Supplemental Material: Vaccination may be economically and epidemiologically advantageous over frequent screening for gonorrhea prevention

January 4, 2024

S1 Supplemental Material

S1.1 Model

Individuals were either susceptible, S, or infected, I. Additionally, infected persons can be either have symptoms or not (A/S). All susceptible individuals are either male or female (M/F), high or low-activity (H/L), enrolled in screening, vaccinated, both, or neither (X/V/XV/Z). For example, the term I_{MLVA} indicates infected men with low-activity who are vaccinated, and not symptomatic. The symbol $\cdot$ indicates the sum over the all partitions in that dimension, e.g. $S_{F\cdot\cdot}$ gives the number of susceptible women.

Individuals mix under the preferred mixing formulation where some contacts are reserved for an activity-level specific mixing site (e.g. where only high-activity persons seek contacts) and the remainder are made at a common site where high and low-activity persons mix. Mixing at the common site is governed by proportional mixing. That is, some fraction of contact are reserved only for persons of the same activity level, while the remaining contacts are made proportional to the high and low activity levels. This formulation allows for enrichment of contact between activity-levels than would occur by chance.

There is no mortality induced by the disease and the removal rate is constant for all states such that the population size is fixed and there is always exactly 50% men and 50% women. Likewise, there is movement between high and low-activity states but (assuming the initial conditions are the disease-free equilibrium) the proportion of the population that is high-activity is constant assuming constant parameter values.

Some fraction of persons that become infected will show symptoms. Those persons will seek out screening and treatment at an elevated rate. Both susceptible and asymptomatically infected men and women will seek out 'background' screening at a given rate, which will result in treatment for those who are infected.

S1.1.1 Controls

We consider 8 total controls in the full system (Table S1). This means that $u_{xFH} = u_{xFL}$, indicated as u_{xF}, where $x \in [1 \ldots 4]$. All of the controls are proportions, i.e. they all represent what proportion of some existing flow go into a given control state, and therefore they should be in $[0, 1]$.

Control	Sex	Enrollment modality	Type
u_{1F}	F	symptomatic visit	programmatic screening
u_{2F}	F	background screening visit	programmatic screening
u_{3F}	F	symptomatic visit	vaccination
u_{4F}	F	background screening visit	vaccination
u_{1M}	M	symptomatic visit	programmatic screening
u_{2M}	M	background screening visit	programmatic screening
u_{3M}	M	symptomatic visit	vaccination
u_{4M}	M	background screening visit	vaccination

Table S1: Definitions of the 8 controls to consider.

S1.1.2 Model Equations

$$
\begin{aligned}
\dot{S}_{MLZ} =& \, 0.5\alpha\pi_L - (\zeta_{ML} + \gamma_H + \mu + u_{2M}\gamma_{MB} + u_{4M}\gamma_{MB} - u_{2M}u_{4M}\gamma_{MB})S_{MLZ} + \delta_X S_{MLX} + \delta_V S_{MLV} \\
&+ ((1-u_{1M})(1-u_{3M})\gamma_{MST} + (1-u_{2M})(1-u_{4M})\gamma_{MB} + \gamma_{MI})I_{MLZS} \\
&+ ((1-u_{2M})(1-u_{4M})\gamma_{MB} + \gamma_{MI})I_{MLZA} + \gamma_L S_{MHZ} \\
\dot{S}_{MLX} =& - (\zeta_{ML} + \gamma_H + \mu + \delta_X + u_{4M}\gamma_{AT})S_{MLX} + (u_{2M} - u_{2M}u_{4M})\gamma_{MB}S_{MLZ} + \delta_V S_{MLXV} \\
&+ ((u_{1M} - u_{1M}u_{3M})\gamma_{MST} + (u_{2M} - u_{2M}u_{4M})\gamma_{MB})I_{MLZS} + (u_{2M} - u_{2M}u_{4M})\gamma_{MB}I_{MLZA} \\
&+ ((1-u_{4M})\gamma_{AT}I_{MLXS} + (1-u_{3M})\gamma_{MST} + \gamma_{MI}) + ((1-u_{4M})\gamma_{AT} + \gamma_{MI})I_{MLXA} + \gamma_L S_{MHX} \\
\dot{S}_{MLV} =& - (\zeta_{ML}(1-\psi_V) + \gamma_H + \mu + \delta_V + u_{2M}\gamma_{MB})S_{MLV} + (u_{4M} - u_{2M}u_{4M})\gamma_{MB}S_{MLZ} + \delta_X S_{MLXV} \\
&+ ((u_{3M} - u_{1M}u_{3M})\gamma_{MST} + (u_{4M} - u_{2M}u_{4M})\gamma_{MB})I_{MLZS} + (u_{4M} - u_{2M}u_{4M})\gamma_{MB}I_{MLZA} \\
&+ ((1-u_{1M})\gamma_{MST} + \gamma_{MI} + (1-u_{2M})\gamma_{MB})I_{MLVS} + \gamma_{MI} + (1-u_{2M})\gamma_{MB}I_{MLVA} + \gamma_L S_{MHV} \\
\dot{S}_{MLXV} =& - (\zeta_{ML}(1-\psi_V) + \gamma_H + \mu + \delta_V + \delta_X)S_{MLXV} + (u_{2M}u_{4M})\gamma_{MB}S_{MLZ} + u_{4M}\gamma_{AT}S_{MLX} \\
&+ u_{2M}\gamma_{MB}S_{MLV} + (u_{1M}u_{3M}\gamma_{MST} + u_{2M}u_{4M}\gamma_{MB})I_{MLZS} + u_{2M}u_{4M}\gamma_{MB}I_{MLZA} \\
&+ (u_{3M}\gamma_{MST} + u_{4M}\gamma_{AT})I_{MLXS} + u_{4M}\gamma_{AT}I_{MLXA} + (u_{1M}\gamma_{MST} + u_{2M}\gamma_{MB})I_{MLVS} \\
&+ u_{2M}\gamma_{MB}I_{MLVA} + (\gamma_{AT} + \gamma_{MST} + \gamma_{MI})I_{MLXVS} + (\gamma_{AT} + \gamma_{MI})I_{MLXVA} + \gamma_L S_{MHXV} \\
\\
\dot{I}_{MLZS} =& - (\gamma_H + \mu + \gamma_{MST} + \gamma_{MB} + \gamma_{MI})I_{MLZS} + \zeta_{ML}(1-\pi_{MA})S_{MLZ} + \delta_X I_{MLXS} \\
&+ \delta_V I_{MLVS} + \gamma_L I_{MHZS} \\
\dot{I}_{MLZA} =& - (\gamma_H + \mu + \gamma_{MB} + \gamma_{MI})I_{MLZA} + \zeta_{ML}\pi_{MA}S_{MLZ} + \delta_X I_{MLXA} + \delta_V I_{MLVA} + \gamma_L I_{MHZA} \\
\dot{I}_{MLXS} =& - (\gamma_H + \mu + \gamma_{AT} + \gamma_{MST} + \gamma_{MI} + \delta_X)I_{MLXS} + \zeta_{ML}(1-\pi_{MA})S_{MLX} + \delta_V I_{MLXVS} + \gamma_L I_{MHXS} \\
\dot{I}_{MLXA} =& - (\gamma_H + \mu + \gamma_{AT} + \gamma_{MI} + \delta_X)I_{MLXA} + \zeta_{ML}\pi_{MA}S_{MLX} + \delta_V I_{MLXVA} + \gamma_L I_{MHXA} \\
\dot{I}_{MLVS} =& - (\gamma_H + \mu + \gamma_{MST} + \gamma_{MI} + \gamma_{MB} + \delta_V)I_{MLVS} + \zeta_{ML}(1-\psi_V)(1-\pi_{MA})S_{MLV} \\
&+ \delta_X I_{MLXVS} + \gamma_L I_{MHVS} \\
\dot{I}_{MLVA} =& - (\gamma_H + \mu + \gamma_{MI} + \gamma_{MB} + \delta_V)I_{MLVA} + \zeta_{ML}(1-\psi_V)\pi_{MA}S_{MLV} + \delta_X I_{MLXVA} + \gamma_L I_{MHVA} \\
\dot{I}_{MLXVS} =& - (\gamma_H + \mu + \gamma_{AT} + \gamma_{MST} + \gamma_{MI} + \delta_V + \delta_X)I_{MLXVS} + \zeta_{ML}(1-\psi_V)(1-\pi_{MA})S_{MLXV} \\
&+ \gamma_L I_{MHXVS} \\
\dot{I}_{MLXVA} =& - (\gamma_H + \mu + \gamma_{AT} + \gamma_{MI} + \delta_V + \delta_X)I_{MLXVA} + \zeta_{ML}(1-\psi_V)\pi_{MA}S_{MLXV} + \gamma_L I_{MHXVA}
\end{aligned} \tag{S1}
$$

$$
\begin{aligned}
\dot{S}_{MHZ} =& 0.5\alpha\pi_H - (\zeta_{MH} + \gamma_L + \mu + u_{2M}\gamma_{MB} + u_{4M}\gamma_{MB} - u_{2M}u_{4M}\gamma_{MB})S_{MHZ} + \delta_X S_{MHX} + \delta_V S_{MHV} \\
&+ ((1-u_{1M})(1-u_{3M})\gamma_{MST} + (1-u_{2M})(1-u_{4M})\gamma_{MB} + \gamma_{MI})I_{MHZS} \\
&+ ((1-u_{2M})(1-u_{4M})\gamma_{MB} + \gamma_{MI})I_{MHZA} + \gamma_H S_{MLZ} \\
\dot{S}_{MHX} =& -(\zeta_{MH} + \gamma_L + \mu + \delta_X + u_{4M}\gamma_{AT})S_{MHX} + (u_{2M} - u_{2M}u_{4M})\gamma_{MB}S_{MHZ} + \delta_V S_{MHXV} \\
&+ ((u_{1M} - u_{1M}u_{3M})\gamma_{MST} + (u_{2M} - u_{2M}u_{4M})\gamma_{MB})I_{MHZS} + (u_{2M} - u_{2M}u_{4M})\gamma_{MB}I_{MHZA} \\
&+ ((1-u_{4M})\gamma_{AT}I_{MHXS} + (1-u_{3M})\gamma_{MST} + \gamma_{MI}) + ((1-u_{4M})\gamma_{AT} + \gamma_{MI})I_{MHXA} + \gamma_H S_{MLX} \\
\dot{S}_{MHV} =& -(\zeta_{MH}(1-\psi_V) + \gamma_L + \mu + \delta_V + u_{2M}\gamma_{MB})S_{MHV} + (u_{4M} - u_{2M}u_{4M})\gamma_{MB}S_{MHZ} + \delta_X S_{MHXV} \\
&+ ((u_{3M} - u_{1M}u_{3M})\gamma_{MST} + (u_{4M} - u_{2M}u_{4M})\gamma_{MB})I_{MHZS} + (u_{4M} - u_{2M}u_{4M})\gamma_{MB}I_{MHZA} \\
&+ ((1-u_{1M})\gamma_{MST} + \gamma_{MI} + (1-u_{2M})\gamma_{MB})I_{MHVS} + \gamma_{MI} + (1-u_{2M})\gamma_{MB}I_{MHVA} + \gamma_H S_{MLV} \\
\dot{S}_{MHXV} =& -(\zeta_{MH}(1-\psi_V) + \gamma_L + \mu + \delta_V + \delta_X)S_{MHXV} + (u_{2M}u_{4M})\gamma_{MB}S_{MHZ} + u_{4M}\gamma_{AT}S_{MHX} \\
&+ u_{2M}\gamma_{MB}S_{MHV} + (u_{1M}u_{3M}\gamma_{MST} + u_{2M}u_{4M}\gamma_{MB})I_{MHZS} + u_{2M}u_{4M}\gamma_{MB}I_{MHZA} \\
&+ (u_{3M}\gamma_{MST} + u_{4M}\gamma_{AT})I_{MHXS} + u_{4M}\gamma_{AT}I_{MHXA} + (u_{1M}\gamma_{MST} + u_{2M}\gamma_{MB})I_{MHVS} \\
&+ u_{2M}\gamma_{MB}I_{MHVA} + (\gamma_{AT} + \gamma_{MST} + \gamma_{MI})I_{MHXVS} + (\gamma_{AT} + \gamma_{MI})I_{MHXVA} + \gamma_H S_{MLXV} \\
\\
\dot{I}_{MHZS} =& -(\gamma_L + \mu + \gamma_{MST} + \gamma_{MB} + \gamma_{MI})I_{MHZS} + \zeta_{MH}(1-\pi_{MA})S_{MHZ} + \delta_X I_{MHXS} + \delta_V I_{MHVS} \\
&+ \gamma_H I_{MLZS} \\
\dot{I}_{MHZA} =& -(\gamma_L + \mu + \gamma_{MB} + \gamma_{MI})I_{MHZA} + \zeta_{MH}\pi_{MA}S_{MHZ} + \delta_X I_{MHXA} + \delta_V I_{MHVA} + \gamma_H I_{MLZA} \\
\dot{I}_{MHXS} =& -(\gamma_L + \mu + \gamma_{AT} + \gamma_{MST} + \gamma_{MI} + \delta_X)I_{MHXS} + \zeta_{MH}(1-\pi_{MA})S_{MHX} + \delta_V I_{MHXVS} + \gamma_H I_{MLXS} \\
\dot{I}_{MHXA} =& -(\gamma_L + \mu + \gamma_{AT} + \gamma_{MI} + \delta_X)I_{MHXA} + \zeta_{MH}\pi_{MA}S_{MHX} + \delta_V I_{MHXVA} + \gamma_H I_{MLXA} \\
\dot{I}_{MHVS} =& -(\gamma_L + \mu + \gamma_{MST} + \gamma_{MI} + \gamma_{MB} + \delta_V)I_{MHVS} + \zeta_{MH}(1-\psi_V)(1-\pi_{MA})S_{MHV} \\
&+ \delta_X I_{MHXVS} + \gamma_H I_{MLVS} \\
\dot{I}_{MHVA} =& -(\gamma_L + \mu + \gamma_{MI} + \gamma_{MB} + \delta_V)I_{MHVA} + \zeta_{MH}(1-\psi_V)\pi_{MA}S_{MHV} + \delta_X I_{MHXVA} + \gamma_H I_{MLVA} \\
\dot{I}_{MHXVS} =& -(\gamma_L + \mu + \gamma_{AT} + \gamma_{MST} + \gamma_{MI} + \delta_V + \delta_X)I_{MHXVS} + \zeta_{MH}(1-\psi_V)(1-\pi_{MA})S_{MHXV} \\
&+ \gamma_H I_{MLXVS} \\
\dot{I}_{MHXVA} =& -(\gamma_L + \mu + \gamma_{AT} + \gamma_{MI} + \delta_V + \delta_X)I_{MHXVA} + \zeta_{MH}(1-\psi_V)\pi_{MA}S_{MHXV} + \gamma_H I_{MLXVA}
\end{aligned}
\tag{S2}
$$

$$
\begin{aligned}
\dot{S}_{FLZ} =& 0.5\alpha\pi_L - (\zeta_{FL} + \gamma_H + \mu + u_{2F}\gamma_{FB} + u_{4F}\gamma_{FB} - u_{2F}u_{4F}\gamma_{FB})S_{FLZ} + \delta_X S_{FLX} + \delta_V S_{FLV} \\
&+ ((1 - u_{1F})(1 - u_{3F})\gamma_{FST} + (1 - u_{2F})(1 - u_{4F})\gamma_{FB} + \gamma_{FI})I_{FLZS} \\
&+ ((1 - u_{2F})(1 - u_{4F})\gamma_{FB} + \gamma_{FI})I_{FLZA} + \gamma_L S_{FHZ} \\
\dot{S}_{FLX} =& - (\zeta_{FL} + \gamma_H + \mu + \delta_X + u_{4F}\gamma_{AT})S_{FLX} + (u_{2F} - u_{2F}u_{4F})\gamma_{FB}S_{FLZ} + \delta_V S_{FLXV} \\
&+ ((u_{1F} - u_{1F}u_{3F})\gamma_{FST} + (u_{2F} - u_{2F}u_{4F})\gamma_{FB})I_{FLZS} + (u_{2F} - u_{2F}u_{4F})\gamma_{FB}I_{FLZA} \\
&+ ((1 - u_{4F})\gamma_{AT}I_{FLXS} + (1 - u_{3F})\gamma_{FST} + \gamma_{FI}) + ((1 - u_{4F})\gamma_{AT} + \gamma_{FI})I_{FLXA} + \gamma_L S_{FHX} \\
\dot{S}_{FLV} =& - (\zeta_{FL}(1 - \psi_V) + \gamma_H + \mu + \delta_V + u_{2F}\gamma_{FB})S_{FLV} + (u_{4F} - u_{2F}u_{4F})\gamma_{FB}S_{FLZ} + \delta_X S_{FLXV} \\
&+ ((u_{3F} - u_{1F}u_{3F})\gamma_{FST} + (u_{4F} - u_{2F}u_{4F})\gamma_{FB})I_{FLZS} + (u_{4F} - u_{2F}u_{4F})\gamma_{FB}I_{FLZA} \\
&+ ((1 - u_{1F})\gamma_{FST} + \gamma_{FI} + (1 - u_{2F})\gamma_{FB})I_{FLVS} + \gamma_{FI} + (1 - u_{2F})\gamma_{FB}I_{FLVA} + \gamma_L S_{FHV} \\
\dot{S}_{FLXV} =& - (\zeta_{FL}(1 - \psi_V) + \gamma_H + \mu + \delta_V + \delta_X)S_{FLXV} + (u_{2F}u_{4F})\gamma_{FB}S_{FLZ} + u_{4F}\gamma_{AT}S_{FLX} \\
&+ u_{2F}\gamma_{FB}S_{FLV} + (u_{1F}u_{3F}\gamma_{FST} + u_{2F}u_{4F}\gamma_{FB})I_{FLZS} + u_{2F}u_{4F}\gamma_{FB}I_{FLZA} \\
&+ (u_{3F}\gamma_{FST} + u_{4F}\gamma_{AT})I_{FLXS} + u_{4F}\gamma_{AT}I_{FLXA} + (u_{1F}\gamma_{FST} + u_{2F}\gamma_{FB})I_{FLVS} + u_{2F}\gamma_{FB}I_{FLVA} \\
&+ (\gamma_{AT} + \gamma_{FST} + \gamma_{FI})I_{FLXVS} + (\gamma_{AT} + \gamma_{FI})I_{FLXVA} + \gamma_L S_{FHXV} \\
\\
\dot{I}_{FLZS} =& - (\gamma_H + \mu + \gamma_{FST} + \gamma_{FB} + \gamma_{FI})I_{FLZS} + \zeta_{FL}(1 - \pi_{FA})S_{FLZ} + \delta_X I_{FLXS} + \delta_V I_{FLVS} + \gamma_L I_{FHZS} \\
\dot{I}_{FLZA} =& - (\gamma_H + \mu + \gamma_{FB} + \gamma_{FI})I_{FLZA} + \zeta_{FL}\pi_{FA}S_{FLZ} + \delta_X I_{FLXA} + \delta_V I_{FLVA} + \gamma_L I_{FHZA} \\
\dot{I}_{FLXS} =& - (\gamma_H + \mu + \gamma_{AT} + \gamma_{FST} + \gamma_{FI} + \delta_X)I_{FLXS} + \zeta_{FL}(1 - \pi_{FA})S_{FLX} + \delta_V I_{FLXVS} + \gamma_L I_{FHXS} \\
\dot{I}_{FLXA} =& - (\gamma_H + \mu + \gamma_{AT} + \gamma_{FI} + \delta_X)I_{FLXA} + \zeta_{FL}\pi_{FA}S_{FLX} + \delta_V I_{FLXVA} + \gamma_L I_{FHXA} \\
\dot{I}_{FLVS} =& - (\gamma_H + \mu + \gamma_{FST} + \gamma_{FI} + \gamma_{FB} + \delta_V)I_{FLVS} + \zeta_{FL}(1 - \psi_V)(1 - \pi_{FA})S_{FLV} + \delta_X I_{FLXVS} + \gamma_L I_{FHVS} \\
\dot{I}_{FLVA} =& - (\gamma_H + \mu + \gamma_{FI} + \gamma_{FB} + \delta_V)I_{FLVA} + \zeta_{FL}(1 - \psi_V)\pi_{FA}S_{FLV} + \delta_X I_{FLXVA} + \gamma_L I_{FHVA} \\
\dot{I}_{FLXVS} =& - (\gamma_H + \mu + \gamma_{AT} + \gamma_{FST} + \gamma_{FI} + \delta_V + \delta_X)I_{FLXVS} + \zeta_{FL}(1 - \psi_V)(1 - \pi_{FA})S_{FLXV} + \gamma_L I_{FHXVS} \\
\dot{I}_{FLXVA} =& - (\gamma_H + \mu + \gamma_{AT} + \gamma_{FI} + \delta_V + \delta_X)I_{FLXVA} + \zeta_{FL}(1 - \psi_V)\pi_{FA}S_{FLXV} + \gamma_L I_{FHXVA}
\end{aligned}
\tag{S3}
$$

$$
\begin{aligned}
\dot{S}_{FHZ} =& 0.5\alpha\pi_H - (\zeta_{FH} + \gamma_L + \mu + u_{2F}\gamma_{FB} + u_{4F}\gamma_{FB} - u_{2F}u_{4F}\gamma_{FB})S_{FHZ} + \delta_X S_{FHX} + \delta_V S_{FHV} \\
&+ ((1-u_{1F})(1-u_{3F})\gamma_{FST} + (1-u_{2F})(1-u_{4F})\gamma_{FB} + \gamma_{FI})I_{FHZS} \\
&+ ((1-u_{2F})(1-u_{4F})\gamma_{FB} + \gamma_{FI})I_{FHZA} + \gamma_H S_{FLZ} \\
\dot{S}_{FHX} =& -(\zeta_{FH} + \gamma_L + \mu + \delta_X + u_{4F}\gamma_{AT})S_{FHX} + (u_{2F} - u_{2F}u_{4F})\gamma_{FB}S_{FHZ} + \delta_V S_{FHXV} \\
&+ ((u_{1F} - u_{1F}u_{3F})\gamma_{FST} + (u_{2F} - u_{2F}u_{4F})\gamma_{FB})I_{FHZS} + (u_{2F} - u_{2F}u_{4F})\gamma_{FB}I_{FHZA} \\
&+ ((1-u_{4F})\gamma_{AT}I_{FHXS} + (1-u_{3F})\gamma_{FST} + \gamma_{FI}) + ((1-u_{4F})\gamma_{AT} + \gamma_{FI})I_{FHXA} + \gamma_H S_{FLX} \\
\dot{S}_{FHV} =& -(\zeta_{FH}(1-\psi_V) + \gamma_L + \mu + \delta_V + u_{2F}\gamma_{FB})S_{FHV} + (u_{4F} - u_{2F}u_{4F})\gamma_{FB}S_{FHZ} + \delta_X S_{FHXV} \\
&+ ((u_{3F} - u_{1F}u_{3F})\gamma_{FST} + (u_{4F} - u_{2F}u_{4F})\gamma_{FB})I_{FHZS} + (u_{4F} - u_{2F}u_{4F})\gamma_{FB}I_{FHZA} \\
&+ ((1-u_{1F})\gamma_{FST} + \gamma_{FI} + (1-u_{2F})\gamma_{FB})I_{FHVS} + \gamma_{FI} + (1-u_{2F})\gamma_{FB}I_{FHVA} + \gamma_H S_{FLV} \\
\dot{S}_{FHXV} =& -(\zeta_{FH}(1-\psi_V) + \gamma_L + \mu + \delta_V + \delta_X)S_{FHXV} + (u_{2F}u_{4F})\gamma_{FB}S_{FHZ} + u_{4F}\gamma_{AT}S_{FHX} \\
&+ u_{2F}\gamma_{FB}S_{FHV} + (u_{1F}u_{3F}\gamma_{FST} + u_{2F}u_{4F}\gamma_{FB})I_{FHZS} + u_{2F}u_{4F}\gamma_{FB}I_{FHZA} \\
&+ (u_{3F}\gamma_{FST} + u_{4F}\gamma_{AT})I_{FHXS} + u_{4F}\gamma_{AT}I_{FHXA} + (u_{1F}\gamma_{FST} + u_{2F}\gamma_{FB})I_{FHVS} \\
&+ u_{2F}\gamma_{FB}I_{FHVA} + (\gamma_{AT} + \gamma_{FST} + \gamma_{FI})I_{FHXVS} + (\gamma_{AT} + \gamma_{FI})I_{FHXVA} + \gamma_H S_{FLXV} \\
\\
\dot{I}_{FHZS} =& -(\gamma_L + \mu + \gamma_{FST} + \gamma_{FB} + \gamma_{FI})I_{FHZS} + \zeta_{FH}(1-\pi_{FA})S_{FHZ} + \delta_X I_{FHXS} + \delta_V I_{FHVS} + \gamma_H I_{FLZS} \\
\dot{I}_{FHZA} =& -(\gamma_L + \mu + \gamma_{FB} + \gamma_{FI})I_{FHZA} + \zeta_{FH}\pi_{FA}S_{FHZ} + \delta_X I_{FHXA} + \delta_V I_{FHVA} + \gamma_H I_{FLZA} \\
\dot{I}_{FHXS} =& -(\gamma_L + \mu + \gamma_{AT} + \gamma_{FST} + \gamma_{FI} + \delta_X)I_{FHXS} + \zeta_{FH}(1-\pi_{FA})S_{FHX} + \delta_V I_{FHXVS} + \gamma_H I_{FLXS} \\
\dot{I}_{FHXA} =& -(\gamma_L + \mu + \gamma_{AT} + \gamma_{FI} + \delta_X)I_{FHXA} + \zeta_{FH}\pi_{FA}S_{FHX} + \delta_V I_{FHXVA} + \gamma_H I_{FLXA} \\
\dot{I}_{FHVS} =& -(\gamma_L + \mu + \gamma_{FST} + \gamma_{FI} + \gamma_{FB} + \delta_V)I_{FHVS} + \zeta_{FH}(1-\psi_V)(1-\pi_{FA})S_{FHV} + \delta_X I_{FHXVS} + \gamma_H I_{FLVS} \\
\dot{I}_{FHVA} =& -(\gamma_L + \mu + \gamma_{FI} + \gamma_{FB} + \delta_V)I_{FHVA} + \zeta_{FH}(1-\psi_V)\pi_{FA}S_{FHV} + \delta_X I_{FHXVA} + \gamma_H I_{FLVA} \\
\dot{I}_{FHXVS} =& -(\gamma_L + \mu + \gamma_{AT} + \gamma_{FST} + \gamma_{FI} + \delta_V + \delta_X)I_{FHXVS} + \zeta_{FH}(1-\psi_V)(1-\pi_{FA})S_{FHXV} + \gamma_H I_{FLXVS} \\
\dot{I}_{FHXVA} =& -(\gamma_L + \mu + \gamma_{AT} + \gamma_{FI} + \delta_V + \delta_X)I_{FHXVA} + \zeta_{FH}(1-\psi_V)\pi_{FA}S_{FHXV} + \gamma_H I_{FLXVA}
\end{aligned}
\tag{S4}
$$

Derived parameters

To simplify the model equations, we use several derived parameters:

- the entry rate of new high activity level persons, $\alpha_H = (S....I.....)\mu\pi_H$;
- the entry rate of new low activity level persons, $\alpha_L = (S....I.....)\mu(1-\pi_H)$;
- the probability a high-activity man is infected, $\tau_{MH} = \frac{I_{MH\cdots}}{I_{MH\cdots}+S_{MH\cdot\cdot}}$;
- the probability an low-activity man is infected, $\tau_{ML} = \frac{I_{ML\cdots}}{I_{ML\cdots}+S_{ML\cdot\cdot}}$;
- the probability that – given the distribution of contacts between high- and low-activity levels – a randomly chosen man is infected, $\tau_M = \frac{\chi_H\tau_{MH}+\chi_L\tau_{ML}}{\chi_H+\chi_L}$;
- the probability an high-activity woman is infected, $\tau_{FH} = \frac{I_{FH\cdots}}{I_{FH\cdots}+S_{FH\cdot\cdot}}$;
- the probability an low-activity woman is infected, $\tau_{FL} = \frac{I_{FL\cdots}}{I_{FL\cdots}+S_{FL\cdot\cdot}}$;

- the probability that – given the distribution of contacts between high- and low-activity levels – a randomly chosen woman is infected, $\tau_F = \frac{\chi_H \tau_{FH} + \chi_L \tau_{FL}}{\chi_H + \chi_L}$;
- the force of infection for high-activity men, $\zeta_{MH} = \psi \chi_H \beta_F \tau_{FH} + (1-\psi)\chi_H \beta_F \tau_F$;
- the force of infection for high-activity women, $\zeta_{FH} = \psi \chi_H \beta_M \tau_{MH} + (1-\psi)\chi_H \beta_M \tau_M$;
- the force of infection for low-activity men, $\zeta_{ML} = \psi \chi_L \beta_F \tau_{FL} + (1-\psi)\chi_L \beta_F \tau_F$;
- the force of infection for low-activity women, $\zeta_{FL} = \psi \chi_L \beta_M \tau_{ML} + (1-\psi)\chi_L \beta_M \tau_M$.

S1.2 Budget Constraint

ID	Event	Personnel	Test	Medication/ Vaccine	Internal	External	Total
c_1	Background screening, susceptible	92.05	35.09	–	–	127.14	127.14
c_2	Background screening, infected	92.05	35.09	7.57	–	134.71	134.71
c_3	Symptomatic visit	169.57	35.09	7.57	–	212.23	212.23
c_4	Screening enrollment	54.68	–	–	54.68	–	54.68
c_5	Express screening, susceptible	92.05	35.09	–	127.14	–	127.14
c_6	Express screening, infected	92.05	35.09	7.57	134.71	–	134.71
c_7	Vaccination	238.78	–	222.80	461.58	–	461.58

Table S2: Cost associated with the cost function. All values in 2022 US dollars. Only internal costs were considered for the budget constraint

Certain flows in the model have associated costs (Table S2) defined as the integral of product of the total flow and the cost over some period of time. Costs are divided into internal and external components; both values are tracked but only the internal costs are budget constrained. We use the term $c_{\cdot}$ to indicate the 'Internal' cost as in table S2, $X_Y^{(i)}$ to indicate the i^{th} flow from state X_Y,and X_Y to indicate the value of the state variable itself. We also assume that the system is normalized such that it sums to 1 and N is the size of the population.

Thus, for each interval $[i, i+1]$, $i = 0, \ldots, 9$, or $i = 0, \ldots, 14$, depending on the length of the interval, the cost function C^i is computed as the integral

$$\begin{aligned} C_i = N \int_i^{i+1} \sum_{k \in M,F} \Big[& c_4 \cdot (u_{k1}\gamma_{kST}(I_{k\cdot ZS} + I_{k\cdot VS}) + u_{k2}\gamma_{kB}(S_{k\cdot V} + (1-u_{k4})S_{k\cdot Z} + I_{k\cdot Z\cdot} + I_{k\cdot V\cdot})) \\ & + c_5 \cdot \gamma_{kAT} \cdot (S_{k\cdot X} + S_{k\cdot XV}) + c_6 \cdot \gamma_{kAT}(I_{k\cdot X\cdot} + I_{k\cdot XV\cdot}) \\ & + c_7 \cdot (u_{k3}\gamma_{kST}(I_{k\cdot ZS} + I_{k\cdot XS}) + u_{k4}\gamma_{AT}(S_{k\cdot X} + I_{k\cdot X\cdot}) + u_{k4}\gamma_{kB}\left(I_{k\cdot Z\cdot} + (1-u_{k2})S_{k\cdot Z}\right)) \Big] dt \end{aligned}$$

S1.3 Objective Function

The objective function was defined as the cumulative incidence:

$$INC = \min_{U=(u_{M1}\dots,u_{F1}\dots)} \int_0^T \zeta_{\cdot\cdot}(S_{\cdot\cdot Z} + S_{\cdot\cdot X} + (1-\psi_V)(S_{\cdot\cdot V} + S_{\cdot\cdot XV}))dt \tag{S5}$$

S1.4 Numerical Methods

The considered optimization problem can be concisely formulated as follows:

$$\text{minimize } INC = \int_0^T i(X(t))dt \tag{S6a}$$

$$\text{s.t. } \dot{X} = f(X,U) \tag{S6b}$$

$$\text{and } C_i = \int_i^{i+1} b(X(t),U(t))dt \le B_i \quad \forall i = 0,\dots T-1. \tag{S6c}$$

Here, $X \in \mathbb{R}_+^n$ and $U \in \mathbb{R}_+^k$ are the states and the controls, all nonnegative; $T \in \mathbb{N}$ is the length of the optimization interval, in years; $i(X,U)$ and $b(X,U)$ are the instantaneous incidence and cost; B_i are the upper limits on the yearly costs.

The optimization problem (S6) was solved using the direct multiple shooting method. To do so, the whole interval $[0,T]$ was divided into T one-year-long intervals $[i,i+1]$, $i = 0,\dots T-1$. Over each interval, the control variables were assumed to be constant with the values $\bar{U}_i$. Let $\bar{X}_i$ be the initial conditions at the beginning of the ith interval. Then the solution of (S6b) for $X(i) = \bar{X}_i$ and with $U(t) = \bar{U}_i$, $t \in [i, i-1)$, is defined as $\mathcal{X}(i,\bar{X}_i,\bar{U}_i;t)$. While the initial condition $\bar{X}_0$ was fixed and equal to the equilibrium state of the system, the intermediate values $\bar{X}_i$, $i = 1,\dots T-1$ were considered as decision variables, whose values were determined from the so-called *defect constraints*:

$$\mathcal{X}(i,\bar{X}_i,\bar{U}_i;i+1) = \bar{X}_{i+1}, \quad \forall i = 0,\dots T-2.$$

Note that the value of the state at the final time T is not restricted. Thus, the considered problem is classified as the *free end-point* problem.

The total incidence to be minimized was computed as the sum of incidence computed over the one-year-long intervals $[i,i+1]$, $i = 0,\dots,T-1$:

$$I\bar{N}C = \sum_{i=0}^{T-1} \int_i^{i+1} i(\mathcal{X}(i,\bar{X}_i,\bar{U}_i;t),\bar{U}_i)dt,$$

while the respective costs were computed in the same manner:

$$\bar{C}_i = \sum_{i=0}^{T-1} \int_i^{i+1} b(\mathcal{X}(i,\bar{X}_i,\bar{U}_i;t),\bar{U}_i)dt.$$

Hence, the optimization problem (S6) was reformulated as a nonlinear constrained minimization problem

$$\text{minimize } I\bar{N}C = \sum_{i=0}^{T-1} \int_i^{i+1} i(\mathcal{X}(i, \bar{X}_i, \bar{U}_i; t), \bar{U}_i) dt \tag{S7a}$$

$$\text{s.t. } \mathcal{X}(i, \bar{X}_i, \bar{U}_i; i+1) = \bar{X}_{i+1}, \quad i = 0, \ldots T-2 \tag{S7b}$$

$$\text{and } \bar{C}_i = \sum_{i=0}^{T-1} \int_i^{i+1} b(\mathcal{X}(i, \bar{X}_i, \bar{U}_i; t), \bar{U}_i) dt \leq B_i \quad \forall i = 0, \ldots T-1. \tag{S7c}$$

The solution to (S6b) was obtained using a numerical differential equation solver, while the who;e problem (S7) was solved using the sequential quadratic programming method embedded in the Matlab function `fmincon`.

Due to the rough functional landscape the optimization routine often converged to quasi-optimal solutions. To overcome this problem, the optimization routine was run 50 times with random initial guesses. The best 5 results were further used to generate a new set of initial guesses. Finally, the best solution was retained.

S1.5 Figures and Tables

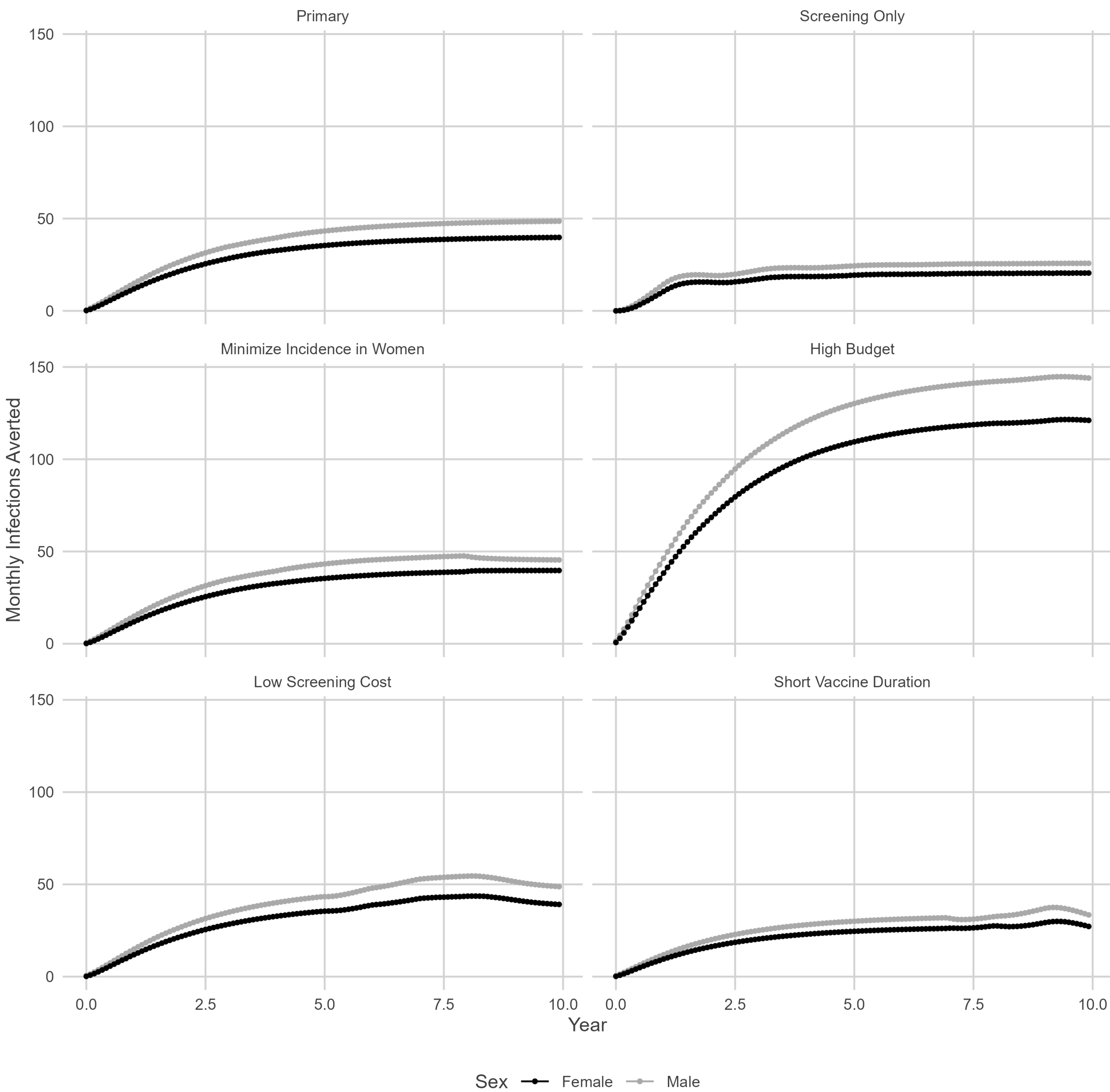

Figure S1: Monthly infections averted, by sex, under selected scenarios

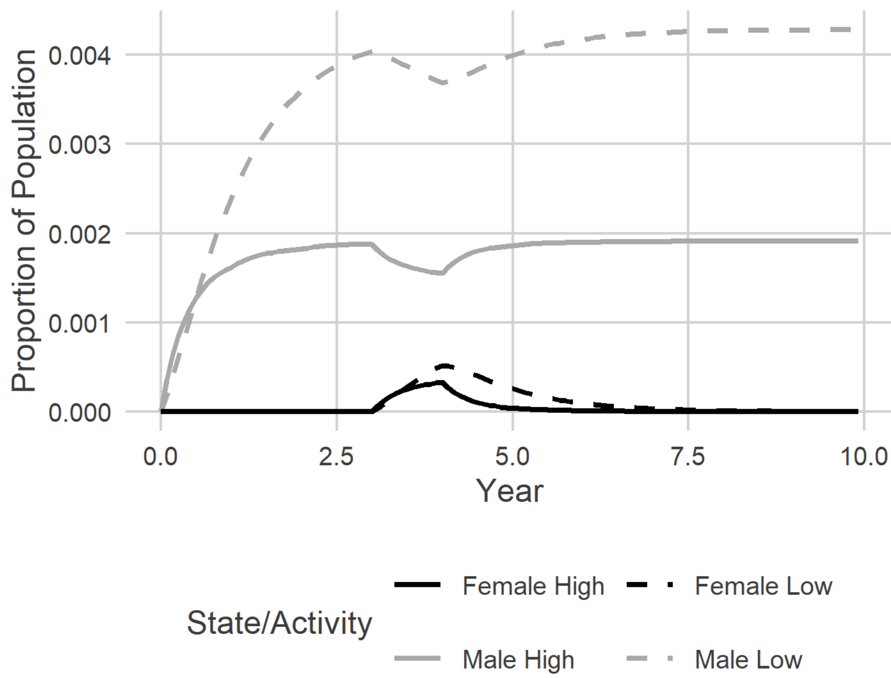

Figure S2: Vaccinated states, by sex and sexual activity type, under primary scenario. States are aggregated over susceptible/infectious categories.

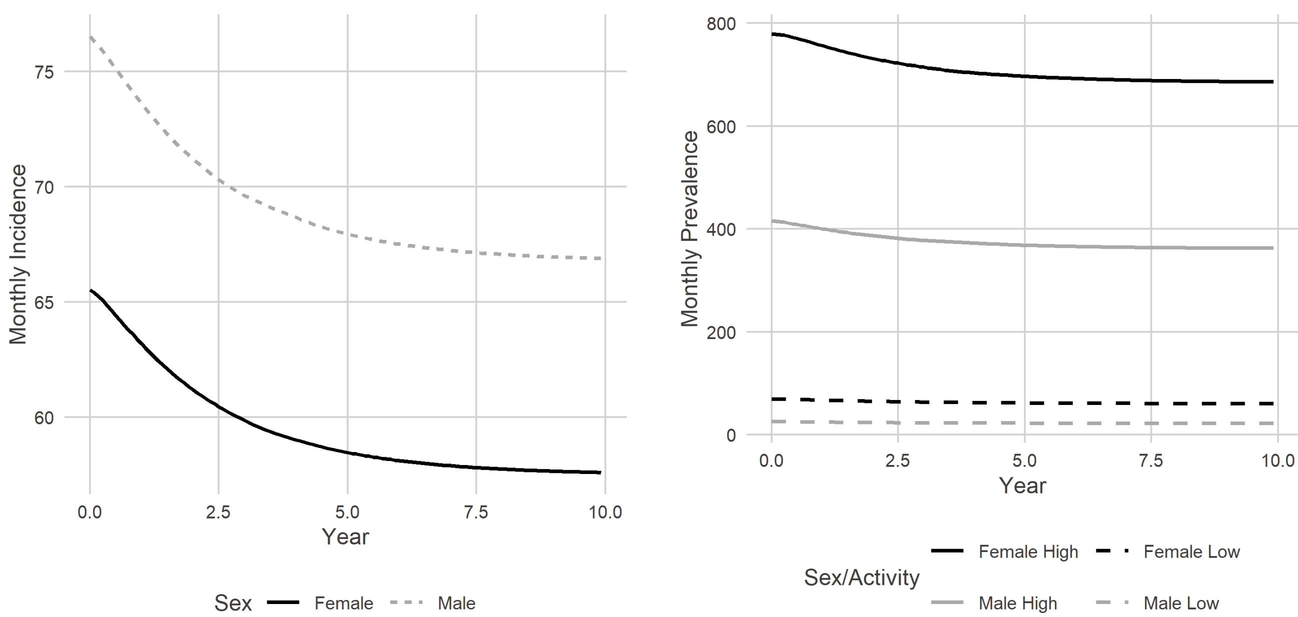

Figure S3: Monthly incidence by sex and prevalence, by sex and sexual activity type, under primary scenario

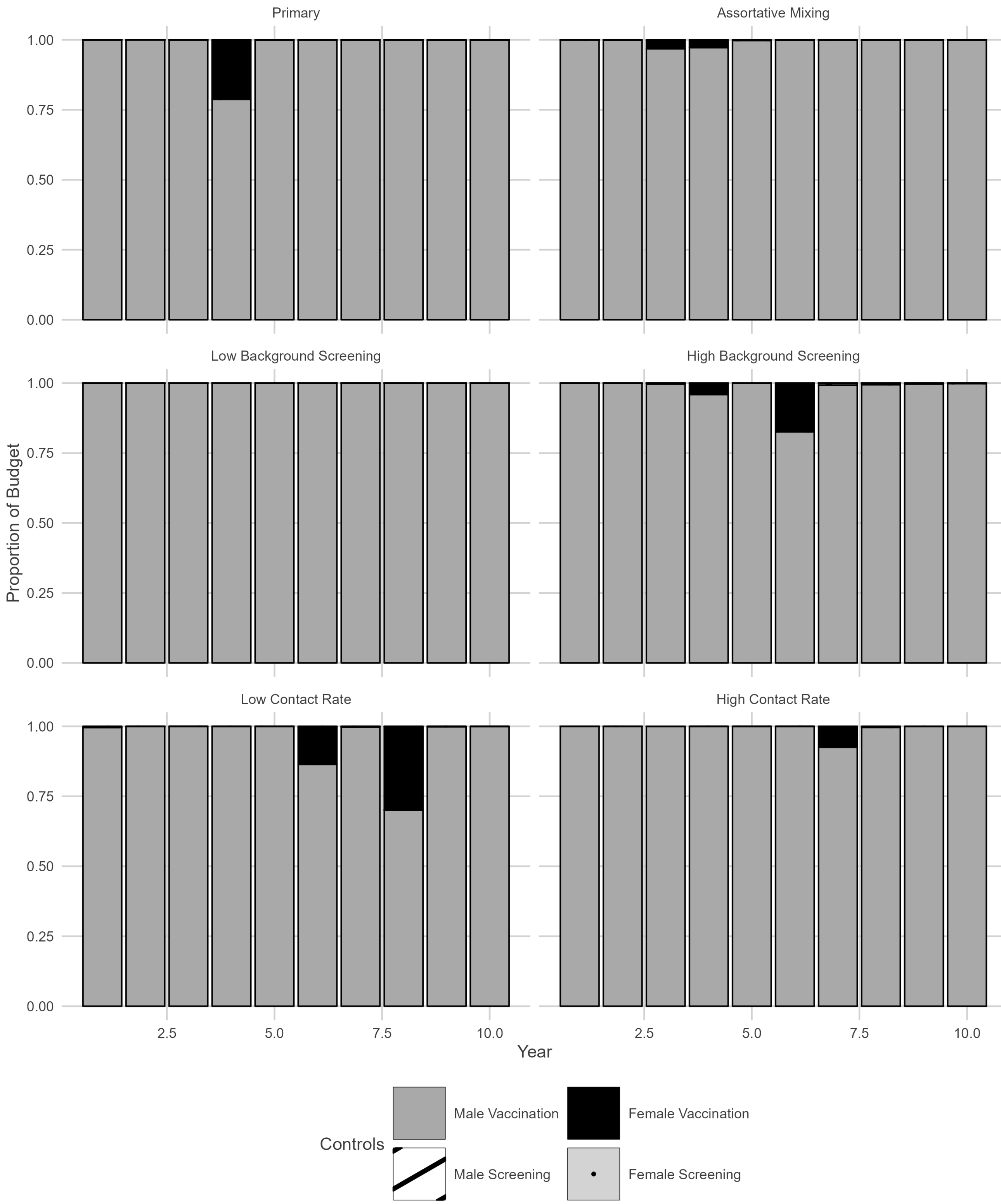

Figure S4: Sensitivity of budget allocation under alternative epidemiological parameter inputs. All vaccination and screening program enrollment occurred through symptomatic visits.

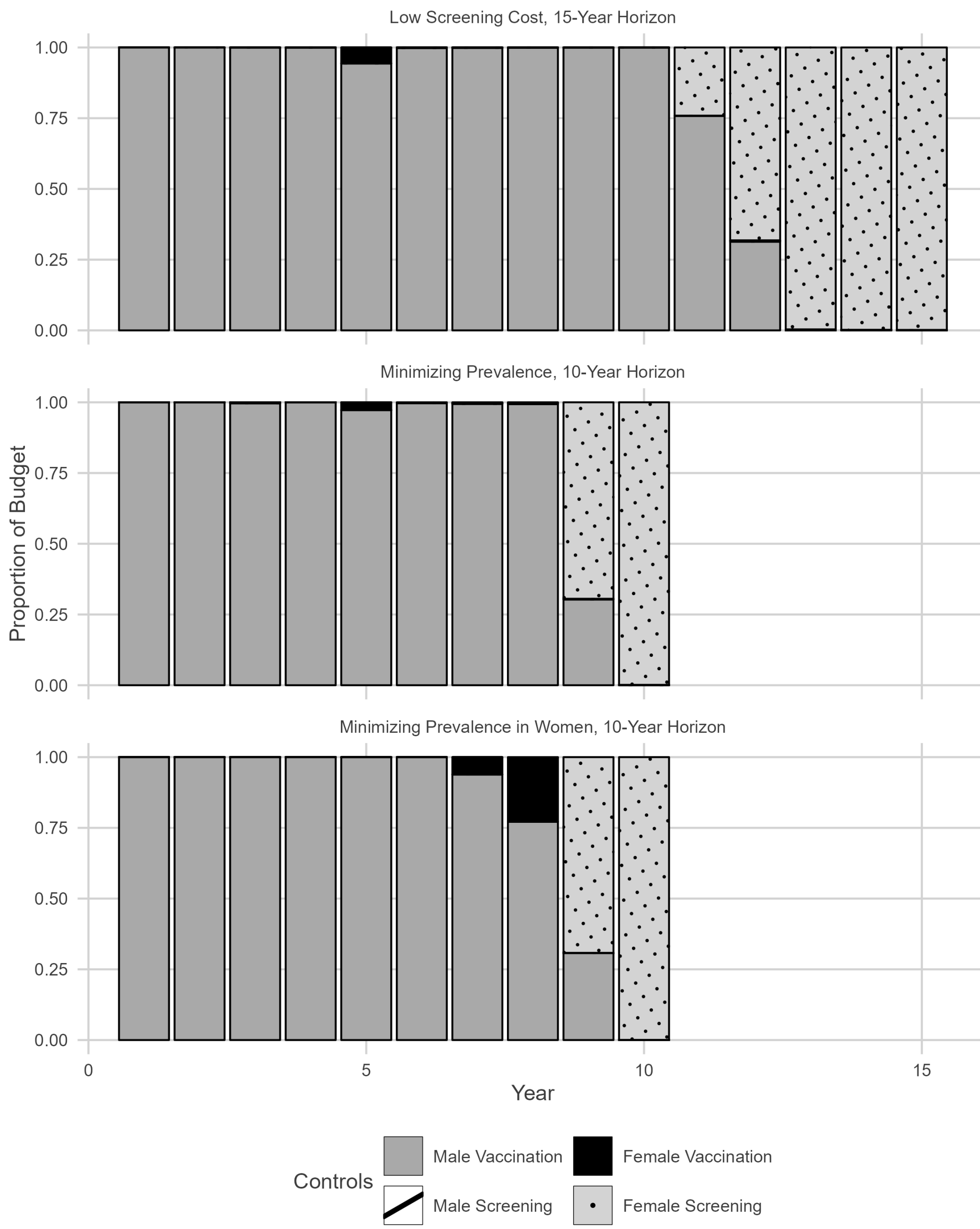

Figure S5: Proportion of budget allocation under additional scenarios: increasing the analytic horizon or minimizing prevalence. All vaccination and screening program enrollment occurred through symptomatic visits.

Single-control	Sex	Infections averted	Percent of infections averted	Courses of antibiotics spared	ICER: program, 10 years
Female screening alone, from symptomatic visits	Total	4,700	5.5	1,800	625
	Male	2,600	5.7		
	Female	2,100	5.3		
Female screening alone, from background visits	Total	2,000	2.3	800	1,486
	Male	1,100	2.4		
	Female	900	2.3		
Female vaccination alone, from symptomatic visits	Total	7,600	8.9	2,700	394
	Male	4,000	8.7		
	Female	3,600	9.2		
Female vaccination alone, from background visits	Total	2,500	2.9	900	1,199
	Male	1,300	2.8		
	Female	1,200	3.1		
Male screening alone, from symptomatic visits	Total	3,200	3.8	1,200	925
	Male	1,700	3.7		
	Female	1,500	3.8		
Male screening alone, from background visits	Total	1,300	1.5	500	2,269
	Male	700	1.5		
	Female	600	1.5		
Male vaccination alone, from symptomatic visits	Total	8,100	9.5	2,900	370
	Male	4,500	9.8		
	Female	3,600	9.2		
Male vaccination alone, from background visits	Total	2,600	3.0	900	1,154
	Male	1,400	3.0		
	Female	1,100	2.8		

Table S3: Infections averted and cost-effectiveness under single-control benchmarks. In the absence of any control, there were 46,000 male infections, 39,300 female infections, 85,300 total infections, and 29,900 courses of antibiotics used. Infections and antibiotic courses spared rounded to nearest 100. ICER: Incremental cost-effectiveness ratio, the additional cost per infection averted (difference in costs divided by difference in infections). Within a given control, ICERs compared the costs and infections under the single-control benchmark to the counterfactual costs and infections in the absence of any intervention.

Scenario	Years	Total incidence	Infections averted	Program cost	Vaccination cost	Screening cost	Total external costs	External costs averted	ICER: program	ICER: health system
Primary	10	77,200	8,100	2,999,000	2,999,000	-	34,112,400	575,100	370	299
	15	117,500	10,500	2,999,300	2,999,300	-	51,279,600	751,600	286	214
High prevalence	10	817,300	9,200	2,996,700	2,997,100	-	87,320,500	686,800	326	251
	15	1,229,900	9,900	2,996,400	2,996,800	-	131,267,700	743,200	303	228
Screening only	10	80,600	4,700	2,968,600	-	2,968,600	34,143,800	543,700	632	516
	15	121,800	6,200	3,445,200	-	3,445,200	51,339,000	692,300	556	444
Screening only, no drop-out	10	82,100	3,100	2,921,800	-	2,921,800	34,242,500	445,000	943	799
	15	123,400	4,600	4,253,800	-	4,253,800	51,380,100	651,200	925	783
Minimize incidence in women	10	77,300	8,000	2,999,300	2,999,300	-	34,117,400	570,100	375	304
	15	117,600	10,400	2,999,500	2,999,500	-	51,289,600	741,700	288	217
Minimize prevalence	10	77,200	8,100	2,995,000	2,484,100	510,900	34,078,600	608,900	370	295
	15	117,500	10,400	3,453,200	2,484,100	969,000	51,212,100	819,200	332	253
Lower screening cost	10	76,800	8,500	3,002,900	1,814,400	1,188,500	21,912,800	683,200	353	273
	15	116,600	11,300	3,474,200	1,814,400	1,659,800	32,963,300	930,800	307	225
Shorter vaccine duration	10	79,500	5,700	2,997,300	2,304,100	693,300	34,231,600	455,900	526	446
	15	120,500	7,400	3,394,400	2,304,100	1,090,400	51,419,400	611,800	459	376
High budget	10	60,600	24,700	9,996,800	8,741,500	1,255,300	32,859,600	1,827,900	405	331
	15	95,200	32,800	10,219,800	8,742,200	1,477,600	49,587,600	2,443,600	312	237

Table S4: Infections averted, costs, and cost-effectiveness under selected scenarios. Incidence, infections averted, and costs rounded to nearest 100. ICER: Incremental cost-effectiveness ratio, the additional cost per infection averted (difference in costs divided by difference in infections). Within a given scenario, ICERs compared the costs and infections under the DOCP to the counterfactual costs and infections in the absence of any intervention. From the program perspective, the difference in cost is equal to the program cost. Health system ICERs subtract external costs averted from program costs.