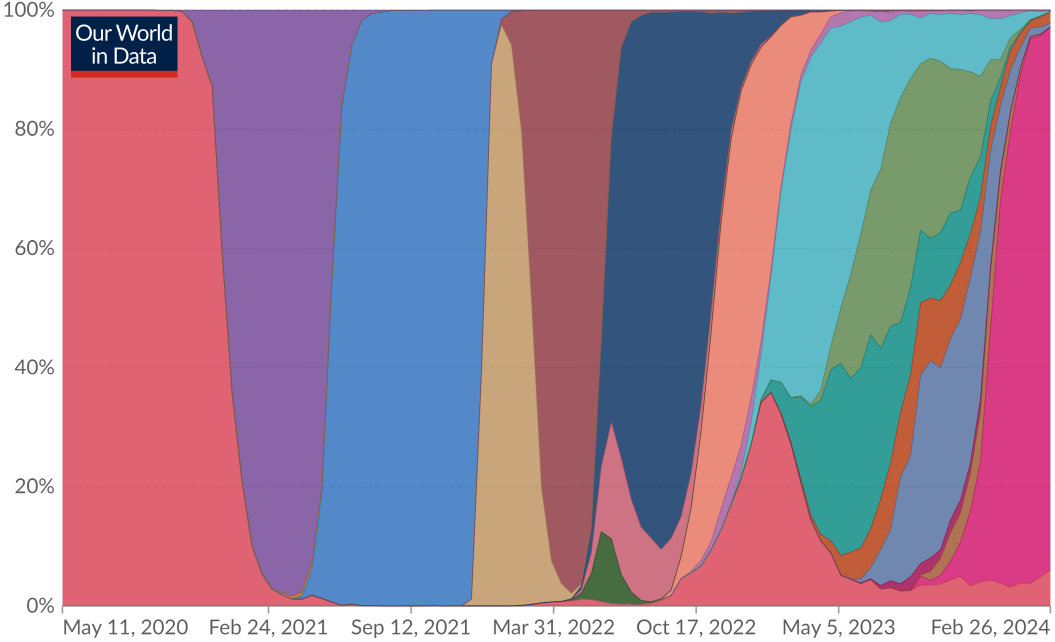
Modelling vaccine escape

Maria A. Gutierrez (mag84) and Julia R. Gog

Dept. of Applied Mathematics and Theoretical Physics (DAMTP)

GATES Cambridge



Our World in Data
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May 11, 2020
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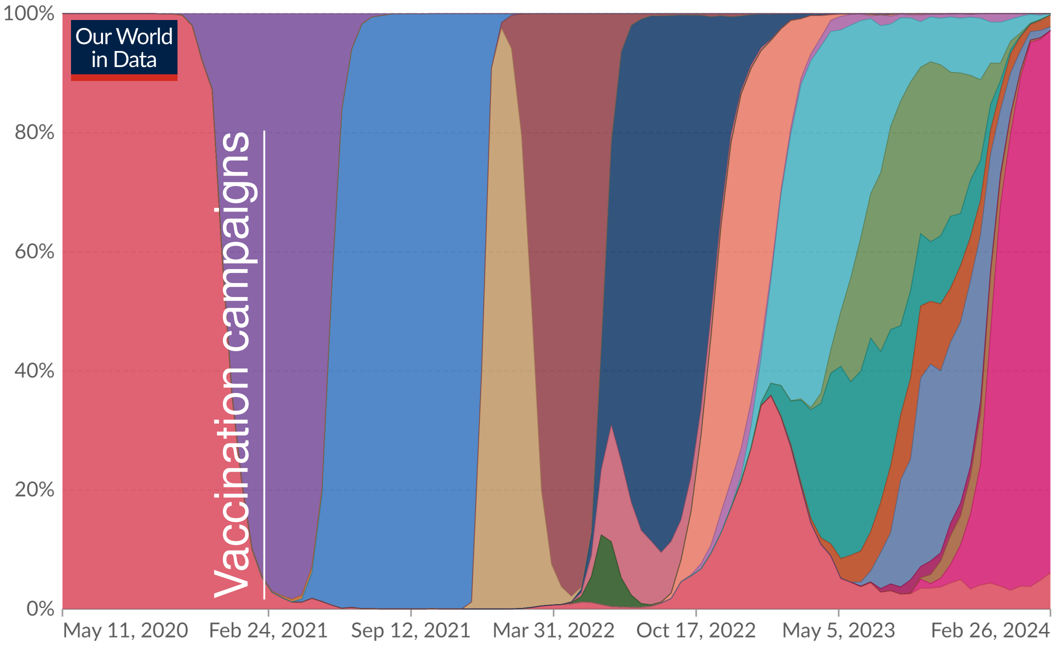
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Vaccination campaigns
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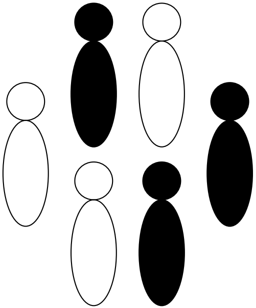
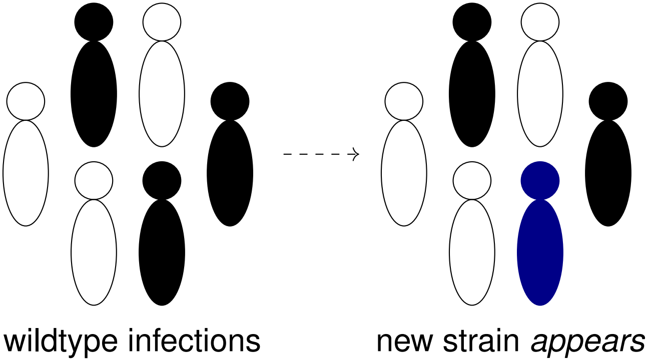
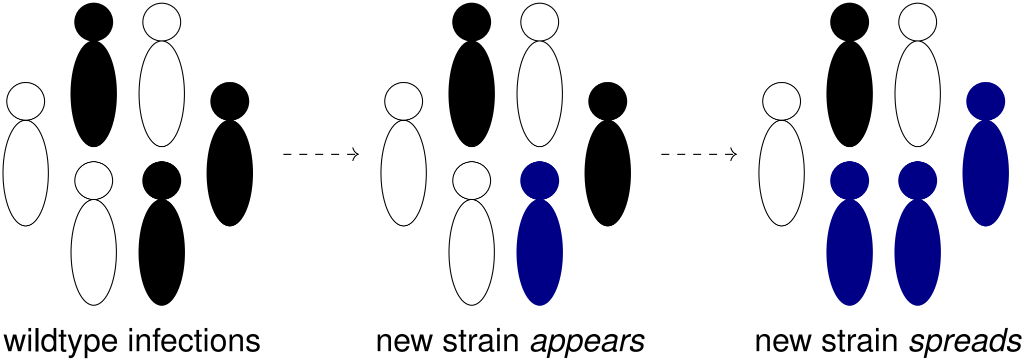
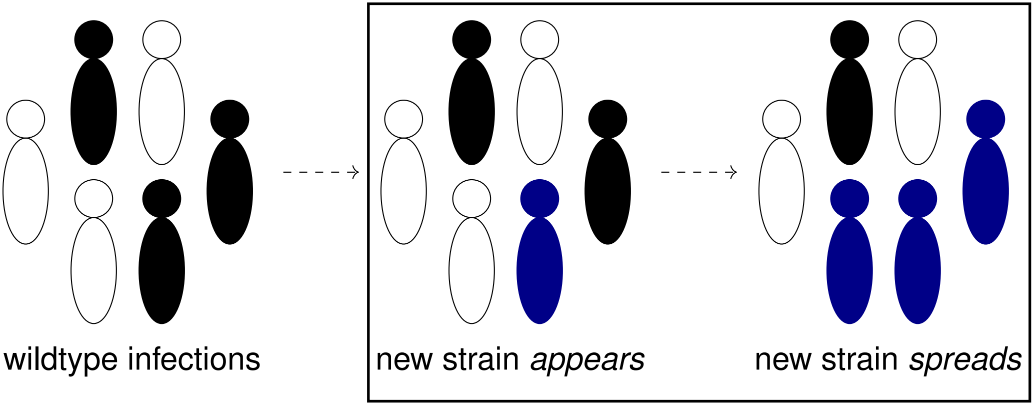


wildtype infections


wildtype infections
new strain *appears*


wildtype infections
new strain *appears*
new strain *spreads*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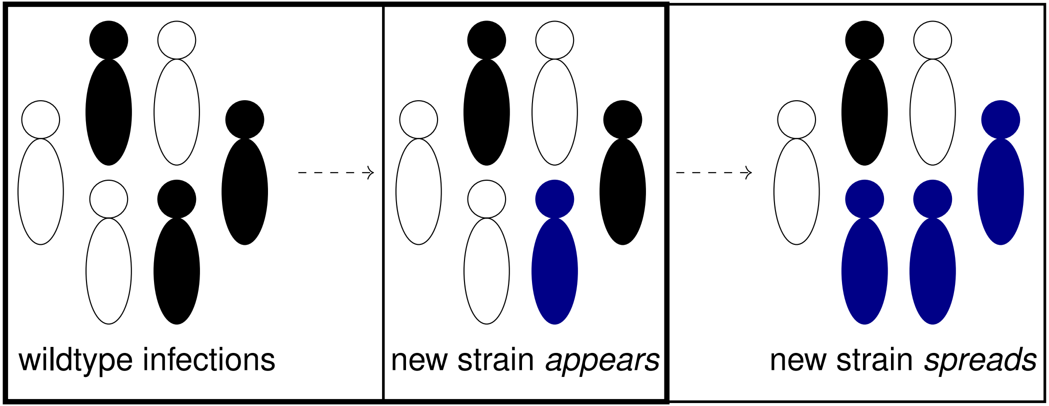
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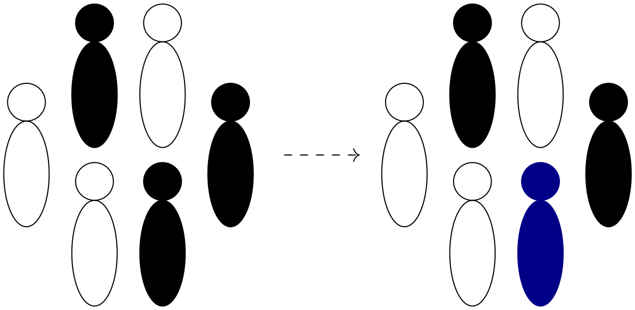
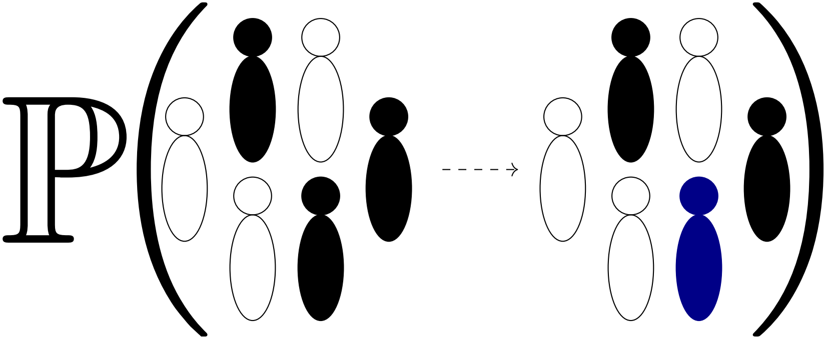
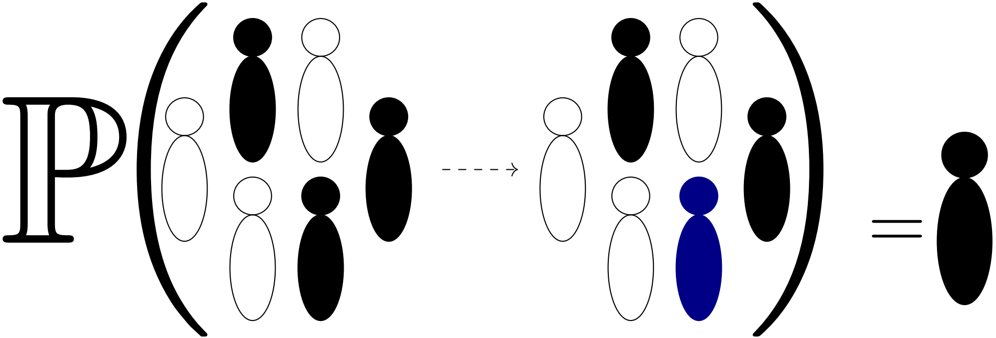
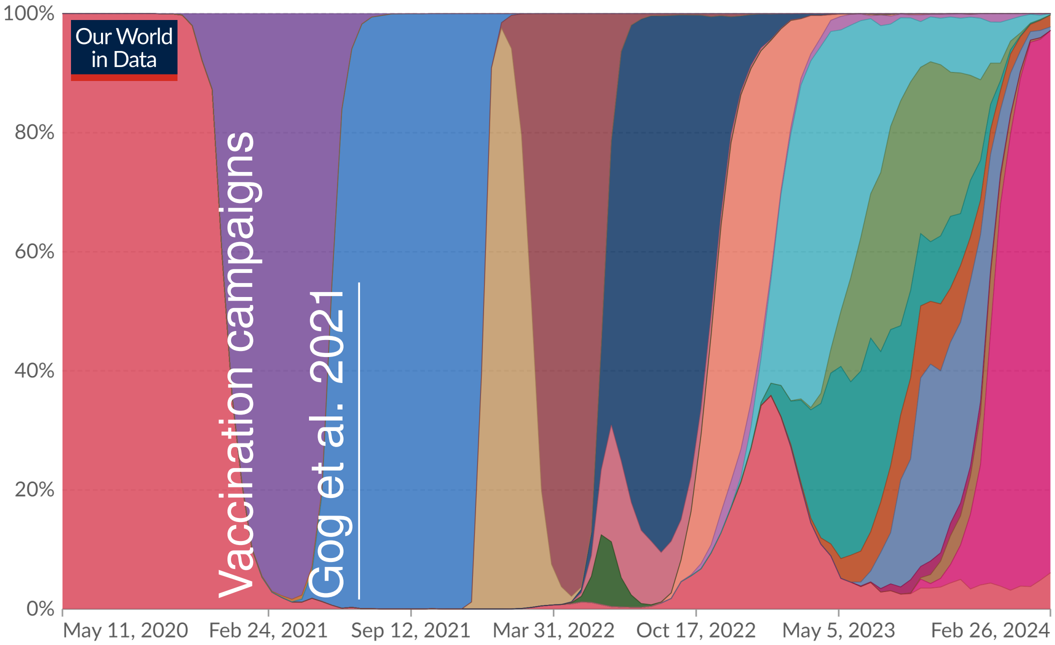






Hartfield et al. 2014, Gog et al. 2021,
Rella et al. 2021, Saad-Roy et al. 2021



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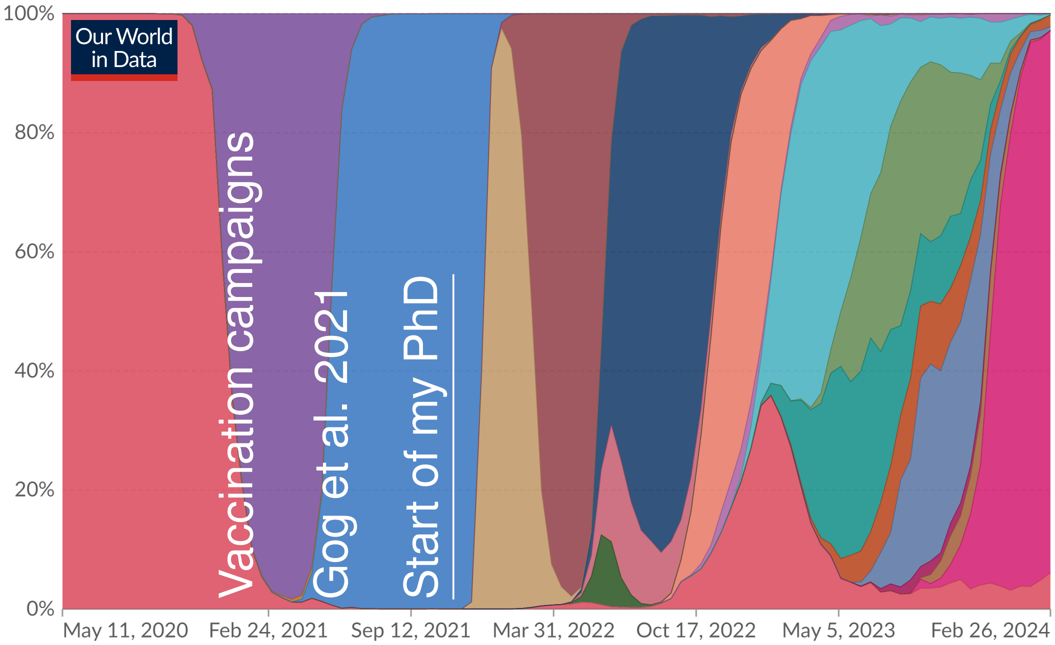

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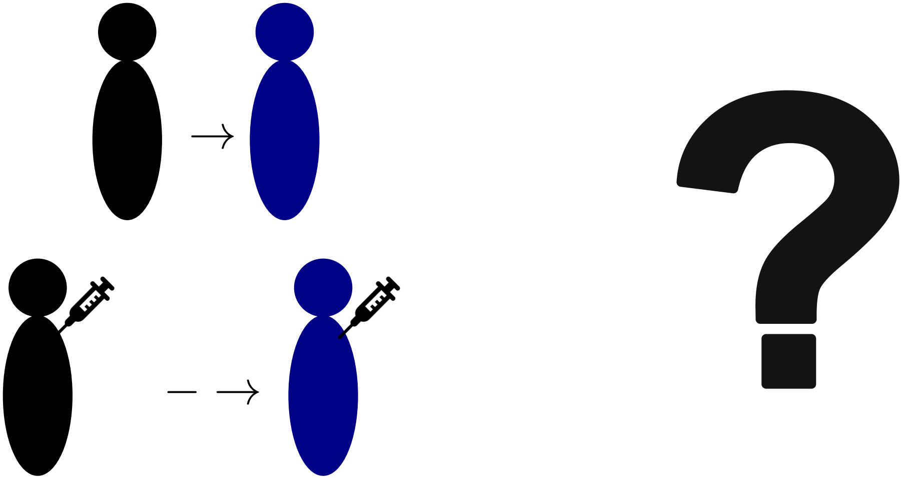
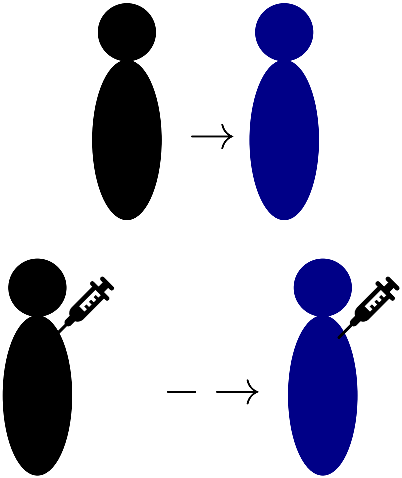
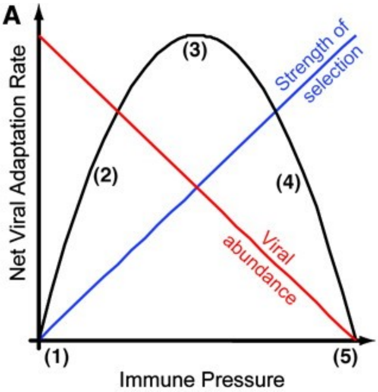
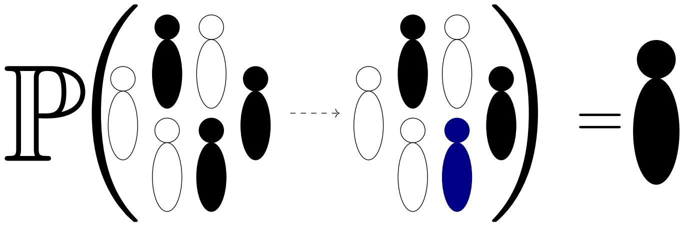
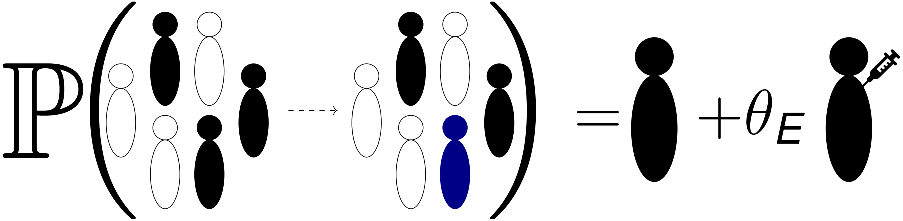


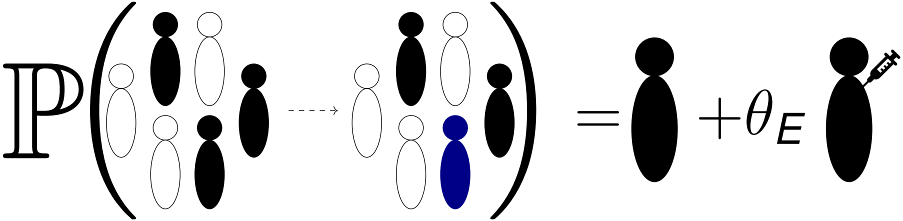




Grenfell *et al.*, Science 2004

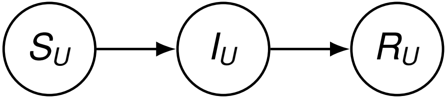



$\mathbb{P}$
$=$
$+\theta_E$



$$P(t) = I_U(t) + \theta_E I_V(t)$$

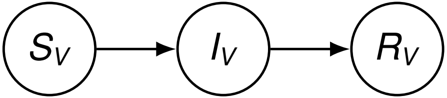
Unvaccinated fraction $(1 - c)$



$$\dot{S}_U = -S_U \lambda(t)$$

$$\dot{I}_U = S_U \lambda(t) - I_U$$

Vaccinated fraction c



$$\dot{S}_V = -S_V \lambda(t)$$

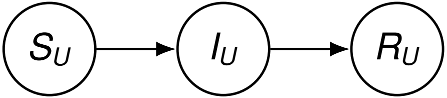
$$\dot{I}_V = S_V \lambda(t) - I_V$$

$$\lambda = R_0(I_U + \theta_I I_V)$$

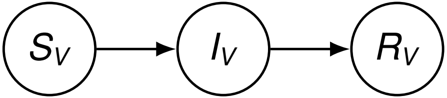
$$S_U(0) = (1 - c)$$

$$S_V(0) = c\theta_S$$

Unvaccinated fraction $(1-c)$



Vaccinated fraction c



$$\dot{S}_U = -S_U\lambda(t) \qquad \dot{S}_V = -S_V\lambda(t)$$

$$\dot{I}_U = S_U\lambda(t) - I_U \qquad \dot{I}_V = S_V\lambda(t) - I_V$$

$$\lambda = R_0(I_U + \theta_I I_V)$$

$$S_U(0) = (1-c) \qquad S_V(0) = c\theta_S$$

$$\forall t$$

$$(1-c)^{-1}(S_U, I_U, R_V) = (c\theta_S)^{-1}(S_V, I_V, R_V)$$

$$(S, I) := (1 - c)^{-1}(S_U, I_U) = (c\theta_S)^{-1}(S_V, I_V)$$

$$R_e = R_0(1 - c(1 - \theta_S\theta_I))$$

$$S(\infty) = -W\left(-R_e e^{-R_e}\right)/R_e$$

$$(S, I) := (1 - c)^{-1}(S_U, I_U) = (c\theta_S)^{-1}(S_V, I_V)$$

$$R_e = R_0(1 - c(1 - \theta_S\theta_I))$$

$$S(\infty) = -W\left(-R_e e^{-R_e}\right)/R_e$$

$$\int_0^\infty P(t)dt = \int_0^\infty (I_U + \theta_E I_V)dt$$

$$\boxed{P = (1 - c + \theta_S\theta_E c)\left(1 + \frac{1}{R_e}W\left(-R_e e^{-R_e}\right)\right)}$$

$P(c)/P(0)$: escape pressure

10

θ_E

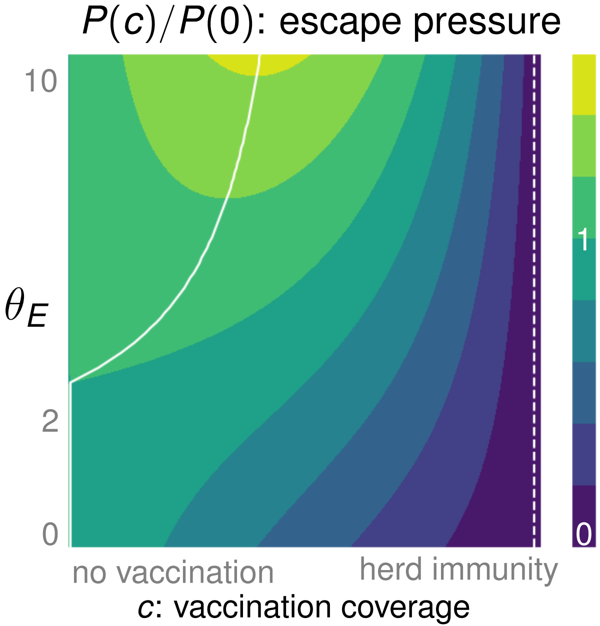
2

0

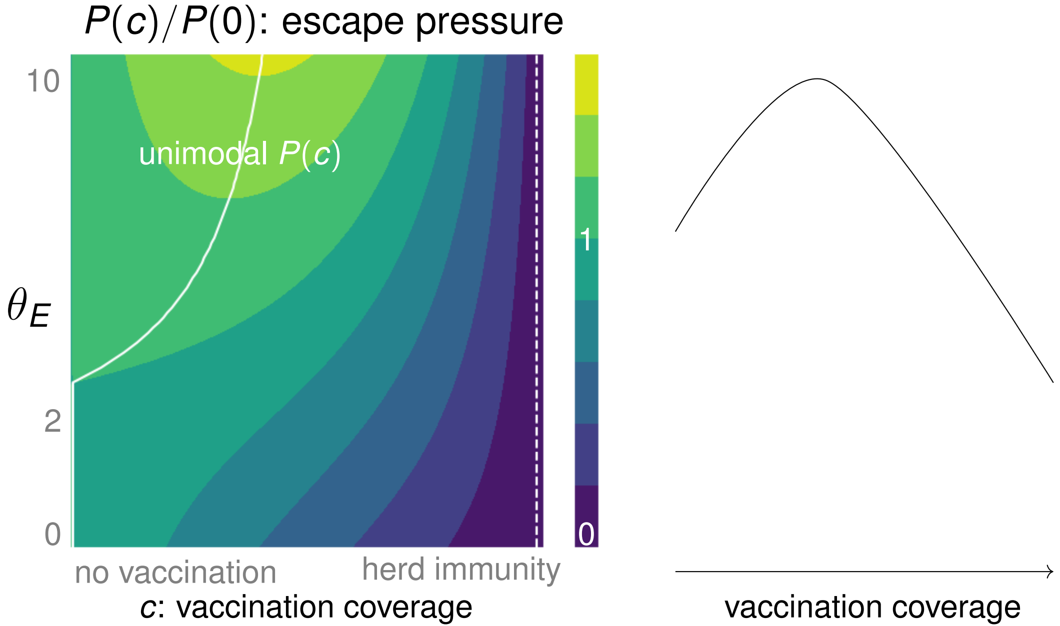
no vaccination

herd immunity

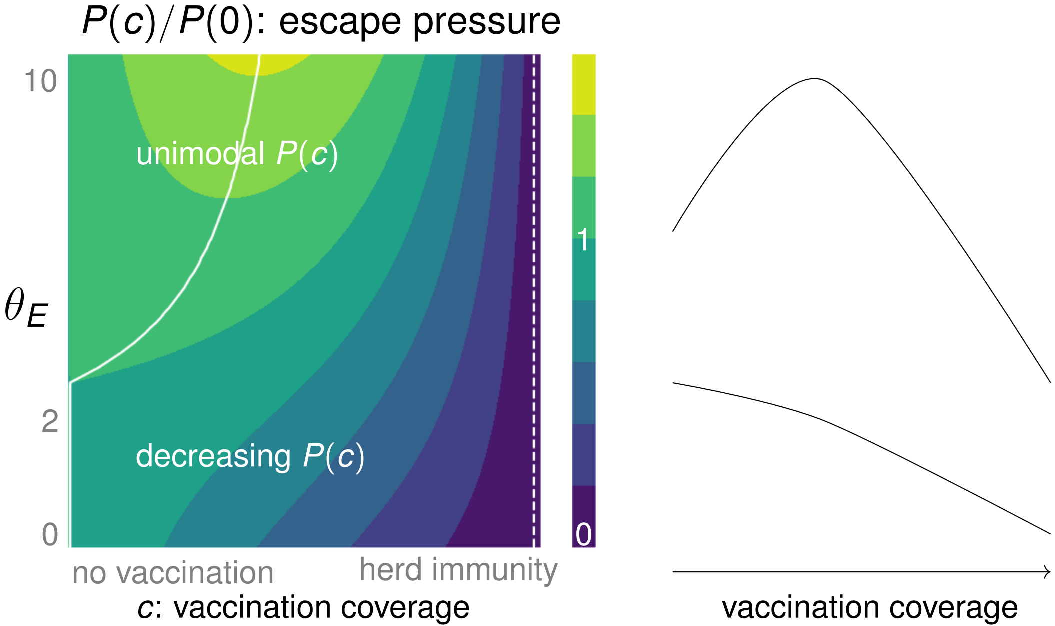
c: vaccination coverage



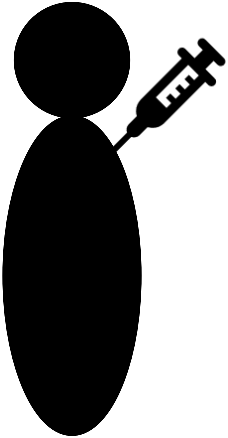
$P(c)/P(0)$: escape pressure
10
2
0
θ_E
1
0
no vaccination
herd immunity
c: vaccination coverage



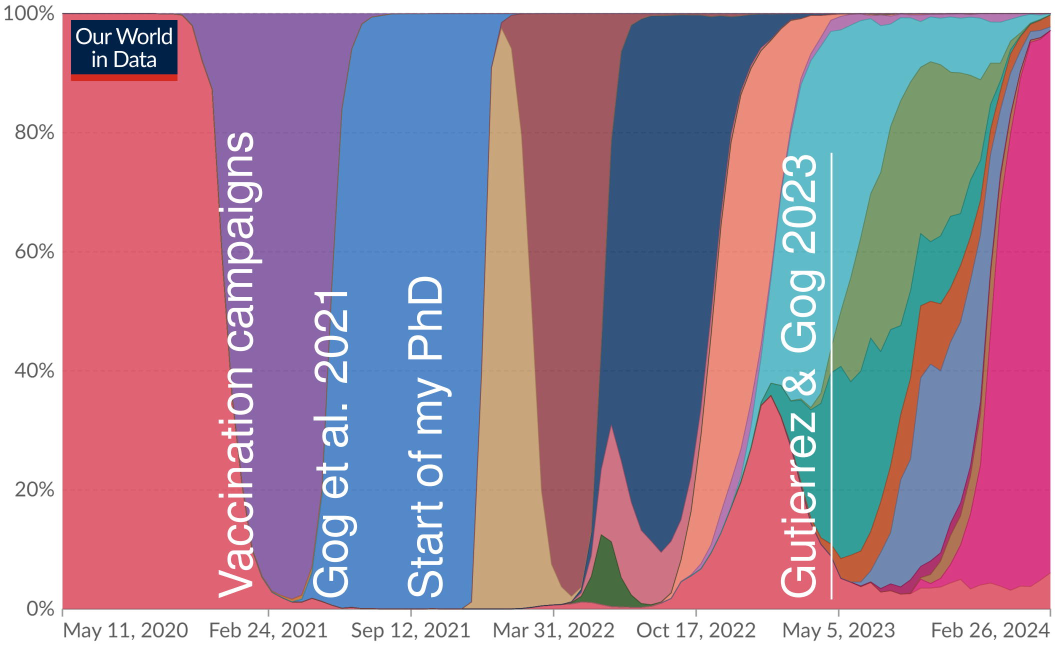
$P(c)/P(0)$: escape pressure
10
2
0
θ_E
unimodal $P(c)$
1
0
no vaccination
herd immunity
c: vaccination coverage
vaccination coverage



$P(c)/P(0)$: escape pressure
10
unimodal $P(c)$
1
θ_E
2
decreasing $P(c)$
0
0
no vaccination
herd immunity
c: vaccination coverage
vaccination coverage



$$\theta_E$$



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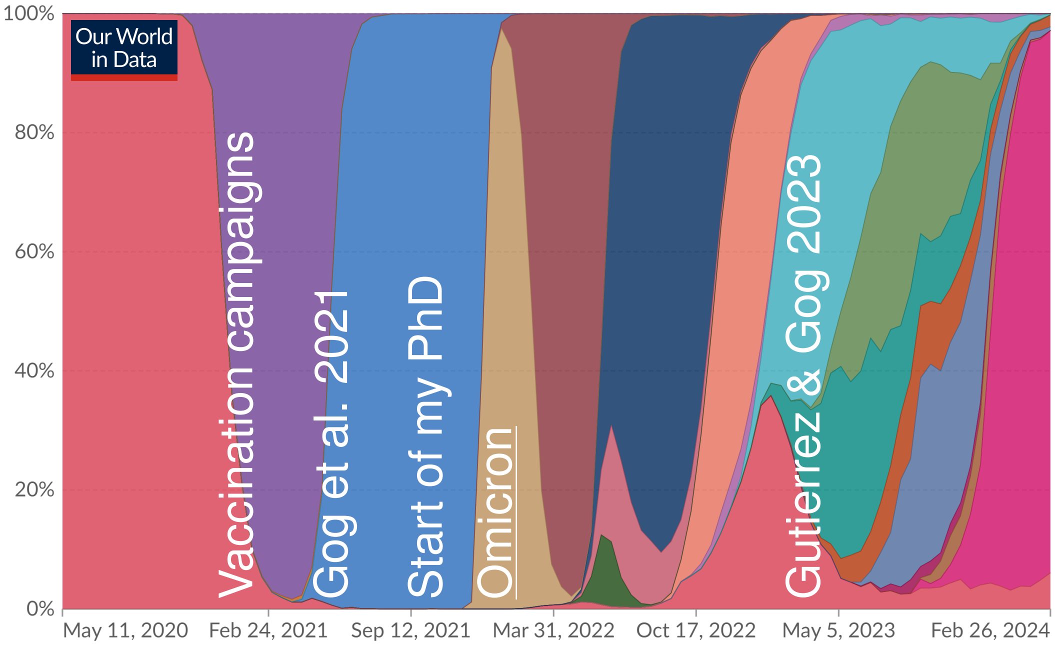
Gutierrez & Gog 2023



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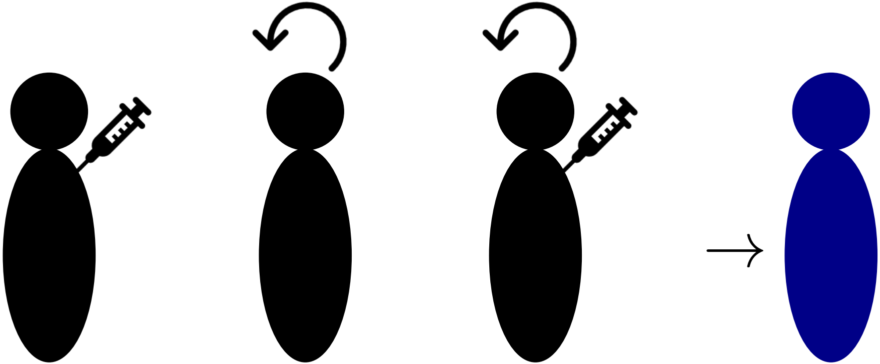

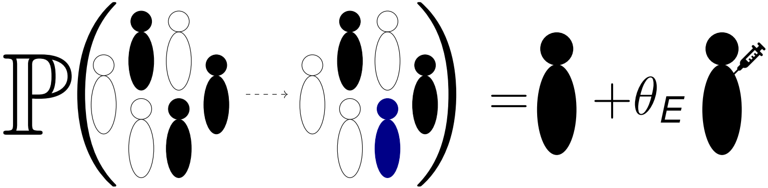
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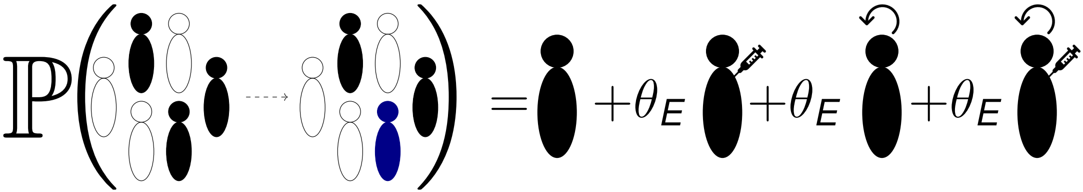
$\mathbb{P}$
$=$
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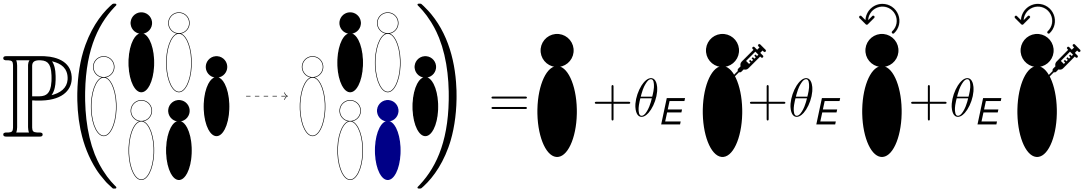
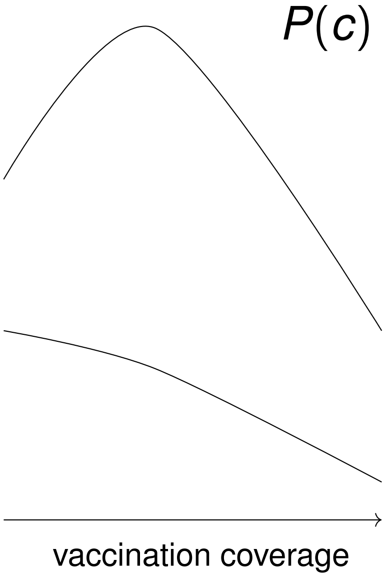
$+\theta_E$

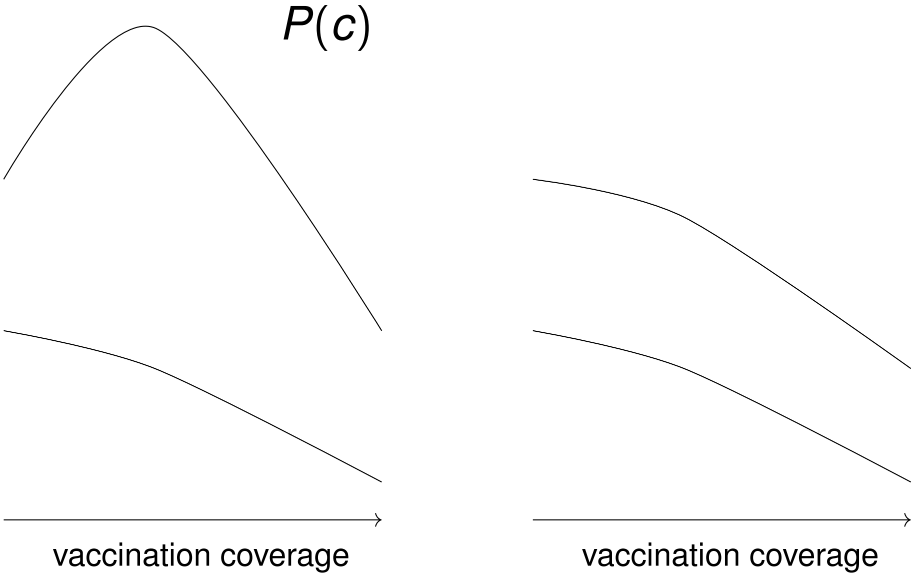


$$P = \left[1 - c + \theta_E \left(\frac{\theta'_S(1 - R_0^{-1}) + c(\theta_S - \theta'_S)}{1 - \theta'_S} \right) \right] \left(1 + \frac{W\left[-re^{-r}\right]}{r} \right)$$

$$r = (R_e - \theta'_S)/(1 - \theta'_S)$$

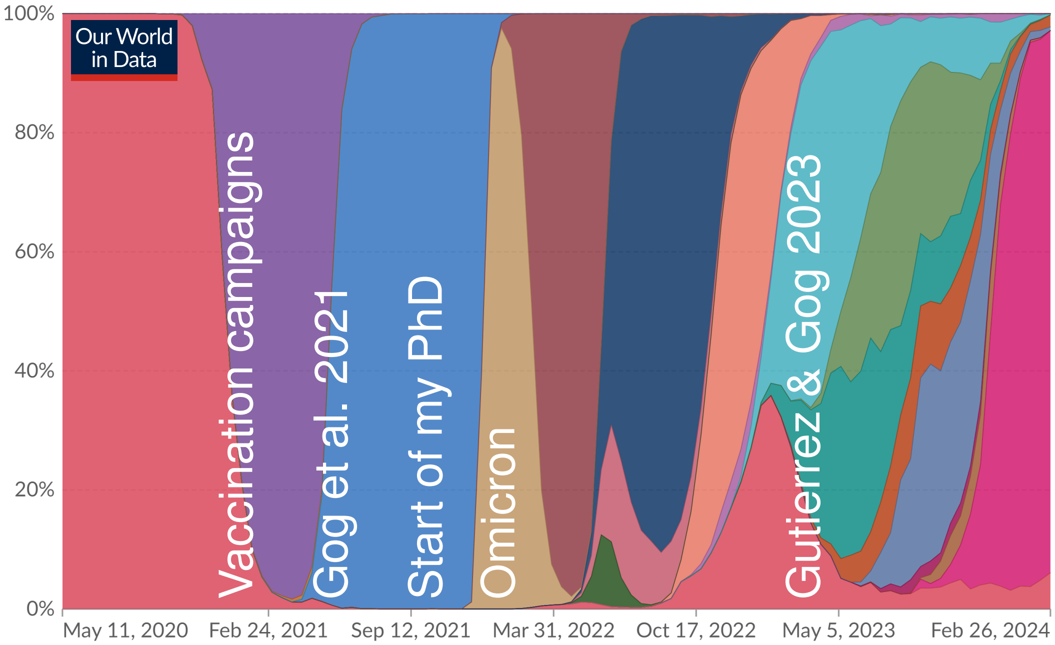


P(c)
vaccination coverage



P(c)
vaccination coverage
vaccination coverage

$$\theta_E, \theta_S, \theta'_S$$



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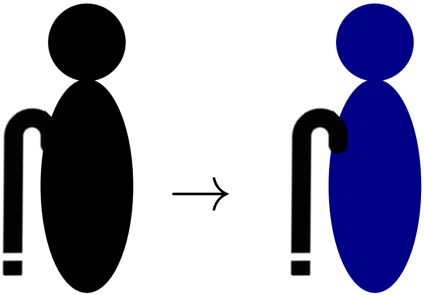
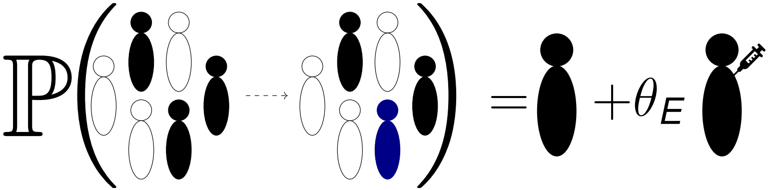
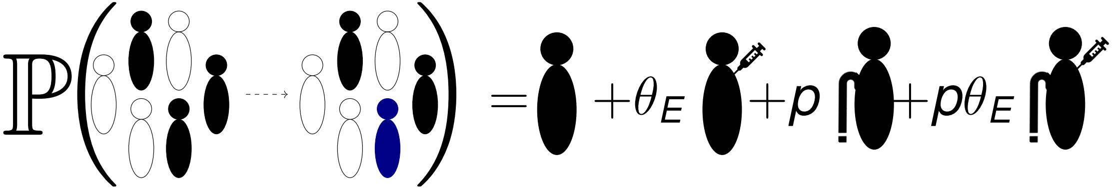
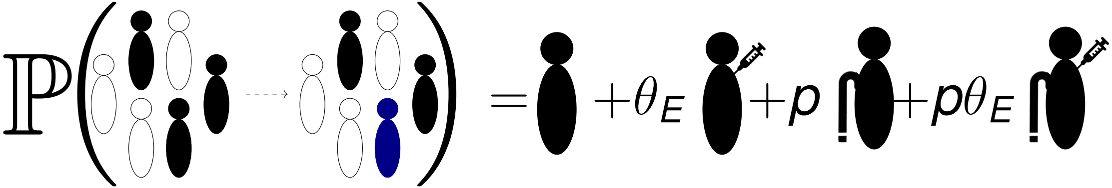


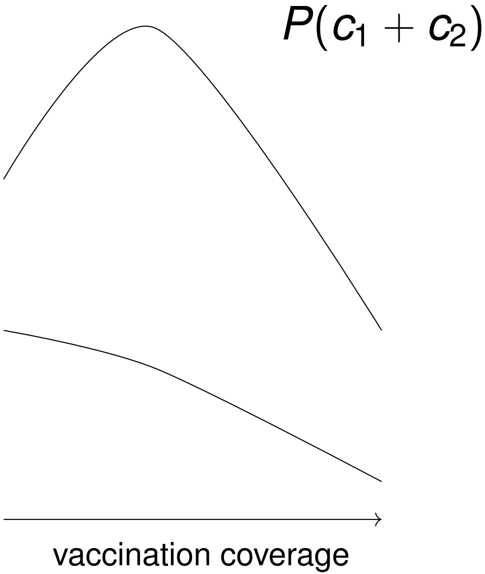


$\mathbb{P}$
$=$
$+\theta_E$

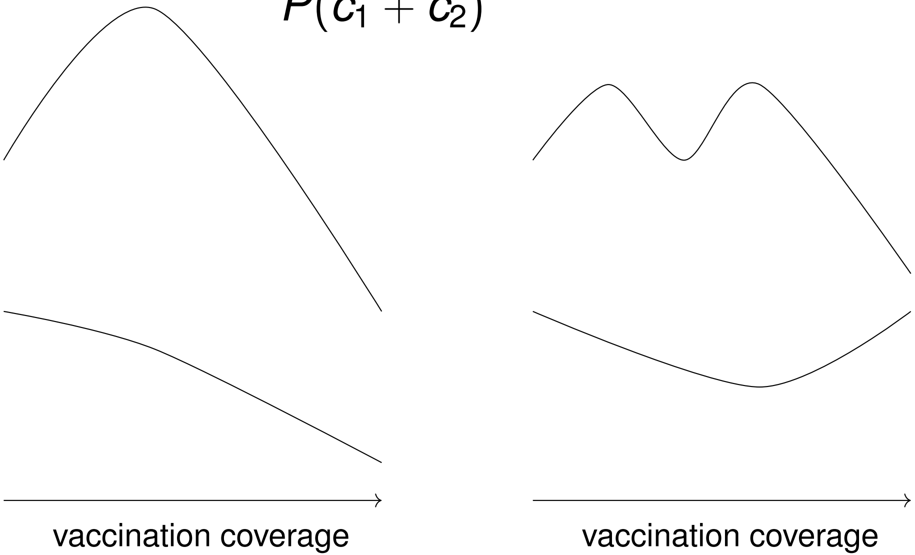

$\mathbb{P}$
$=$
$+\theta_E$
$+p$
$+p\theta_E$

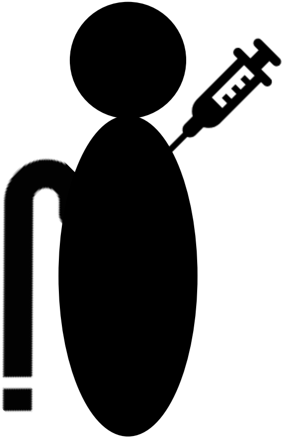


$$P(c_1, c_2)$$

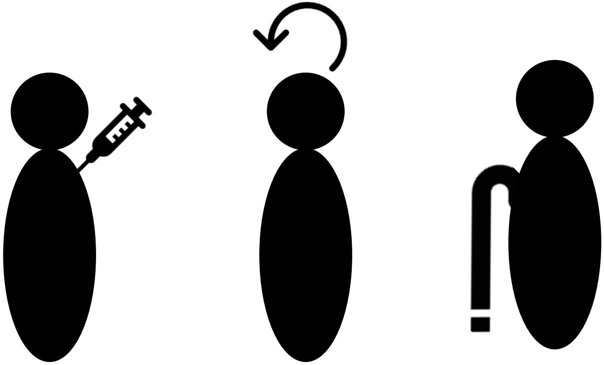

$P(c_1 + c_2)$
vaccination coverage

$$P(c_1 + c_2)$$

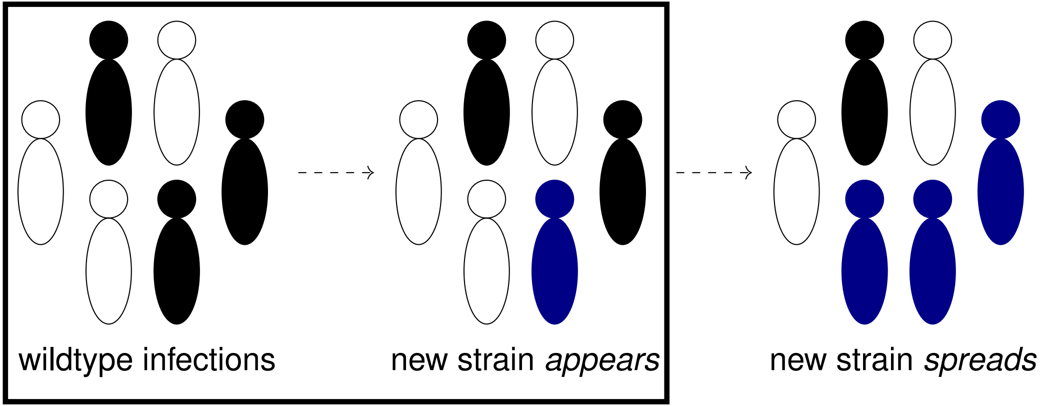




θ_E, p



θ_E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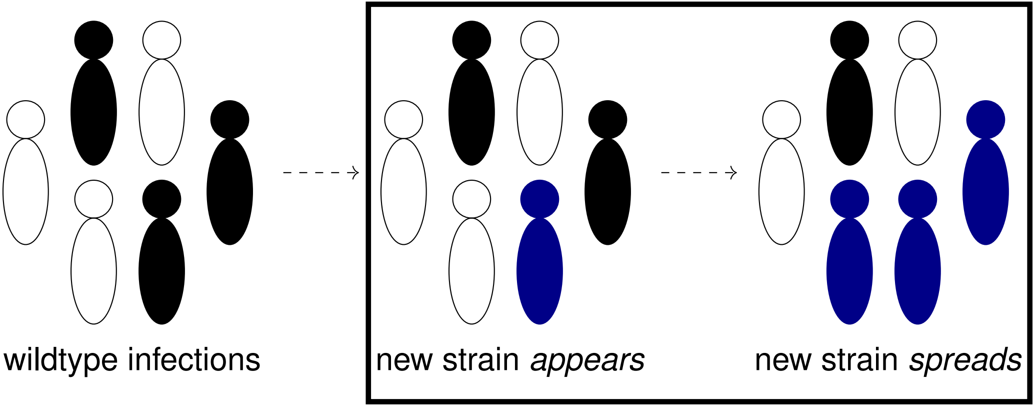
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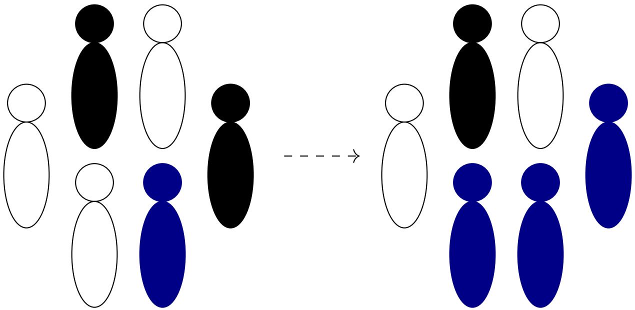
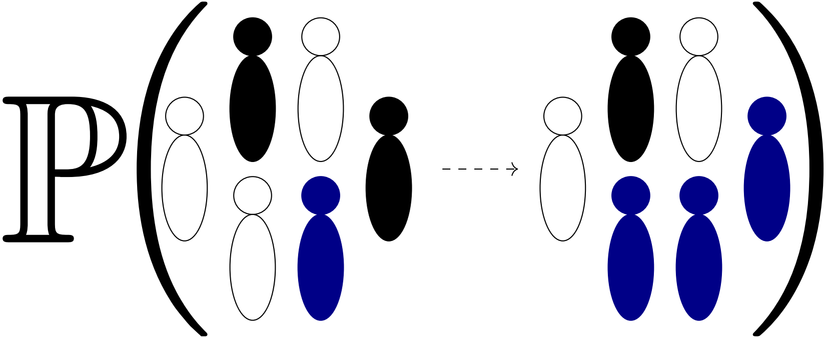
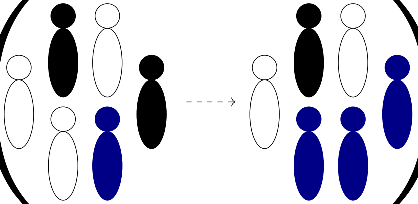
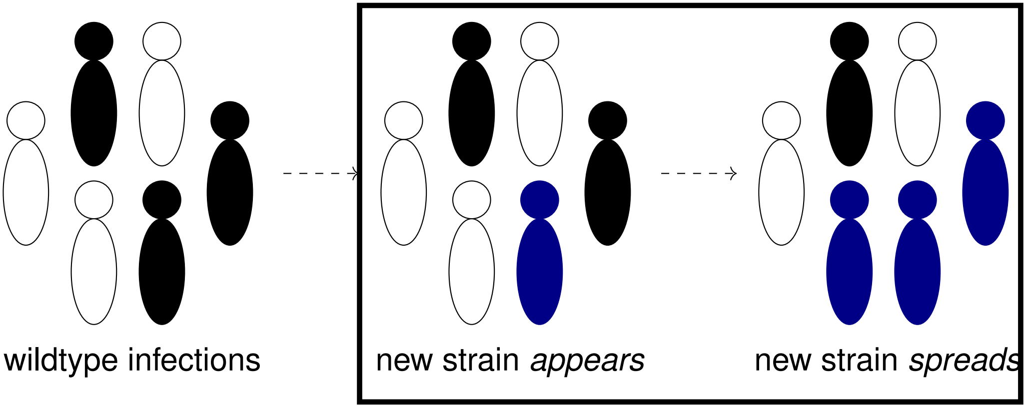




$\mathbb{P}\Big($  $\Big) \neq 1 - \frac{1}{R(t)}$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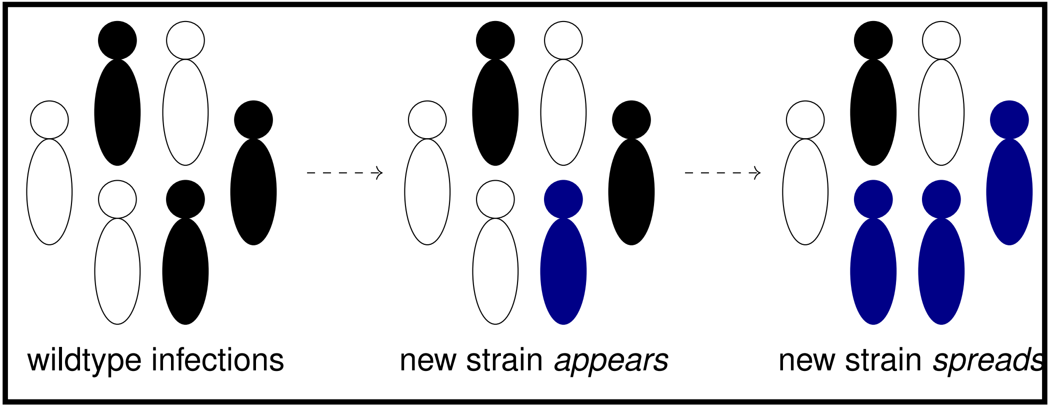
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