use this parameterization.

Continuous importation of infections was assumed to begin on March 1. This importation only occurred in the primary node.

Intervention Parameters

Several interventions were used to affect disease transmission.

1) Baseline Social Distancing

A transition between normal contact patterns and revised contact patterns was assumed to occur on March 15 (citation, citation, citation). Social distancing measures included a 50% reduction in work contacts and 10% in community contacts and 100% in school contacts. Twenty percent of reduced work and school contacts were redistributed to the home route.

2) Increased Social Distancing

Additional revisions to contact patterns, depending on the scenario. In all cases twenty percent of reduced work and school contacts were redistributed to the home route.

3) Self-Mitigation

When infected, 10% of individuals with symptoms that persisted for 2 or more days (75% of all infected individuals have symptoms that persist for 2 or more days) start taking measures to reduce their rate of transmission (measures assumed to have 80% effectiveness). These measures were intended to represent self-imposed, non-pharmaceutical interventions.

3) Personal Protective Equipment (PPE)

Acquisition and transmission in the health care worker (HCW) group was reduced by either 95% (good protection) or 50% (poor protection). These measures were intended to represent the use of PPE.

Scenarios

Simulations for each scenario explored infectivity levels between R_0 = 2.0 and R_0 = 4.0; minimal data were available to further constrain the infectivity.

1) Base case

Base case scenarios incorporated the social distancing measures applied on March 15 and that 10% of symptomatic individuals. Base case scenarios also include reduced susceptibility of children. These scenarios use well-connected populations representative of urban areas.

2) Fixed post SIAs

These scenarios use the base case configuration and layer brief duration (7 days) step-changes in contacts representative of fixed-post SIAs. Contacts increase by 50% within the under-5yr age group and within the 20 – 35 yr age groups. Contacts increase by 200% between these age groups.

Each 7-day duration change results in a 15% increase in the infectivity across the entire population due to the increased contacts.

3) House-to-house SIAs

These scenarios use the base case configuration and layer brief duration (7 days) reconfigurations of health care worker (HCW) contact patterns. During contact-pattern reconfiguration, HCWs work contacts are redistributed to the <5yr age group (80%) and the 20 - 40 yr age groups (20%). Total contact rates remain unchanged.

Each 7-day reconfiguration results in less than 1% increase in the infectivity across the entire population due to the redistributed contacts.

4) Rural Outreach SIAs

These scenarios use the base case configuration and modify the connectivity pattern between population centers to create a distribution of rural locations surrounding a single urban center.

A rural outreach SIA was implemented as a moderate duration (30 day) reconfiguration of health care worker (HCW) contact patterns in the urban center, followed by daily round trips to rural locations. Rural locations were selected randomly and independent of distance to the urban center. Each day during the SIA period, 5 groups of 5 – 15 HCW each departed the urban node. HCW were selected at random. A HCW included as part of a group on day X would be eligible for group inclusion on day X+2, but would be absent from the urban center on day X+1.

Appendix 2: Scenario results confidence intervals

Uncertainty in the simulation modeling results are listed below for each of the primary outcomes, by scenario. Each scenario that was run impacted the total number of cases, maximum prevalence rates, and age groups differently.

Table S1 summarizes the total infections count per 100,000 population. Table S2 summarizes the maximum daily number of cases per 100,000 population. Table S3 summarizes the infection rate in individuals over age 50 per 100,000 population. Table S4 summarizes the portion of healthcare workers (HCW) infected with SARS-CoV2.

Campaign	Setting	Scenario Details	R0	25th Percentile	Median	Mean	75th Percentile
Baseline	Urban	-	2.8	28,260	35,978	37,616	45,147
Fixed Post	Urban	June	2.8	28,104	36,162	38,007	45,969
Fixed Post	Urban	July	2.8	28,044	35,511	37,366	44,767
Fixed Post	Urban	August	2.8	28,668	36,252	38,024	45,486
Fixed Post	Urban	Sept.	2.8	28,351	36,251	38,024	45,850
Fixed Post	Urban	All 4	2.8	29,501	37,608	39,239	47,138
H2H	Urban	Good PPE	2.8	27,923	35,400	37,147	44,514
H2H	Urban	Partial PPE	2.8	29,327	37,314	39,133	47,001
Baseline*	Rural	-	2.8	12,698	21,430	27,739	37,970
Fixed Post*	Rural	Worst timing	2.8	13,185	21,936	28,008	37,515
H2H*	Rural	Good PPE	2.8	12,903	21,749	27,844	37,491
H2H*	Rural	Partial PPE	2.8	16,590	26,939	32,196	43,246
Baseline	Urban	Soc. Dist. B	2.8	25,640	32,455	34,294	41,045
Fixed Post	Urban	Soc. Dist. B + All 4	2.8	26,312	33,535	35,290	42,406
Baseline	Urban	Soc. Dist. C	2.8	16,392	21,416	23,161	28,342
Fixed Post	Urban	Soc. Dist. C + All 4	2.8	17,198	22,449	24,360	29,803
Baseline	Urban	-	3.4	41,603	52,885	54,676	65,245
Fixed Post	Urban	June	3.4	40,574	52,946	54,788	66,371
Fixed Post	Urban	July	3.4	41,239	53,430	55,194	66,538
Fixed Post	Urban	August	3.4	41,410	53,694	55,588	66,958
Fixed Post	Urban	Sept.	3.4	41,588	53,291	55,339	66,650
Fixed Post	Urban	All 4	3.4	42,858	54,949	56,967	68,433
H2H	Urban	Good PPE	3.4	40,475	52,773	54,591	66,052
H2H	Urban	Partial PPE	3.4	40,953	53,696	55,710	67,524
Baseline*	Rural	-	3.4	20,298	35,600	43,618	59,572
Fixed Post*	Rural	Worst timing	3.4	20,448	37,380	45,293	63,416
H2H*	Rural	Good PPE	3.4	20,359	36,232	44,129	60,814
H2H*	Rural	Partial PPE	3.4	28,364	44,649	50,013	65,078
Baseline	Urban	Soc. Dist. B	3.4	37,957	49,813	51,644	62,812
Fixed Post	Urban	Soc. Dist. B + All 4	3.4	40,533	52,166	53,961	64,640
Baseline	Urban	Soc. Dist. C	3.4	33,173	42,665	44,296	53,312
Fixed Post	Urban	Soc. Dist. C + All 4	3.4	34,928	44,698	46,361	55,632

Table S1. Results from simulated COVID outbreaks for the total infections per 100,000 population. R0 = baseline reproductive rate. H2H = house-to-house campaign. In scenarios including an SIA, heath care workers could be provided with either good PPE (95% reduction in acquisition and transmission) or partial PPE (50% reduction in acquisition and transmission). In scenarios with a fixed post campaign, the start date could be in June, July, August, September, or all four. Baseline scenarios had no campaigns. *Rural population only, reported values do not include urban infections.

Campaign	Setting	Scenario Details	R0	25th Percentile	Median	Mean	75th Percentile
Baseline	Urban	-	2.8	181	220	236	280
Fixed Post	Urban	June	2.8	182	222	239	290
Fixed Post	Urban	July	2.8	176	214	231	275
Fixed Post	Urban	August	2.8	188	228	243	288
Fixed Post	Urban	Sept.	2.8	210	257	275	326
Fixed Post	Urban	All 4	2.8	227	276	296	350
H2H	Urban	Good PPE	2.8	176	212	228	271
H2H	Urban	Partial PPE	2.8	193	236	252	300
Baseline*	Rural	-	2.8	77	118	144	184
Fixed Post*	Rural	Worst timing	2.8	83	128	152	194
H2H*	Rural	Good PPE	2.8	76	117	145	188
H2H*	Rural	Partial PPE	2.8	100	145	168	212
Baseline	Urban	Soc. Dist. B	2.8	159	194	207	246
Fixed Post	Urban	Soc. Dist. B + All 4	2.8	190	237	255	305
Baseline	Urban	Soc. Dist. C	2.8	77	97	106	130
Fixed Post	Urban	Soc. Dist. C + All 4	2.8	94	118	129	156
Baseline	Urban	-	3.4	406	474	492	568
Fixed Post	Urban	June	3.4	391	464	486	568
Fixed Post	Urban	July	3.4	411	490	523	613
Fixed Post	Urban	August	3.4	481	555	575	658
Fixed Post	Urban	Sept.	3.4	400	475	494	576
Fixed Post	Urban	All 4	3.4	488	568	588	673
H2H	Urban	Good PPE	3.4	404	473	492	572
H2H	Urban	Partial PPE	3.4	416	492	514	598
Baseline*	Rural	-	3.4	137	216	266	346
Fixed Post*	Rural	Worst timing	3.4	154	237	281	358
H2H*	Rural	Good PPE	3.4	139	219	266	343
H2H*	Rural	Partial PPE	3.4	182	256	292	371
Baseline	Urban	Soc. Dist. B	3.4	363	433	452	530
Fixed Post	Urban	Soc. Dist. B + All 4	3.4	451	520	540	613
Baseline	Urban	Soc. Dist. C	3.4	247	293	309	359
Fixed Post	Urban	Soc. Dist. C + All 4	3.4	304	366	384	451

Table S2. Results from simulated COVID outbreaks for maximum daily number of cases per 100,000 population. R0 = baseline reproductive rate. H2H = house-to-house campaign. In scenarios including an SIA, heath care workers could be provided with either good PPE (95% reduction in acquisition and transmission) or partial PPE (50% reduction in acquisition and transmission). In scenarios with a fixed post campaign, the start date could be in June, July, August, September, or all four. Baseline scenarios had no campaigns. *Rural population only, reported values do not include urban infections.

Campaign	Setting	Scenario Details	R0	25th Percentile	Median	Mean	75th Percentile
Baseline	Urban	-	2.8	4,790	7,078	7,808	10,164
Fixed Post	Urban	June	2.8	4,796	7,146	7,888	10,277
Fixed Post	Urban	July	2.8	4,753	7,011	7,774	10,081
Fixed Post	Urban	August	2.8	4,867	7,181	7,900	10,278
Fixed Post	Urban	Sept.	2.8	4,861	7,202	7,890	10,327
Fixed Post	Urban	All 4	2.8	5,080	7,469	8,154	10,548
H2H	Urban	Good PPE	2.8	4,705	6,962	7,697	10,025
H2H	Urban	Partial PPE	2.8	5,185	7,690	8,384	10,927
Baseline*	Rural	-	2.8	1,913	4,095	5,598	8,110
Fixed Post*	Rural	Worst timing	2.8	1,997	4,161	5,664	8,132
H2H*	Rural	Good PPE	2.8	1,963	4,137	5,617	8,071
H2H*	Rural	Partial PPE	2.8	2,852	5,396	6,873	9,666
Baseline	Urban	Soc. Dist. B	2.8	3,772	5,749	6,411	8,460
Fixed Post	Urban	Soc. Dist. B + All 4	2.8	3,868	5,927	6,600	8,714
Baseline	Urban	Soc. Dist. C	2.8	2,254	3,914	4,451	6,299
Fixed Post	Urban	Soc. Dist. C + All 4	2.8	2,459	4,126	4,658	6,620
Baseline	Urban	-	3.4	9,280	12,640	13,381	16,704
Fixed Post	Urban	June	3.4	9,113	12,624	13,408	16,893
Fixed Post	Urban	July	3.4	9,271	12,746	13,507	16,967
Fixed Post	Urban	August	3.4	9,345	12,825	13,601	17,042
Fixed Post	Urban	Sept.	3.4	9,336	12,737	13,550	16,980
Fixed Post	Urban	All 4	3.4	9,656	13,159	13,937	17,400
H2H	Urban	Good PPE	3.4	9,064	12,568	13,334	16,765
H2H	Urban	Partial PPE	3.4	9,466	13,099	13,949	17,586
Baseline*	Rural	-	3.4	4,155	8,196	10,599	14,868
Fixed Post*	Rural	Worst timing	3.4	4,415	8,636	11,023	15,582
H2H*	Rural	Good PPE	3.4	4,292	8,373	10,753	15,104
H2H*	Rural	Partial PPE	3.4	6,463	10,778	12,519	16,818
Baseline	Urban	Soc. Dist. B	3.4	7,617	10,716	11,454	14,554
Fixed Post	Urban	Soc. Dist. B + All 4	3.4	8,144	11,207	11,952	15,019
Baseline	Urban	Soc. Dist. C	3.4	6,766	9,689	10,397	13,378
Fixed Post	Urban	Soc. Dist. C + All 4	3.4	7,211	10,160	10,879	13,857

Table S3. Results from simulated COVID outbreaks for the total infections in individuals over age 50, per 100,000 population. R0 = baseline reproductive rate. H2H = house-to-house campaign. In scenarios including an SIA, heath care workers could be provided with either good PPE (95% reduction in acquisition and transmission) or partial PPE (50% reduction in acquisition and transmission). In scenarios with a fixed post campaign, the start date could be in June, July, August, September, or all four. Baseline scenarios had no campaigns. *Rural population only, reported values do not include urban infections.

Campaign	Setting	Scenario Details	R0	25th Percentile	Median	Mean	75th Percentile
Baseline	Urban	-	2.8	0.0%	12.4%	16.7	29.0%
Fixed Post	Urban	June	2.8	0.0%	13.0%	17.1%	29.7%
Fixed Post	Urban	July	2.8	0.0%	12.5%	16.9%	29.0%
Fixed Post	Urban	August	2.8	0.0%	11.9%	16.3%	30.2%
Fixed Post	Urban	Sept.	2.8	0.1%	12.3%	16.0%	29.2%
Fixed Post	Urban	All 4	2.8	0.5%	12.7%	16.2%	30.3%
H2H	Urban	Good PPE	2.8	0.0%	12.5%	16.8%	30.5%
H2H	Urban	Partial PPE	2.8	38.8%	69.9%	80.0%	>99%
Baseline*	Rural	-	2.8	0.0%	0.0%	9.4%	17.0%
Fixed Post*	Rural	Worst timing	2.8	0.0%	0.0%	9.6%	17.6%
H2H*	Rural	Good PPE	2.8	0.0%	0.0%	9.2%	16.6%
H2H*	Rural	Partial PPE	2.8	12.4%	41.4%	63.2%	91.8%
Baseline	Urban	Soc. Dist. B	2.8	0.0%	10.6%	15.5%	25.7%
Fixed Post	Urban	Soc. Dist. B + All 4	2.8	0.0%	10.9%	15.7%	27.8%
Baseline	Urban	Soc. Dist. C	2.8	0.0%	0.0%	6.6%	19.6%
Fixed Post	Urban	Soc. Dist. C + All 4	2.8	0.0%	0.1%	10.2%	19.5%
Baseline	Urban	-	3.4	10.6%	25.3%	31.4%	45.6%
Fixed Post	Urban	June	3.4	10.4%	24.4%	31.1%	46.7%
Fixed Post	Urban	July	3.4	11.5%	26.1%	31.8%	46.1%
Fixed Post	Urban	August	3.4	11.7%	26.2%	31.3%	45.9%
Fixed Post	Urban	Sept.	3.4	10.7%	25.6%	31.1%	46.1%
Fixed Post	Urban	All 4	3.4	13.5%	27.6%	31.9%	46.5%
H2H	Urban	Good PPE	3.4	11.3%	25.2%	32.7%	47.9%
H2H	Urban	Partial PPE	3.4	52.7%	84.2%	94.7%	>99%
Baseline*	Rural	-	3.4	0.0%	8.7%	22.1%	34.3%
Fixed Post*	Rural	Worst timing	3.4	0.0%	11.0%	23.2%	35.2%
H2H*	Rural	Good PPE	3.4	0.0%	9.1%	21.8%	32.2%
H2H*	Rural	Partial PPE	3.4	27.9%	61.3%	82.9%	>99%
Baseline	Urban	Soc. Dist. B	3.4	9.1%	22.6%	28.9%	43.2%
Fixed Post	Urban	Soc. Dist. B + All 4	3.4	10.4%	24.5%	30.7%	45.1%
Baseline	Urban	Soc. Dist. C	3.4	7.3%	18.4%	26.1%	39.0%
Fixed Post	Urban	Soc. Dist. C + All 4	3.4	8.1%	21.3%	25.9%	41.4%

Table S4. Results from simulated COVID outbreaks for the portion of healthcare workers infected with SARS-CoV2. R0 = baseline reproductive rate. H2H = house-to-house campaign. In scenarios including an SIA, heath care workers could be provided with either good PPE (95% reduction in acquisition and transmission) or partial PPE (50% reduction in acquisition and transmission). In scenarios with a fixed post campaign, the start date could be in June, July, August, September, or all four. Baseline scenarios had no campaigns. *Rural population only, reported values do not include urban infections.