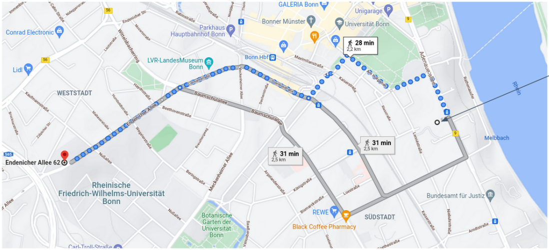
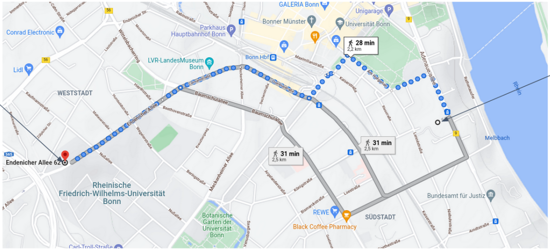
About me



Begin of the Master in Economics in 2019

About me

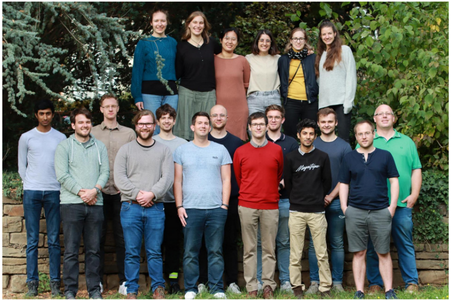
Begin of the PhD in the group of Jan Hasenauer in 2021 (Computational Life Sciences)



Begin of the Master in Economics in 2019

Hasenauer group - Computational Life Sciences

Hasenauer group



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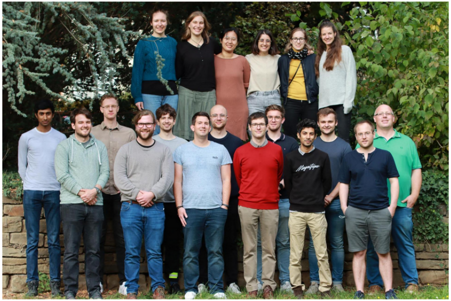

Our work covers:

- Multi-cellular modelling
- Metabolic modelling

- Bioinformatics and machine learning
- Statistical inference for dynamical systems
- Infectious disease modelling

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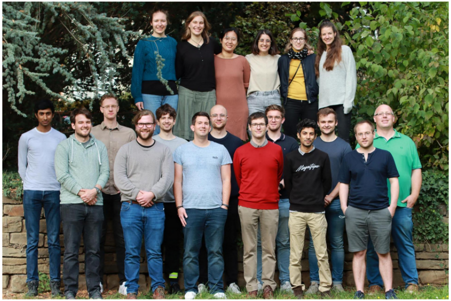

Our work covers:

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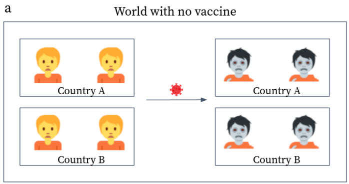
Topic of today

SIRD models for the optimal allocation of vaccines across countries

Manuel Huth
Supervision: Lorenzo Contento, Jan Hasenauer, Lena Janys

November 17, 2021

Why do we need an optimized vaccine allocation scheme?



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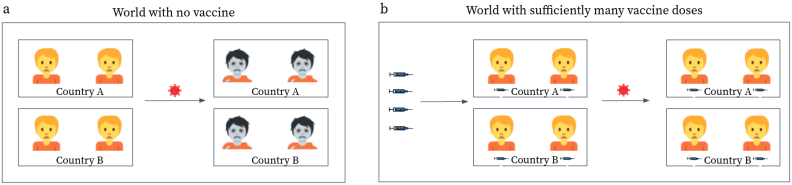

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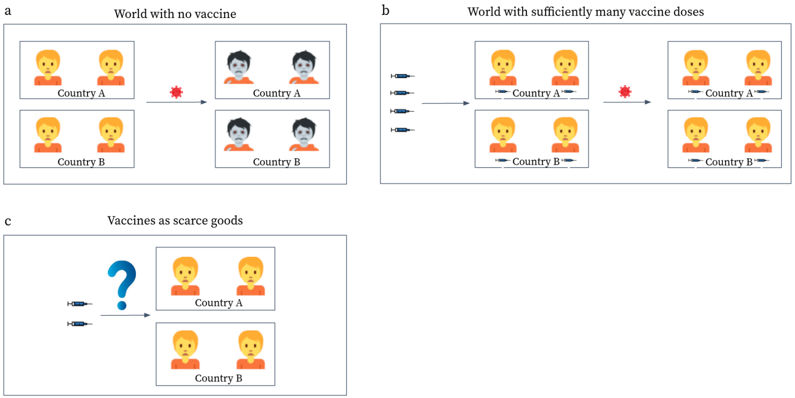

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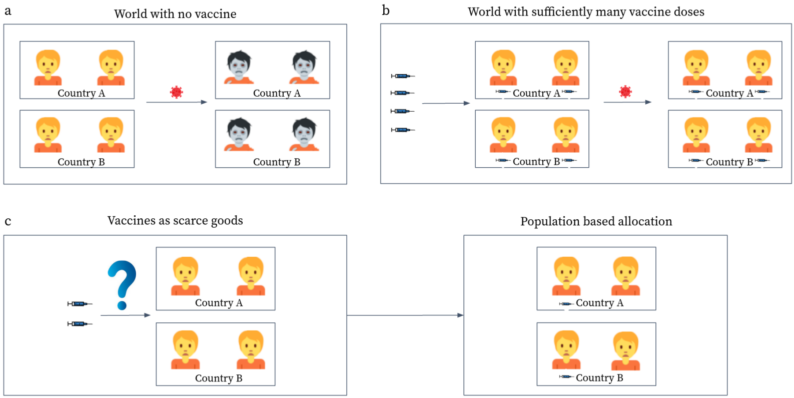

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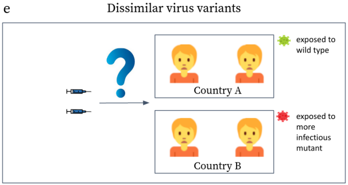
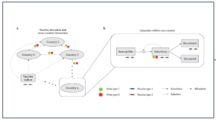


Why do we need an optimized vaccine allocation scheme?

General model building

Graphical Model



ODE model

$x(t)$	state vector
$u(t)$	vaccine pathways
θ	vaccine parameter vector
ϕ	fixed parameter vector

$$\dot{x}(t) = f(x(t), u(t;\theta), \phi, t)$$
$$x(0) = x_0$$

Optimal control problem

$$\min_{\theta} \; Deaths(T)$$
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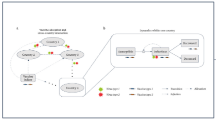

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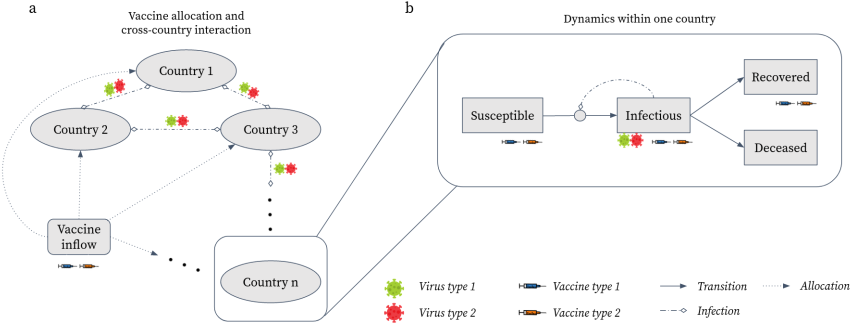

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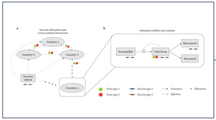

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How to solve for the state vector?

- > 100 states
- non-linear ODE system
- no closed-form solution

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Numerical simulation

AMICI

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Vaccination pathways

Problem: u(t) can potentially be any function

Vaccination pathways

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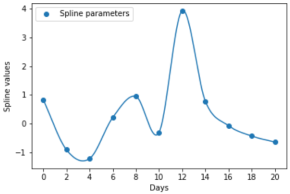
Solution: Impose functional form of u(t)

Vaccination pathways

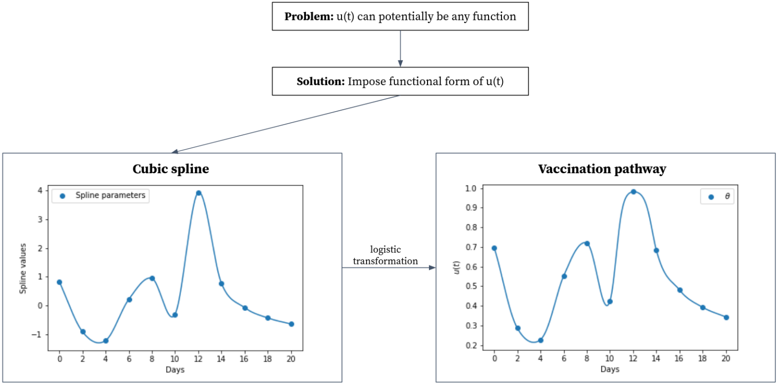
Problem: u(t) can potentially be any function

Solution: Impose functional form of u(t)

Cubic spline



Vaccination pathways



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Optimal strategy
(global minimum)

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Pareto optimal strategy

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Every country needs to be at least as *good* as within a population based vaccine allocation.

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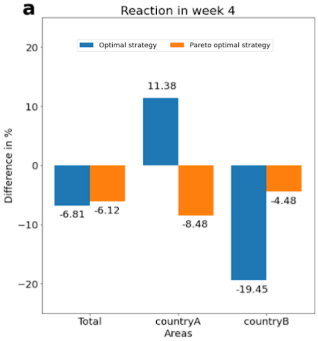

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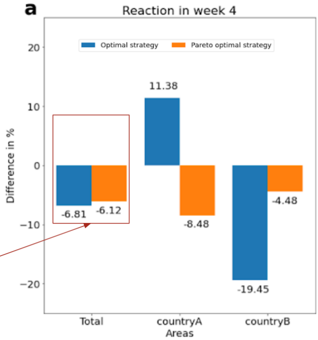

How can we interpret these numbers?

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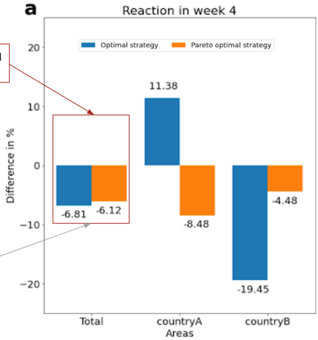
Overall the globally optimal strategy performs better



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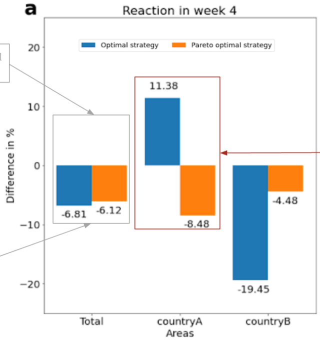

The globally optimal strategy yields no improvement for country A but the Pareto optimal strategy does so.

How can we interpret these numbers?

Aim: Find the minimal number of deaths in country A, given the number of deaths in country B.

Optimization - Pareto front

Optimal strategy
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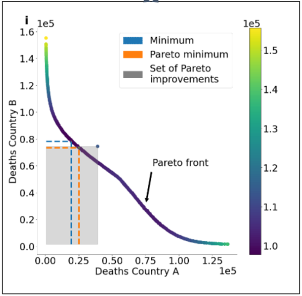
Compute the
Pareto front



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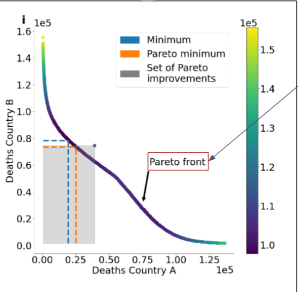

No country can be better off without the other country being worse off

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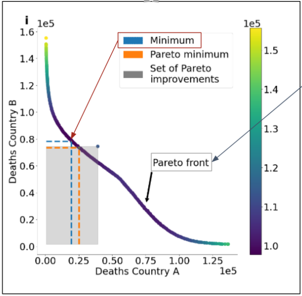

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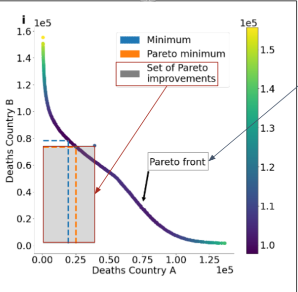

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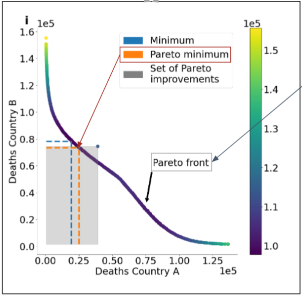

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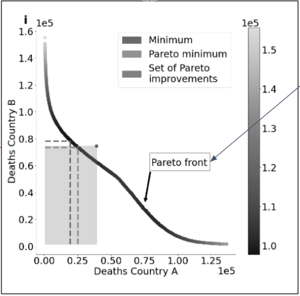

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Computational implementation

Pareto front

- Python module *pymoo*
- NSGA-II algorithm

Additional optimization

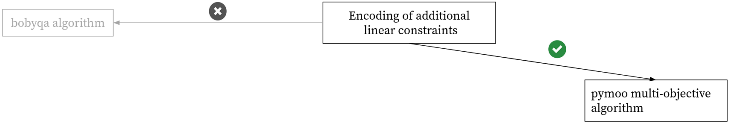
- *estimagic*
- bobyqa algorithm

Optimization - Many countries

Encoding of additional linear constraints

Optimization - Many countries

Optimization - Many countries



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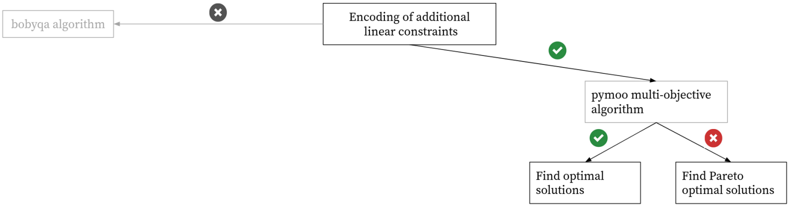

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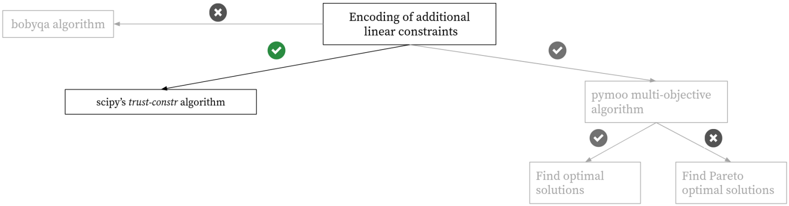

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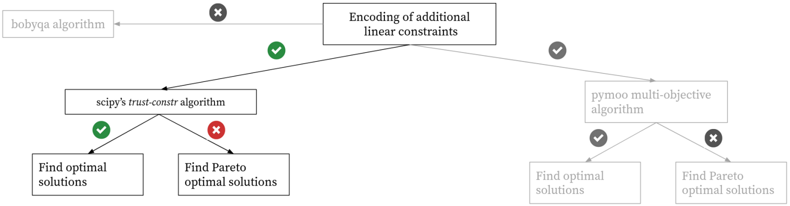

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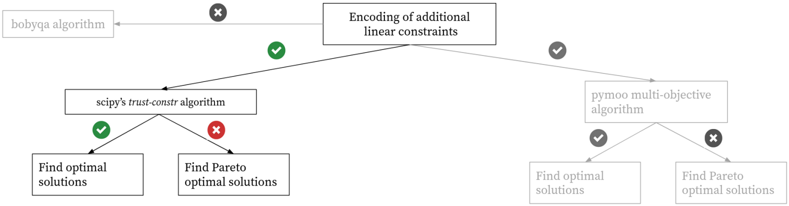

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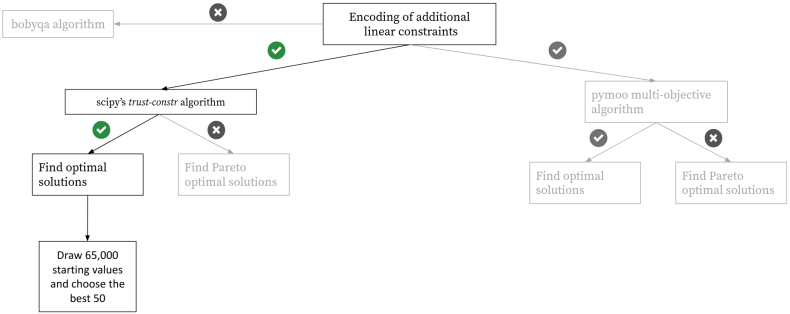

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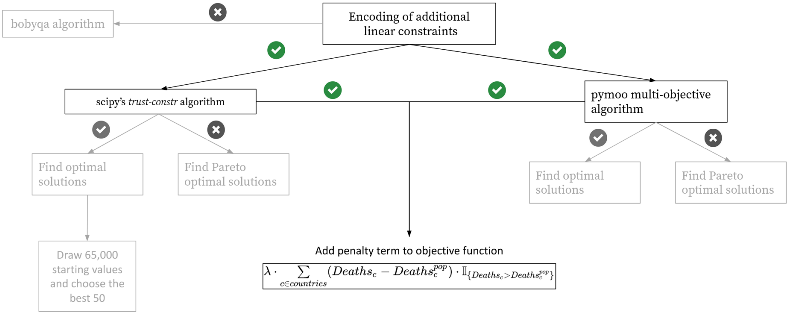

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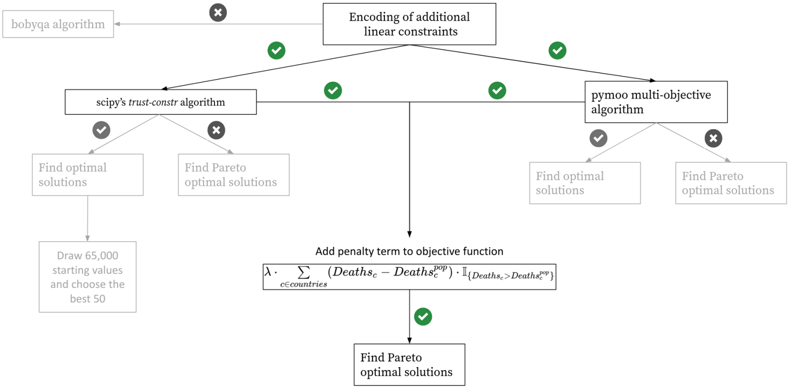

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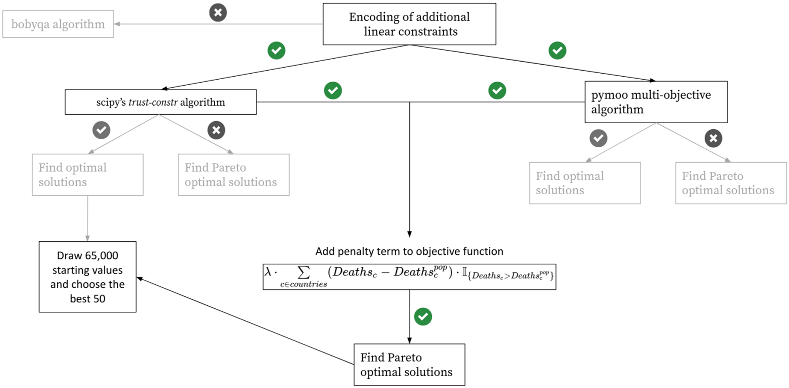
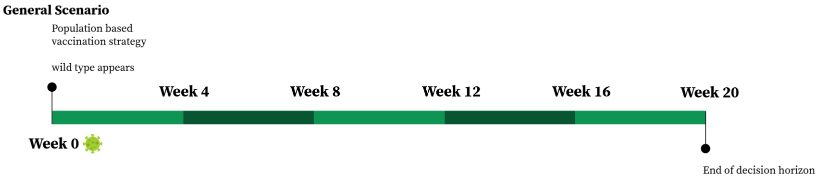
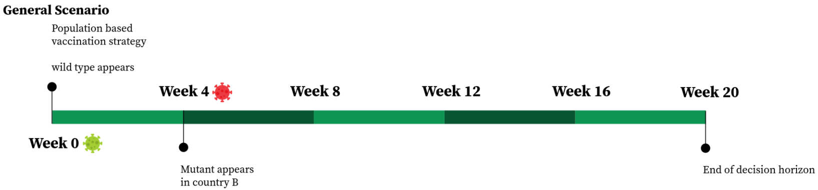


Additional material

Examining policy decision delays



Examining policy decision delays



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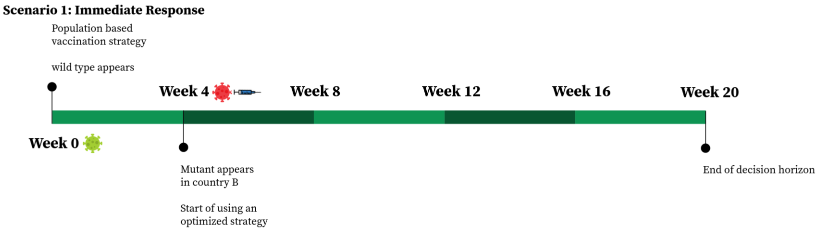
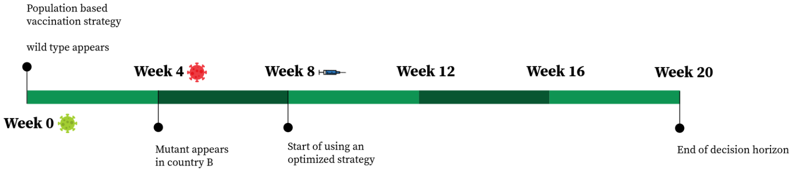


Examining policy decision delays

Scenario 2: 4 weeks delay



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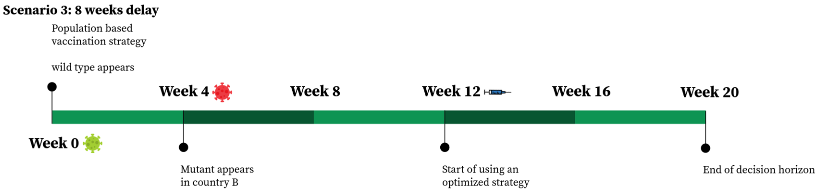

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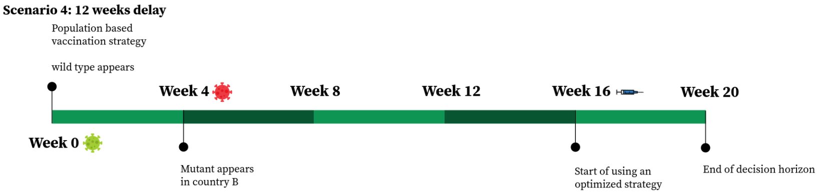
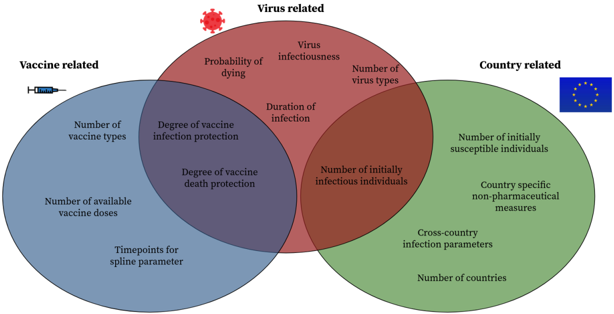
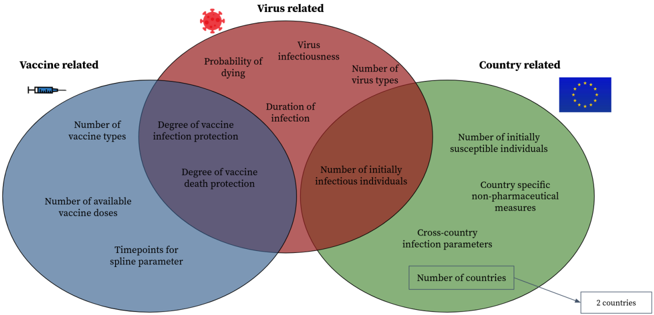


Fixed Parameters



Fixed Parameters



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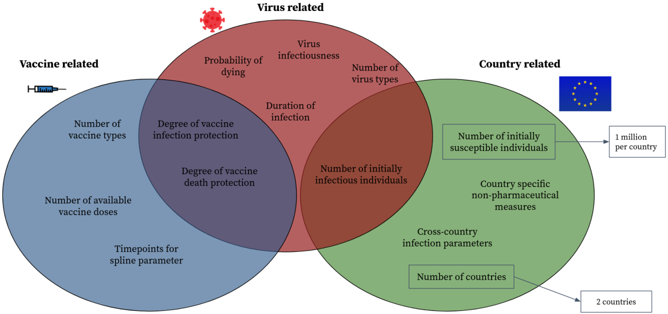

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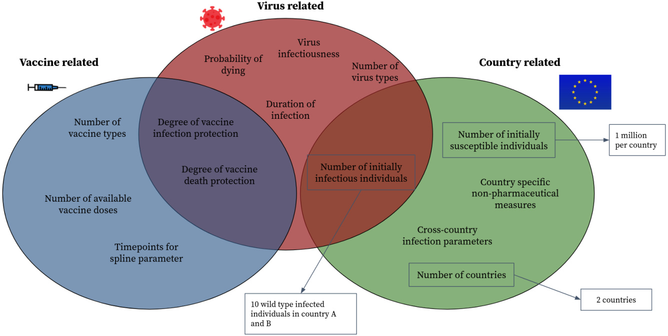

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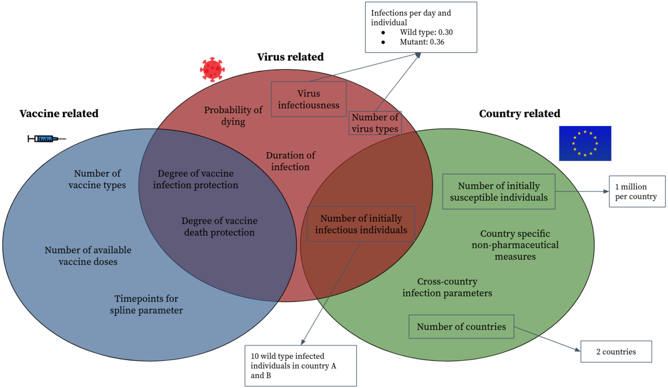
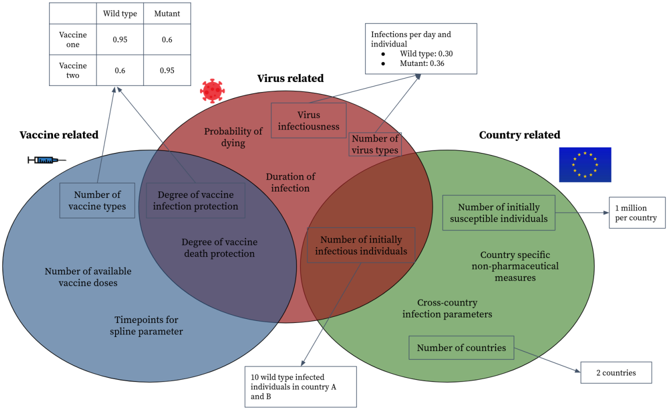
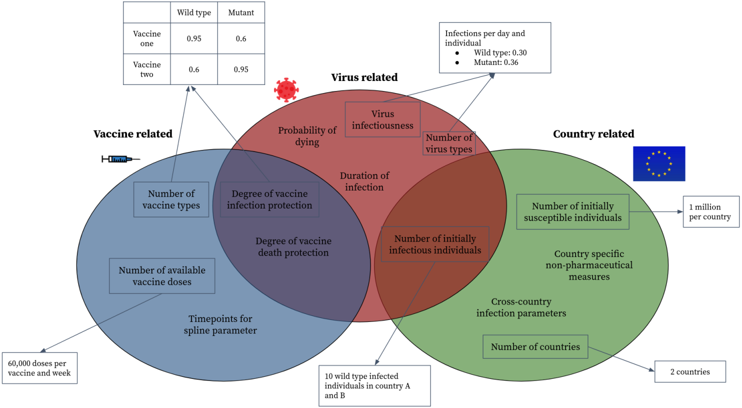


Fixed Parameters

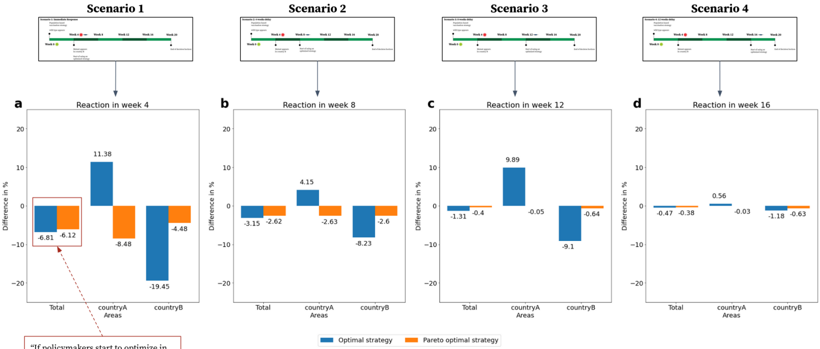


	Wild type	Mutant
Vaccine one	0.95	0.6
Vaccine two	0.6	0.95

Fixed Parameters

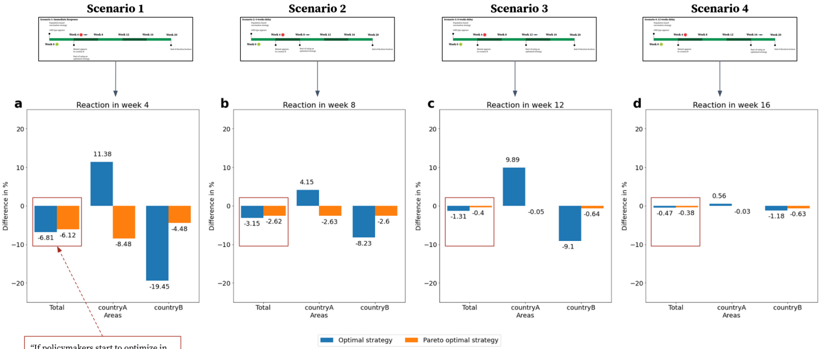


Results relative to population based strategy



"If policymakers start to optimize in week 4, the optimal strategy yields 6.81% fewer deaths and a Pareto optimal strategy yields 6.12% fewer deaths compared to the population based strategy."

Results relative to population based strategy



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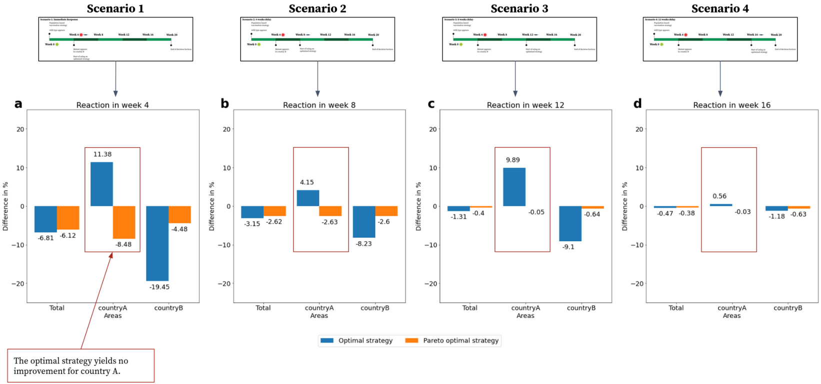

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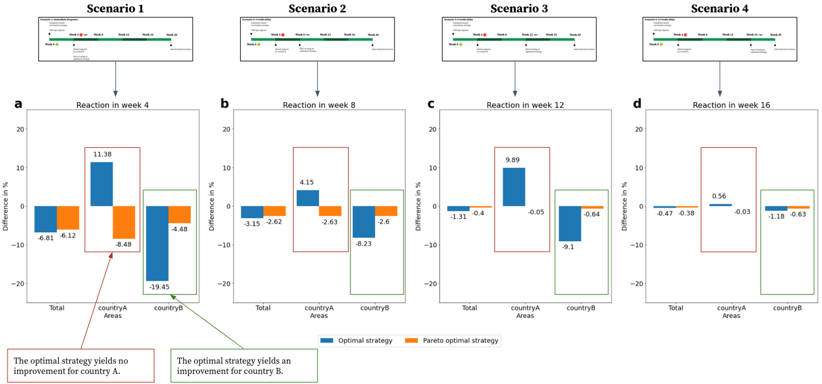

Infection constant

potentially infectious contacts per day per infectious individual

Transmission reduction against virus e if susceptible individual is vaccinated

Degree of lockdown in the countries of the susceptible and infectious individual

$$c_t(a^S, a^I, v^S, v^I, e^I) = \beta \cdot \underbrace{[1 - \gamma(v^I)] \cdot [1 - \delta(v^S, e^I)] \cdot \eta(e^I)}_{\text{ii) vaccine and virus specific}} \cdot \underbrace{\left[\tfrac{1}{2}r(a^S) + \tfrac{1}{2}r(a^I)\right] \cdot \rho(a^S, a^I)}_{\text{iii) area specific}}$$

Transmision reduction if infectious individual is vaccinated

Increase in infections if e is a mutant virus

Cross-country adjustment

Extensions - Countries decide on lockdowns

$$Infection\,constant^{(i)}(t) = Vaccine/Virus\,parameters \times \rho^{(i)}(t)$$

Extensions - Countries decide on lockdowns

multiplier in country i
"lockdown parameter"

$$Infection\ constant^{(i)}(t) = Vaccine/Virus\ parameters \times \boxed{\rho^{(i)}(t)}$$

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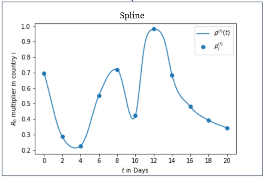

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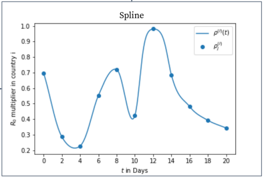
Exogenous



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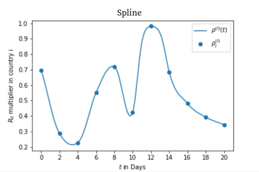
Countries specify multiplier with decision criterion function

$$\rho(t)^{(i)} = g_i\left(states(t), vaccines(t), \int_{t-a}^{t} \rho(t)^{(i)}\, dt\right)$$



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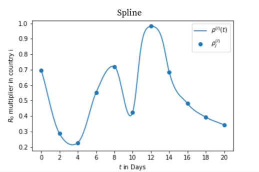
Countries receive utility dependent on deaths and lockdowns

$$utility^{(i)} = U^{(i)}\left(deaths^{(i)}, \int_{0}^{T} \rho(t)^{(i)}\, dt\right)$$



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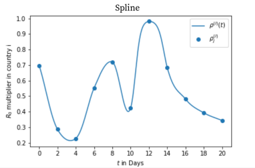
utility over multiplier

$$\max_{\rho^{(i)}(t)}\ utility^{(i)}$$



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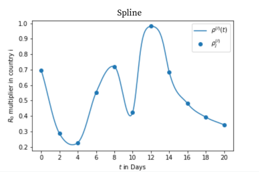

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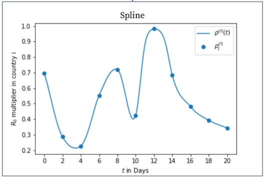
(ii) Vaccine allocator aim to minimize total deaths over vaccine allocation

$$\min_{vaccines(t)} \sum_{i \in I} deaths^{(i)}$$



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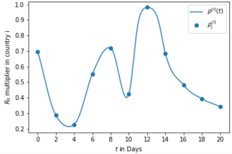
Sequential game

- Nash equilibrium?
- Subgame perfect equilibrium?

Spline



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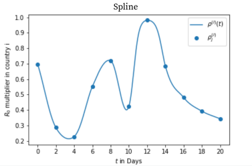

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Sequential game

- Nash equilibrium?
- Subgame perfect equilibrium?

Define order of decisions and conduct backward induction

SIRD models for the optimal allocation of vaccines across countries

Manuel Huth
Supervision: Lorenzo Contento, Jan Hasenauer, Lena Janys

November 17, 2021

HelmholtzZentrum münchen
German Research Center for Environmental Health