

TECHNICAL APPENDIX

Main paper: Duintjer Tebbens RJ, Pallansch MA, Cochi SL, Wassilak SGF, Thompson KM: An economic analysis of poliovirus risk management policy options for 2013-2052. BMC Infect Dis 2015; DOI: 10.1186/s12879-015-1112-8

See main paper for list of abbreviations. Table numbers not preceded by “A” refer to the main paper.

A1. Equations for ICER and INB estimation

We express the ICER in incremental costs per prevented (paralytic) polio case and per disability-adjusted life-years (DALYs)[1] averted according to the following equations:

$$\begin{aligned} \text{ICER}_{\text{case}} (\textit{alt vs. ref}) &= \text{incremental costs per prevented polio case} \\ &= ((\text{FC}_{\text{alt}} - \text{FC}_{\text{ref}}) - T \times (\text{PP}_{\text{ref}} - \text{PP}_{\text{alt}})) / (\text{PP}_{\text{ref}} - \text{PP}_{\text{alt}}) \end{aligned}$$

$$\begin{aligned} \text{ICER}_{\text{DALY}} (\textit{alt vs. ref}) &= \text{incremental costs per averted DALY} \\ &= ((\text{FC}_{\text{alt}} - \text{FC}_{\text{ref}}) - T \times (\text{PP}_{\text{ref}} - \text{PP}_{\text{alt}})) / (D \times (\text{PP}_{\text{ref}} - \text{PP}_{\text{alt}})) \end{aligned}$$

where FC_{ref} = cumulative, discounted financial costs associated with the reference case
 FC_{alt} = cumulative, discounted financial costs associated with the alternative policy
 PP_{ref} = cumulative, discounted number of polio cases with the reference case
 PP_{alt} = cumulative, discounted number of polio cases with the alternative policy
 T = average treatment costs per polio case
 D = average number of DALYs per polio case.

We compute the incremental net benefits of an alternative option (*alt*) compared to each reference case (*ref*) as:

$$\text{INB} (\textit{alt vs. ref}) = (T+S) \times (\text{PP}_{\text{ref}} - \text{PP}_{\text{alt}}) - (\text{FC}_{\text{alt}} - \text{FC}_{\text{ref}})$$

where S = average societal economic costs per polio case.

A2. Description and calibration of poliovirus transmission model

We conducted an extensive expert review[2, 3] and elicitation process[4] to inform the generic model inputs (e.g., characterization of immunity states, properties of the OPV evolution process).[5] We then calibrated the generic model inputs within the uncertainty ranges obtained from the expert elicitation process[4] to produce behavior consistent with the evidence for 10 different epidemiological situations, which include experience with WPV incidence and die-out for all 3 serotypes, absence of cVDPVs in some situations but emergence in others, VAPP cases and secondary OPV immunity, and different age distributions of cases.[5-7] To simulate die-out and cVDPV emergence in the model, we evaluate the effective proportion infectious (EPI, i.e., the infectious-weighted prevalence) for any given virus strain (i.e., WPV or any OPV reversion stage) and mixing age group to determine if it exceeds a “transmission threshold” (EPI*) that we

calibrated across the situations.[5] If $EPI < EPI^*$, then the model sets the force-of-infection for the virus strain and mixing age group to 0 and transmission dies out. We further developed methods to: (1) appropriately characterize age-specific RI with OPV-only, IPV-only, or IPV/OPV, including simultaneous administration of both vaccines,[8] (2) model the reality of repeatedly missed children during supplemental immunization activities (SIAs),[6] and (3) characterize overall population immunity to poliovirus transmission as a single quantity in the context of partial immunity to poliovirus transmission and heterogeneous mixing between age groups and subpopulations.[9]

A3. Modeling virus reintroductions using the probability of an effective introduction function (PEF)

We assume a logarithmic increase in PEF for $R_n > 1$, with values of 0.2 when R_n equals 1 (i.e., population immunity at the threshold to support sustained transmission) and 0.5 when R_n equals 5 or more (i.e., very low population immunity), as shown in Figure A1. We associate a random uniform number (U) with every potential poliovirus introduction. If a potential introduction event occurs during a stochastic iteration of the global poliovirus transmission model, then we assume that the introduction is effective if $U < PEF(R_n)$. If an effective introduction occurs, then the model generates exactly enough initial infections in the receiving subpopulation to exceed the transmission threshold and potentially lead to circulation. Specifically, we increase the effective prevalence of infections (i.e., EPI) to the transmission threshold (i.e., EPI^*) (see appendix A2) by moving a fraction EPI^* of all fully susceptible individuals in each age group to the first infectious stage.[5] If the proportion fully susceptible in an age group equals less than EPI^* , then this does not preclude an effective virus introduction, because individuals with immunity to polio (disease) still contribute to varying degrees to poliovirus transmission.[5] Therefore, if the proportion fully susceptible in an age group already equals less than EPI^* , then we move a fraction $EPI^*/RCT(i)$ in each immunity state i to the first infectious stage for the immunity state, where RCT equals the relative contribution to combined fecal-oral and oropharyngeal transmission for the immunity state i . [4, 5, 10]

A4. List of subpopulation characteristics, assignment to blocks and regions, and the model mechanics of selecting the locations for virus exportations

Table A1 provides the assumptions that we varied across the 710 subpopulations in the global model, intended to reflect real variability that exists in the world and allow the model to capture stratified mixing between subpopulations. Many subpopulation within blocks, and some blocks within large multi-block countries reflect identical properties, and therefore we showed these as single rows in Table A1. Table A2 defines the OPV take rate and SIA impact level inputs used in Table A1. To characterize the variability in conditions relevant to poliovirus transmission, we focus on a number of model inputs (i.e., the basic reproduction number (R_0), its seasonal amplitude (α) and peak day (pd), the proportion of transmissions via the oropharyngeal route (p^{oro}), the strength of preferential mixing (κ), the OPV take rate level (trl), RI coverage with 3 or more non-birth doses ($POL3$), the SIA impact level (sil , characterized by the true coverage and repeated missed probability).[6] and the detection threshold (dt) based on prior work) (see appendix A4).[11, 12, 6, 5] We assume inputs not controlled by policies (e.g., R_0 , α , pd , p^{oro} , κ , and trl) remain the same for all subpopulations within a block, with the exception of 3 HIGH

blocks in which we allowed a slightly higher R_0 and lower p^{oro} in one subpopulation than all other subpopulations to examine the possibility of some poliovirus spread in the areas that currently use IPV-only with high coverage.[7] We assume appropriate positive correlations between higher R_0 , lower α , lower p^{oro} , and lower tr . As appropriate, we vary the more policy-controllable inputs $POL3$, tcl , sil between subpopulations of the same block to account for real heterogeneity in RI, SIAs, and surveillance within blocks. Within blocks, we assume positive correlations between higher $POL3$, higher SIA impact, and lower dt . We assume that one LOW and 3 LMI blocks each contain one chronically under-vaccinated subpopulation with much lower $POL3$, SIA impact, and higher dt than the other subpopulations. These subpopulations can sustain poliovirus transmission despite frequent SIAs and represent the last reservoirs of indigenous WPV transmission, and in this regard they resemble the final 4 reservoirs of indigenous WPV1 transmission in the real world. We characterized these populations considering lessons learned from prior modeling.[8, 9] In two of these, we assumed improvements since 2010, while in the other two we assume intensification of efforts to eliminate WPV through increased frequency of low-impact SIAs alone. Although we only used a discrete set of $POL3$ values (i.e., 0.05, 0.1, 0.3, 0.6, 0.9, and 0.98), we chose values such that the averages in blocks correspond approximately to values estimated for different populations in each income level.[13] We assumed no changes in coverage levels over time going forward.

Although we do not attempt to characterize the full mixing structure between all 710 subpopulations in the world, the model accounts for randomness in virus exportations while still allowing replication of the simulation by specifying a pre-run list of 200 recipient subpopulations for each subpopulation. In this list, the probability that a recipient subpopulation resides in the same block as the exporting subpopulation equals 0.96. Each time step when the CEI in a subpopulation exceeds the E^* , we introduce the exported virus into the next subpopulation on the list of the exporting subpopulation, until we reach the end of the list, at which point we start again from the beginning of the list. We use the same list for all of the policies considered in an effort to reduce the differential impact of random exportations on the results for different policies, but we use a different randomly generated list for each stochastic iteration of the overall economic model.

A5. Details about the run-up, the assumed planned, preventive SIA (pSIA) schedules in blocks that use OPV-only or IPV/OPV, and the specific vaccines used

Facing high computational demands and highly variable polio control histories in different countries, we used a simplified and compressed run-up. We start all subpopulations at effectively 43 years before T_0 (i.e., year -43) with only fully susceptible individuals and then introduce a single infection in each of them. In the absence of vaccination, this leads all subpopulations to a state near the oscillating pre-vaccine equilibrium after a period of time, depending on R_0 and the seasonal amplitude. We start tOPV RI with SIAs in HIGH blocks first, effectively 23 years before T_0 , according to the subpopulation-specific $POL3$ and SIA impact assumptions and apply the SIA assumptions specified in Table 4. In all other blocks, we assume tOPV RI starts effectively 13 years before T_0 , with linearly increasing $POL3$ from 0 when introduced to 50% within 5 years. At that point, tOPV SIAs start at the subpopulation-specific impact level and $rcov$ changes to the subpopulation-specific values as well, which in a few subpopulations with very low $POL3$ implies a decrease in $POL3$ due to increased reliance on SIAs for polio immunization. Blocks in different strata of income level and polio vaccine use at

T_0 (Table 3) then switch to IPV-only or IPV/OPV at different times (Table 1). We do not characterize the relatively brief period of mOPV use for some SIAs, but instead introduce bOPV for SIAs 3 years before T_0 by switching a fraction of SIAs from tOPV to bOPV from that point forward. Table A3 shows the assumed planned, preventive SIA (pSIA) schedules in blocks that use OPV-only or IPV/OPV, depending on the WPV elimination status and RI coverage. We define WPV elimination in a block as lack of transmission of any WPV serotype in any subpopulation as a result of WPV prevalence of infections falling below the EPI*. While WPV importations can potentially delay WPV elimination, once a block reaches post-WPV-elimination status, it retains this status even after any subsequent WPV importations. All OPV-using blocks start with two annual tOPV SIAs and increase the frequency by one each year until they reach WPV elimination. In the event of continued indigenous WPV transmission in a block beyond the bOPV introduction time (i.e., T_0-3), the vaccine choice for each round depends on RI coverage. After WPV elimination, blocks switch to the post-WPV-elimination schedule, for which the number of rounds also depends on RI coverage. All blocks that use IPV-only at T_0 achieve WPV elimination before they switch to IPV-only, and we assume no SIAs in blocks that use IPV-only. The choice of vaccine depends on the time period, with tOPV-only initially, predominantly bOPV with some tOPV in lower RI coverage blocks after bOPV introduction, predominantly tOPV with some bOPV starting the last full year before OPV2 cessation in April 2016, and bOPV-only between OPV2 cessation and OPV13 cessation.

Figure A2 shows the results burn in period. Prior to the start of vaccination (i.e., year -23 in HIGH blocks, year -13 in other block), the global incidence oscillates around 500,000 annual cases. With RI vaccination increasing to current levels in all countries, the annual incidence drops to around 100,000 annual cases (i.e., year -9), and with the onset of SIAs (i.e., year -8) in non-HIGH blocks, the incidence drops dramatically. Global WPV2 elimination occurs within 2 years of this instantaneous global start of SIAs with most countries eliminating all indigenous WPVs within a few years. However, due to the inclusion of some blocks with properties similar to the last known WPV reservoirs with preferentially mixing under-vaccinated subpopulations (characterized by prior studies that modeled 3 of the 4 of these reservoirs[6, 5]), WPV3 continues to circulate in the last subpopulation until the start of year 1, and WPV1 until the start of year 3. In the last subpopulation with endemic WPV, a cVDPV2 also emerges, but gets controlled due to the intensification of tOPV SIAs between year 2 and OPV2 cessation.

A6. Generation of new long-term iVDPV excretors resulting from any mOPV use after OPV cessation

We use the DES model[14] that tracks the prevalence of and generates potentially effective introductions from, long-term excretors infected prior to OPV cessation (see Methods section of the main paper) also to create new iVDPV excretors as a result of any mOPV use to respond to outbreaks after OPV cessation. For each individual born with a pre-disposition of developing a PID, the DES model pre-determines at birth whether the individual could acquire a long-term iVDPV infection if infected with OPV after PID onset.[14] All patients living with a PID for any time after OPV cessation and pre-determine to exhibit potential long-term iVDPV excretion if infected could develop long-term excretion as a result of any mOPV use after OPV cessation in their subpopulation. Therefore, for all individuals meeting those criteria in a stochastic realization of the DES model, we record events that affect their ability to become newly generated iVDPV excretors, including (1) time of PID onset, (2) time of PID diagnosis (which

affects their probability of receiving OPV or becoming secondarily exposed to OPV), (3) time when any intravenous immunoglobulin treatments starts or falls into a lapse (which affects their probability of establishing a long-term infection), (4) time of death, (5) times of contacts with the general populations. Moreover, we pre-determine random characteristics of any new OPV infections that these individuals would experience in the event of mOPV oSIAs in their subpopulation. To do so, we generate random numbers to characterize 10 possible exposures to OPV after OPV cessation, including (1) ten uniform random numbers to compare against the probability of infection given exposure, (2) ten random durations of an infection to apply in the event a new infection, (3) ten uniform random numbers to determine if the time of VAPP onset in the event of a new infection, (4) one uniform random number to determine whether fatal VAPP occurs in the event VAPP occurs prior to the time of death in the absence of VAPP and prior to recovery from the new infection, (5) two random numbers to determine whether the patient would receive PAVDs and whether the PAVD would clear the infection in the event of a new infection and one of the two PAVD use scenarios. In the very unlikely event of more than ten OPV exposures after OPV cessation, we restart from the beginning of the appropriate lists of random numbers. If an OPV oSIA occurs after OPV cessation, then we calculate the probability of infection given exposure for each alive, clinical PID patient not already infected at the time of the oSIA based on its diagnosis and treatments status based on infection probabilities used in the DES model.[14] We then model a new infection if the random uniform number of the corresponding exposure is less than the probability of infection given exposure. If a new infection occurs, then use the infection duration of the corresponding exposure and similarly determine whether (fatal) VAPP occurs and PAVD treatment clears the infection (which depends on the PAVD scenario) by comparing the appropriate random uniform number to the appropriate probability.

A7. Blocks with potential IPV production sites

The overall rate of releases from IPV production sites remains 1 per 5 years (Table 4), and for each release we randomly select the IPV production site that releases either WPV (if the production site makes wIPV) or Sabin (if the production site makes sIPV). The exact locations of future IPV production sites remains uncertain, but some indication exists about the spectrum of properties of the populations currently considering the potential to host an IPV production site in the future. Therefore, we construct a single list of potential populations that may host an IPV production site in the future and randomly select locations for each stochastic iteration from these populations as follows (see Table A1 for the properties of the blocks):

- 5 wIPV production sites deterministically distributed in 5 different subpopulations of 2 European blocks (i.e., subpopulations 5, 6, and 7 of block 45 and subpopulations 3 and 4 of block 45)
- 1 sIPV production site in a random subpopulation in the region of China and neighbors, comprising 14 blocks
- 3 more sIPV production sites in 3 different randomly selected UMI blocks from the sublist containing blocks 35, 37, 60, 62, 70 and one of blocks 61 and 63 with equal chance.
- 1 sIPV production site in a random subpopulation in the Indian region, comprising 12 blocks

- 1 sIPV production site in a random subpopulation in blocks 13, 14, or 15 with equal probability
- 1 sIPV production site in a random subpopulation of block 6 or 69 with equal probability

For the policy option of IPV through T_{end} , we add 3 more sIPV production sites to the list in the event of a release after 2029 (i.e., more than 10 years after OPV13 cessation):

- 2 in randomly selected non-Chinese UMI blocks from the list (second bullet above) that do not already have an sIPV production site
- 1 in either block 34 or in whichever of blocks 6 or 69 (last bullet above) does not already have an sIPV production site

To ensure fair comparisons between policies, we pre-select all introductions over the entire time horizon at the beginning of a stochastic iteration. If random selection of the release location results in a LMI production site, then the release does not take place after global IPV use stopped, because LOW and LMI blocks will stop using IPV by then (while UMI and HIGH blocks continue to use IPV). This implies that the effective rate of releases goes down slightly after global IPV cessation (i.e., some fraction of releases does not occur).

A8. Details of stochastic iterations that led to OPV restart

Table A4 lists the characteristics of stochastic iterations that led to an OPV restart (based on 50,000 cumulative cases between 2016-2051) for one or more of the main policies.

Table A1: List of variability inputs for 710 subpopulations in the global poliovirus transmission model (list of symbols provided at bottom of table)

Region	Block	Sub-population(s)	Income level	Polio vaccine at T ₀	R ₀	α	pd	κ	trl	POL3	sil	dt	p ^{oro}
Africa	1	1-2	LOW	OPV-only	11	0.15	0	0.35	3	0.3	3	3	0.3
Africa	1	3-3	LOW	OPV-only	11	0.15	0	0.35	3	0.6	4	3	0.3
Africa	1	5-9	LOW	OPV-only	11	0.15	0	0.35	3	0.9	4	2	0.3
Africa	1	10	LOW	OPV-only	11	0.15	0	0.35	3	0.98	5	1	0.3
Africa	2	1	LOW	OPV-only	10	0.1	180	0.35	3	0.3	4	2	0.3
Africa	2	2	LOW	OPV-only	10	0.1	180	0.35	3	0.6	4	2	0.3
Africa	2	3-10	LOW	OPV-only	10	0.1	180	0.35	3	0.9	4	2	0.3
Africa	3	1	LOW	OPV-only	10	0.15	180	0.35	3	0.3	3	3	0.3
Africa	3	2	LOW	OPV-only	10	0.15	180	0.35	3	0.6	3	3	0.3
Africa	3	5-8	LOW	OPV-only	10	0.15	180	0.35	3	0.9	4	2	0.3
Africa	3	9	LOW	OPV-only	10	0.15	180	0.35	3	0.98	4	1	0.3
Africa	4	1-2	LOW	OPV-only	9	0.2	0	0.35	3	0.6	4	2	0.3
Africa	4	3-8	LOW	OPV-only	9	0.2	0	0.35	3	0.9	4	1	0.3
Africa	4	9-10	LOW	OPV-only	9	0.2	0	0.35	3	0.98	4	1	0.3
Africa	5	1	LOW	OPV-only	10	0.1	120	0.4	3	0.3	3	3	0.3
Africa	5	2-4	LOW	OPV-only	10	0.1	120	0.4	3	0.6	3	2	0.3
Africa	5	5-10	LOW	OPV-only	10	0.1	120	0.4	3	0.9	4	1	0.3
Africa	6	1-4	LMI	OPV-only	9	0.2	0	0.4	2	0.9	4	2	0.3
Africa	6	5-6	LMI	OPV-only	9	0.2	0	0.4	2	0.9	4	1	0.3
Africa	6	7-10	LMI	OPV-only	9	0.2	0	0.4	2	0.98	5	1	0.3
Africa	7	1	LMI	OPV-only	7	0.15	0	0.4	4	0.3	4	2	0.3
Africa	7	2-8	LMI	OPV-only	7	0.15	0	0.4	4	0.6	4	2	0.3
Africa	7	9-10	LMI	OPV-only	7	0.15	0	0.4	4	0.9	4	1	0.3
Africa	8	1	LMI	OPV-only	8	0.1	120	0.4	3	0.05	1	3	0.3
Africa	8	2-10	LMI	OPV-only	8	0.1	120	0.4	3	0.3	3	2	0.3
Africa	9	1-6	LMI	OPV-only	9	0.05	120	0.4	3	0.6	4	2	0.3
Africa	9	7-10	LMI	OPV-only	9	0.05	120	0.4	3	0.9	4	1	0.3
Africa	10	1	LMI	OPV-only	8	0.1	120	0.4	4	0.6	4	2	0.3
Africa	10	2-6	LMI	OPV-only	8	0.1	120	0.4	4	0.9	4	2	0.3
Africa	10	7-10	LMI	OPV-only	8	0.1	120	0.4	4	0.98	5	1	0.3
Africa	11	1-2	UMI	OPV-only	7	0.25	300	0.35	5	0.9	4	2	0.6
Africa	11	3-10	UMI	OPV-only	7	0.25	300	0.35	5	0.98	5	1	0.6
Australasia	12	1	LMI	OPV-only	7	0.15	180	0.4	5	0.6	4	2	0.5
Australasia	12	2-10	LMI	OPV-only	7	0.15	180	0.4	5	0.9	5	1	0.5
Australasia	13	1	LMI	OPV-only	8	0.2	120	0.35	3	0.3	4	2	0.3
Australasia	13	2-7	LMI	OPV-only	8	0.2	120	0.35	3	0.6	4	2	0.3
Australasia	13	8	LMI	OPV-only	8	0.2	120	0.35	3	0.9	4	1	0.3
Australasia	13	9-10	LMI	OPV-only	8	0.2	120	0.35	3	0.98	4	1	0.3
Australasia	14	1-5	LMI	OPV-only	7	0.2	120	0.4	4	0.6	4	2	0.5
Australasia	14	6-9	LMI	OPV-only	7	0.2	120	0.4	4	0.6	4	1	0.5
Australasia	14	10	LMI	OPV-only	7	0.2	120	0.4	4	0.9	4	1	0.5
Australasia	15	1-5	LMI	OPV-only	6	0.2	120	0.4	5	0.6	4	2	0.6
Australasia	15	6-9	LMI	OPV-only	6	0.2	120	0.4	5	0.6	4	1	0.6

Australasia	15	10	LMI	OPV-only	6	0.2	120	0.4	5	0.9	4	1	0.6
Australasia	16	1-4	HIGH	IPV-only	5	0.2	60	0.45	7	0.9	4	2	0.8
Australasia	16	5-10	HIGH	IPV-only	5	0.2	60	0.45	7	0.98	5	1	0.8
Australasia	17	1-6	HIGH	IPV-only	4	0.2	120	0.45	8	0.98	5	1	0.9
Australasia	17	7-10	HIGH	IPV-only	4	0.2	120	0.45	8	0.98	5	2	0.9
China and neighbors	18	1	UMI	OPV-only	7	0.4	180	0.5	6	0.9	4	2	0.6
China and neighbors	18	2-10	UMI	OPV-only	7	0.4	180	0.5	6	0.98	5	1	0.6
China and neighbors	19	1-10	UMI	OPV-only	6	0.35	180	0.5	7	0.98	5	1	0.8
China and neighbors	20	1-10	UMI	OPV-only	8	0.35	180	0.5	5	0.9	4	2	0.6
China and neighbors	21-31	1-10	UMI	OPV-only	7	0.35	180	0.5	6	0.98	5	1	0.6
East and Central Asia	32	1	LOW	OPV-only	11	0.2	180	0.35	2	0.1	2	3	0.3
East and Central Asia	32	2-10	LOW	OPV-only	11	0.2	180	0.35	2	0.6	4	2	0.3
East and Central Asia	33	1	LMI	OPV-only	7	0.5	60	0.3	2	0.6	5	2	0.8
East and Central Asia	33	2-3	LMI	OPV-only	7	0.5	60	0.3	2	0.9	5	2	0.8
East and Central Asia	33	4-10	LMI	OPV-only	7	0.5	60	0.3	2	0.98	5	1	0.8
East and Central Asia	34	1-3	LMI	OPV-only	11	0.15	180	0.35	2	0.6	3	2	0.3
East and Central Asia	34	4-10	LMI	OPV-only	11	0.15	180	0.35	2	0.9	4	1	0.3
East and Central Asia	35	1-3	UMI	OPV-only	7	0.2	60	0.35	5	0.6	4	2	0.6
East and Central Asia	35	4	UMI	OPV-only	7	0.2	60	0.35	5	0.9	5	1	0.6
East and Central Asia	35	5-10	UMI	OPV-only	7	0.2	60	0.35	5	0.98	5	1	0.6
East and Central Asia	36	1	UMI	IPV/OPV	6	0.25	60	0.35	5	0.3	3	3	0.6
East and Central Asia	36	2	UMI	IPV/OPV	6	0.25	60	0.35	5	0.6	4	2	0.6
East and Central Asia	36	3	UMI	IPV/OPV	6	0.25	60	0.35	5	0.9	5	1	0.6
East and Central Asia	36	4-10	UMI	IPV/OPV	6	0.25	60	0.35	5	0.98	5	1	0.6
East and Central Asia	37	1	UMI	IPV/OPV	7	0.2	120	0.35	5	0.9	4	2	0.6
East and Central Asia	37	2-10	UMI	IPV/OPV	7	0.2	120	0.35	5	0.98	5	2	0.6
Europe	38	1-2	UMI	IPV/OPV	6	0.4	180	0.45	6	0.6	3	3	0.8
Europe	38	3-5	UMI	IPV/OPV	6	0.4	180	0.45	6	0.9	4	2	0.8
Europe	38	6-10	UMI	IPV/OPV	6	0.4	180	0.45	6	0.98	5	1	0.8
Europe	39	1-2	HIGH	IPV/OPV	6	0.5	180	0.45	6	0.9	4	2	0.8
Europe	39	3-10	HIGH	IPV/OPV	6	0.5	180	0.45	6	0.98	5	1	0.8
Europe	40	1-2	HIGH	IPV/OPV	6	0.5	180	0.45	6	0.9	4	2	0.8
Europe	40	3-10	HIGH	IPV/OPV	6	0.5	180	0.45	6	0.98	5	1	0.8
Europe	41	1-4	HIGH	IPV-only	5	0.4	240	0.4	7	0.9	4	2	0.9
Europe	41	5-10	HIGH	IPV-only	5	0.4	240	0.4	7	0.98	5	1	0.9
Europe	42	1	HIGH	IPV-only	6	0.2	180	0.35	7	0.9	4	2	0.6
Europe	42	2	HIGH	IPV-only	5	0.2	180	0.35	7	0.9	4	2	0.8
Europe	42	3	HIGH	IPV-only	5	0.2	180	0.35	7	0.98	4	2	0.8
Europe	42	4-10	HIGH	IPV-only	5	0.2	180	0.35	7	0.98	5	1	0.8
Europe	43	1-2	HIGH	IPV-only	5	0.2	180	0.35	7	0.9	4	2	0.8
Europe	43	3	HIGH	IPV-only	5	0.2	180	0.35	7	0.98	4	2	0.8
Europe	43	4-9	HIGH	IPV-only	5	0.2	180	0.35	7	0.98	5	1	0.8
Europe	43	10	HIGH	IPV-only	6	0.2	180	0.35	7	0.98	5	1	0.6
Europe	44	1-5	HIGH	IPV-only	5	0.4	240	0.4	7	0.9	4	2	0.8
Europe	44	6-10	HIGH	IPV-only	5	0.4	240	0.4	7	0.98	5	1	0.8
Europe	45	1-6	HIGH	IPV-only	5	0.35	240	0.4	7	0.9	4	2	0.9
Europe	45	7-10	HIGH	IPV-only	5	0.35	240	0.4	7	0.98	5	1	0.9
India	46-47	1	LMI	OPV-only	13	0.2	180	0.35	1	0.3	2 ^a	1	0.3

India	46-47	2-10	LMI	OPV-only	13	0.2	180	0.35	1	0.6	5	1	0.3
India	48	1-5	LMI	OPV-only	12	0.2	180	0.35	2	0.6	5	1	0.3
India	48	6-10	LMI	OPV-only	12	0.2	180	0.35	2	0.9	5	1	0.3
India	49-53	1-5	LMI	OPV-only	11	0.15	240	0.35	3	0.6	5	1	0.3
India	49-53	6-10	LMI	OPV-only	11	0.15	240	0.35	3	0.9	5	1	0.3
India	54-55	1-5	LMI	OPV-only	11	0.1	240	0.35	3	0.6	5	1	0.3
India	54-55	6-10	LMI	OPV-only	11	0.1	240	0.35	3	0.9	5	1	0.3
India	56-57	1-5	LMI	OPV-only	10	0.1	240	0.35	3	0.6	5	1	0.3
India	56-57	6-10	LMI	OPV-only	10	0.1	240	0.35	3	0.9	5	1	0.3
Latin America & Caribbean	58	1	LMI	OPV-only	8	0.05	180	0.3	3	0.6	3	3	0.3
Latin America & Caribbean	58	2-8	LMI	OPV-only	8	0.05	180	0.3	3	0.9	4	2	0.3
Latin America & Caribbean	58	9-10	LMI	OPV-only	8	0.05	180	0.3	3	0.98	5	1	0.3
Latin America & Caribbean	59	1	UMI	OPV-only	8	0.2	240	0.35	5	0.6	4	2	0.6
Latin America & Caribbean	59	2-6	UMI	OPV-only	8	0.2	240	0.35	5	0.9	5	2	0.6
Latin America & Caribbean	59	7-10	UMI	OPV-only	8	0.2	240	0.35	5	0.98	5	2	0.6
Latin America & Caribbean	60	1	UMI	OPV-only	7	0.1	0	0.35	5	0.6	4	2	0.6
Latin America & Caribbean	60	2-9	UMI	OPV-only	7	0.1	0	0.35	5	0.9	5	1	0.6
Latin America & Caribbean	60	10	UMI	OPV-only	7	0.1	0	0.35	5	0.98	5	1	0.6
Latin America & Caribbean	61	1-5	UMI	IPV/OPV	8	0.1	300	0.35	4	0.9	5	2	0.5
Latin America & Caribbean	61	6-10	UMI	IPV/OPV	8	0.1	300	0.35	4	0.98	5	1	0.5
Latin America & Caribbean	62	1	UMI	IPV/OPV	7	0.05	120	0.35	5	0.9	5	2	0.6
Latin America & Caribbean	62	2-5	UMI	IPV/OPV	7	0.05	120	0.35	5	0.98	5	2	0.6
Latin America & Caribbean	62	6-10	UMI	IPV/OPV	7	0.05	120	0.35	5	0.98	5	1	0.6
Latin America & Caribbean	63	1-5	UMI	IPV/OPV	8	0.05	300	0.35	4	0.9	5	2	0.5
Latin America & Caribbean	63	6-10	UMI	IPV/OPV	8	0.05	300	0.35	4	0.98	5	1	0.5
North America	64	1-4	HIGH	IPV-only	4	0.4	240	0.35	7	0.9	4	2	0.9
North America	64	5-10	HIGH	IPV-only	4	0.4	240	0.35	7	0.98	5	1	0.9
North America	65	1-4	HIGH	IPV-only	5	0.3	240	0.35	7	0.9	4	2	0.8
North America	65	5-10	HIGH	IPV-only	5	0.3	240	0.35	7	0.98	5	1	0.8
North America	66	1-4	HIGH	IPV-only	5	0.05	180	0.35	7	0.9	4	2	0.8
North America	66	5-9	HIGH	IPV-only	5	0.05	180	0.35	7	0.98	5	1	0.8
North America	66	10	HIGH	IPV-only	6	0.05	180	0.35	7	0.98	5	1	0.6
South Asia	67	1	LOW	OPV-only	12	0.3	180	0.3	1	0.9	4	2	0.3
South Asia	67	2-5	LOW	OPV-only	12	0.3	180	0.3	1	0.9	4	1	0.3
South Asia	67	6-10	LOW	OPV-only	12	0.3	180	0.3	1	0.98	5	1	0.3
South Asia	68	1	LOW	OPV-only	13	0.1	180	0.3	1	0.6	4	2	0.3
South Asia	68	2-7	LOW	OPV-only	13	0.1	180	0.3	1	0.9	4	1	0.3
South Asia	68	8-10	LOW	OPV-only	13	0.1	180	0.3	1	0.98	5	1	0.3
South Asia	69	1-3	LMI	OPV-only	8	0.15	180	0.4	4	0.9	4	2	0.3
South Asia	69	4-10	LMI	OPV-only	8	0.15	180	0.4	4	0.98	5	1	0.3
South Asia	70	1-10	UMI	OPV-only	7	0.1	240	0.35	5	0.98	5	1	0.6
South Asia	71	1-2	UMI	IPV/OPV	7	0.15	0	0.35	5	0.6	5	2	0.6
South Asia	71	3-5	UMI	IPV/OPV	7	0.15	0	0.35	5	0.9	5	1	0.6
South Asia	71	6-10	UMI	IPV/OPV	7	0.15	0	0.35	5	0.98	5	1	0.6

Model input symbols:[5, 12] R_0 , average annual basic reproduction number for WPV 1; α , seasonal amplitude of R_0 , defined as the “proportional change in R_0 due to seasonality” [5, p. 717]; pd , peak day of R_0 ; κ , strength of preferential mixing between age groups, defined as the “proportion of contacts reserved for individuals within the same mixing age group”[5, p. 717]; trl , OPV take rate level (see Table A2); POL3, RI coverage with 3 or more non-

birth doses; sil , SIA impact level (see Table A2) dt , detection threshold, defined as the cumulative incidence of paralytic polio cases per 10 million people required to detect an outbreak due to a poliovirus introduction in a subpopulation [5], p^{oro} , proportion of transmissions via oropharyngeal route

Acronyms: HIGH, high-income; IPV, inactivated poliovirus vaccine; LMI, lower middle-income; LOW, low-income; OPV, oral poliovirus vaccine; UMI, upper middle-income

Footnote: ^a Assumed to increase to SIA impact level 4 in 2010 as a result of intensification of efforts to interrupt wild poliovirus transmission in these reservoirs.

Table A2: SIA impact and OPV take rate levels used in Table A1, generalized from situation-specific values used in prior work[5, 12, 6, 7]

Take rate level	Average per-dose take rate for:							
	tOPV1	tOPV2	tOPV3	mOPV1	mOPV2	mOPV3	bOPV1	bOPV3
1	0.35	0.60	0.27	0.45	0.60	0.45	0.42	0.42
2	0.40	0.65	0.32	0.52	0.65	0.52	0.50	0.50
3	0.45	0.70	0.35	0.60	0.70	0.60	0.54	0.54
4	0.50	0.72	0.40	0.70	0.65	0.65	0.60	0.60
5	0.55	0.73	0.45	0.80	0.85	0.75	0.70	0.70
6	0.60	0.74	0.50	0.85	0.90	0.80	0.75	0.75
7	0.65	0.75	0.55	0.90	0.95	0.85	0.80	0.80
8	0.70	0.80	0.60	0.95	0.98	0.90	0.85	0.85
SIA impact level	True coverage				Repeated missed probability ^a			
1	0.15				0.95			
2	0.35				0.95			
3	0.50				0.80			
4	0.80				0.70			
5	0.95				0.50			

Acronyms: bOPV(1,3), bivalent oral poliovirus vaccine (serotype 1 and serotype 3 component, respectively); mOPV(1,2,3), monovalent oral poliovirus vaccine (containing serotype 1, serotype 2, and serotype 3, respectively); SIA, supplemental immunization activity; tOPV(1,2,3), trivalent oral poliovirus vaccine (serotype 1, serotype 2, and serotype 3 component, respectively)

Footnote: ^a Defined as the proportion of targeted individuals missed by an SIA who were targeted and missed by the previous SIA[6]

Table A3: Assumptions for planned, preventive SIAs (pSIAs) in OPV-using blocks

Time period	RI coverage (POL3)	SIA schedule showing: vaccine (day(s) of year)
Before elimination of all WPVs in block^a		
Year < -3 (before bOPV introduction)	Any	tOPV (0, 30, 60, ..., 360)
-3 ≤ year < 2 (before tOPV intensification)	0.05 or 0.1	tOPV (0, 240); bOPV (30, 60, 90, 120, 150, 180, 210, 270, 300, 330)
	0.3	tOPV (0, 30); bOPV(60, 90,...,360)
	0.6 (R ₀ ≤ 10)	tOPV (0); bOPV(30, 60, 90,...,360)
	0.6 (R ₀ > 10)	tOPV (0, 30); bOPV(60, 90,...,360)
	0.9 or 0.98	tOPV (0, 30, 60,...,330)
2 ≤ year < OPV2 cessation time (after tOPV intensification)	0.05 or 0.1	tOPV (0, 30, 270, 300); bOPV (60, 90, 120, 150, 180, 210, 330)
	0.3	tOPV (0, 30, 270); bOPV(60, 90, 120, 150, 180, 210, 300, 330)
	0.6 (R ₀ ≤ 10)	tOPV (0); bOPV(30, 60, 90,...,360)
	0.6 (R ₀ > 10)	tOPV (0, 30, 270); bOPV(60, 90, 120, 150, 180, 210, 300, 330)
	0.9 or 0.98	tOPV (0, 30, 60,...,330)
OPV2 cessation time ≤ year < OPV13 cessation time (after OPV2 cessation)	Any	bOPV (0, 30, 60, ..., 360)
After elimination of all WPVs in block		
Year < -3 (before bOPV introduction)	0.05 or 0.1	tOPV (0, 40, 80, 140, 240, 300)
	0.3	tOPV (0, 40, 80, 140, 240)
	0.6 (R ₀ ≤ 10)	tOPV (0, 60, 120)
	0.6 (R ₀ > 10)	tOPV (0, 40, 80, 140, 240)
	0.9	tOPV (0)
	0.98 (R ₀ ≤ 10)	No SIAs
	0.98 (R ₀ > 10)	tOPV (0)
-3 ≤ year < 2 (before tOPV intensification)	0.05 or 0.1	tOPV (0, 40); bOPV (80, 140, 240, 300)
	0.3	tOPV (0, 40); bOPV (80, 140, 240)
	0.6 (R ₀ ≤ 10)	tOPV (0); bOPV (60, 120)
	0.6 (R ₀ > 10)	tOPV (0, 40); bOPV(80, 140, 240)
	0.9	tOPV (0)
	0.98 (R ₀ ≤ 10)	No SIAs
	0.98 (R ₀ > 10)	tOPV (0)
2 ≤ year < OPV2 cessation time (after tOPV intensification)	0.05 or 0.1	tOPV (0, 40, 80, 300); bOPV (140, 240)
	0.3	tOPV (0, 40, 80); bOPV (140, 240)
	0.6 (R ₀ ≤ 10)	tOPV (0, 60); bOPV (120)
	0.6 (R ₀ > 10)	tOPV (0, 40, 80); bOPV (140, 240)
	0.9	tOPV (0)
	0.98 (R ₀ ≤ 10)	No SIAs
	0.98 (R ₀ > 10)	tOPV (0)
OPV2 cessation time ≤ year < OPV13 cessation time (after OPV2 cessation)	0.05 or 0.1	bOPV (0, 40, 80, 140, 240, 300)
	0.3	bOPV (0, 40, 80, 140, 240)
	0.6 (R ₀ ≤ 10)	bOPV (0, 60, 120)
	0.6 (R ₀ > 10)	bOPV (0, 40, 80, 140, 240)
	0.9	bOPV (0)
	0.98 (R ₀ ≤ 10)	No SIAs
	0.98 (R ₀ > 10)	bOPV (0)

Acronyms: bOPV, bivalent OPV; OPV, oral poliovirus vaccine; OPV13, serotype 1- and 3-containing OPV; OPV2, serotype-2-containing OPV; POL3, coverage with 3 or more non-birth RI doses; RI, routine immunization; SIA, supplemental immunization activity; tOPV, trivalent OPV; WPV, wild poliovirus

^a Annual frequency of SIAs starts at 2 and increase by one each year until all WPV eliminated from the block

Table A4: Characteristics of stochastic iterations that led to OPV restart

Year OPV restarts	Triggering event(s)								
	Time	Type of event	Sero -type	Block # (sub- pop #)	Block with conditions like	Income level	Polio vaccine at T ₀	R ₀	POL3
OPV restarted with IPV5, IPV10 (n=2)									
2051	2049.6	Other release	3	10 (5)	W-Africa ^a	LMI	OPV-only	8	0.9
2043	2021.8 2024.1	iVDPV (CVID) iVDPV (new)	1	32 (0) 32 (9)	N Pak/Afg	LOW	OPV-only OPV-only	11	0.1 0.6
OPV restarted with IPV through T_{end} (n=10)									
2041	2037.7	sIPV site release	1	16 (3)	India	LMI	OPV-only	11	0.6
2051	2049.6	Other release	3	10 (5)	W-Africa ^a	LMI	OPV-only	8	0.9
2040	2037.1	sIPV site release	2	6 (8)	Egypt	LMI	OPV-only	9	0.9
2046	2043.5	sIPV site release	2	54 (1)	India	LMI	OPV-only	11	0.6
2045	2041.8	sIPV site release	1	53 (1)	India	LMI	OPV-only	11	0.6
2052	2049.9	sIPV site release	2	57 (5)	India	LMI	OPV-only	10	0.9
2041	2039.2	sIPV site release	2	6 (5)	Egypt	LMI	OPV-only	9	0.9
2053	2050.8	sIPV site release	2	6 (8)	Egypt	LMI	OPV-only	9	0.9
2043	2021.8 2024.1	iVDPV (CVID) iVDPV (new)	1	32 (0) 32 (9)	N Pak/Afg	LOW	OPV-only OPV-only	11	0.1 0.6
2047	2043.2	sIPV site release	2	50 (9)	India	LMI	OPV-only	11	0.9
OPV restarted with no IPV (n=6)									
2051	2049.6	Other release	3	10 (5)	W-Africa ^a	LMI	OPV-only	8	0.9
2030	2020.0 2028.0	iVDPV (CVID) iVDPV (new)	1	33 (8)	Eurasia	LMI	OPV-only	8	0.98
2044	2020.6	iVDPV (CVID)	2	7 (8)	Africa- Arabia	LMI	OPV-only	7	0.9
2036	2019.7	iVDPV (oPID)	1	46 (2)	India	LMI	OPV-only	13	0.6
2041	2021.4	iVDPV (CVID)	3	3 (9)	E-Africa ^b	LOW	OPV-only	10	0.98
2034	2020.8	iVDPV (CVID)	2	19 (8)	China	UMI	OPV-only	6	0.98

Acronyms (see Table 1 for policy abbreviations): CVID, common variable immunodeficiency diseases; iVDPV, immunodeficiency-associated vaccine-derived poliovirus; LMI, lower middle-income; LOW, low-income; N Pak/Afg, North Pakistan and Afghanistan; noPID, other primary immunodeficiency disease (i.e., not CVID); OPV, oral poliovirus vaccine; R₀, average annual basic reproduction number for serotype 1 wild poliovirus, sIPV, inactivated poliovirus vaccine produced from Sabin seed strains; T₀, start of analytical time horizon (i.e., first day of 2013); UMI, upper middle-income

Footnotes: ^a Not including Nigeria; ^be.g., Kenya

Figure A1: Probability of effective introduction function (PEF)

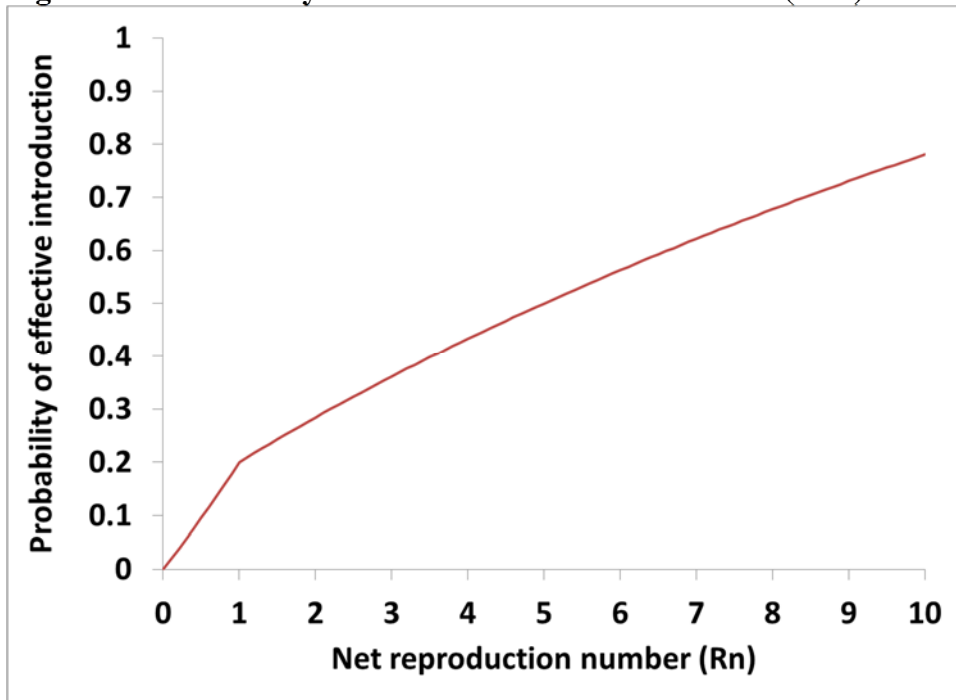
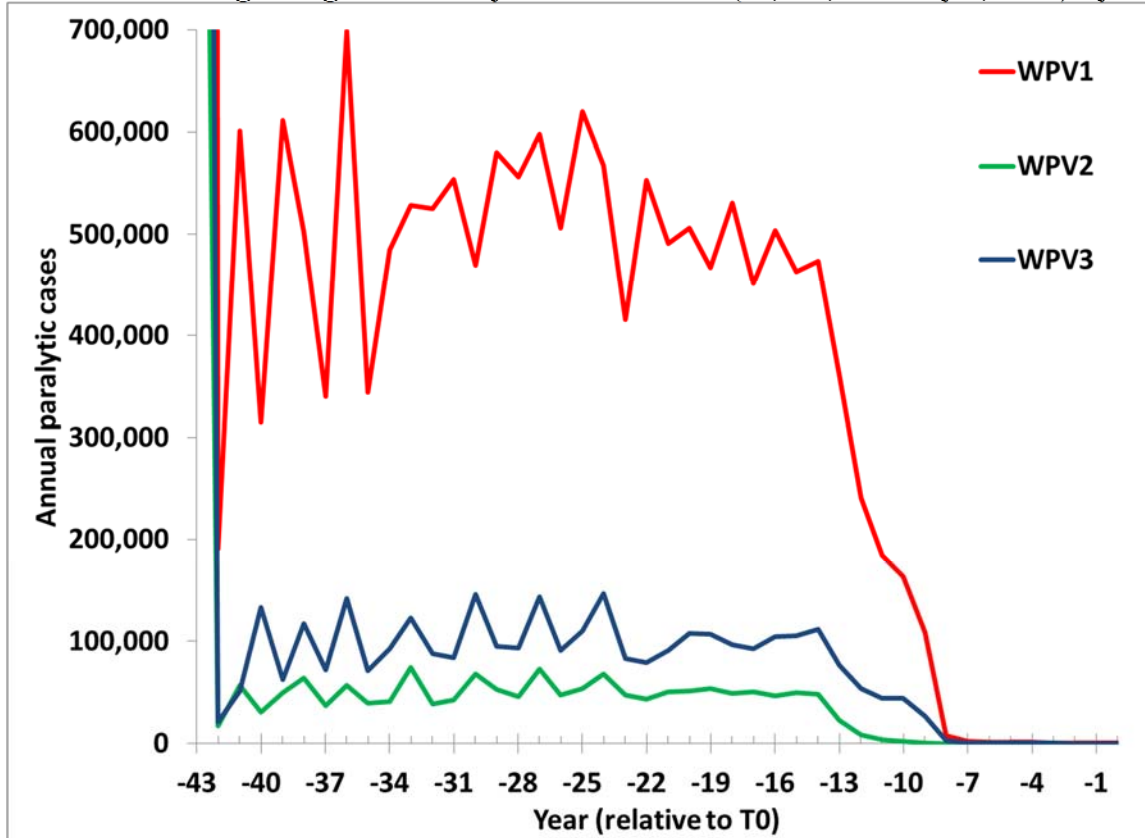


Figure A2: Annual wild poliovirus (WPV) incidence during the 43-year burn-in period relative to the beginning of the analytic time horizon (T_0 , i.e., January 1, 2013) by serotype.



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