Finding the Cost Minimizing Path of Public Health Interventions During the COVID-19 Pandemic

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The views expressed in this presentation are mine and should not be interpreted as CBO's.

Context

- The dials of public health measures containing the COVID-19 pandemic have been turned up and down.
- Projecting the course of the epidemic requires judgment about which policies will be used and when.
- A cost minimization model of policy sequencing supplies a clear rationale for those judgments.
- The results of the cost minimization model do not constitute recommendations. (Its assumptions are much too strong).

Summary

- Review of epidemiological concepts: Effective R0, Herd Immunity, Attack Rate, and policy effects
- Model for finding the cost minimizing Policy Sequence
  - Requires a menu of policies (characterized by R_0, daily economic cost)
  - Works backwards from the end of the epidemic to solve for the policy sequence that minimizes the combination of economic and health-related costs.
- Projections
  - The "effective herd immunity threshold" under sustainable policy determines the outcome of the epidemic in many cases.
  - The epidemic plays out over the fall of 2020 in those cases, even without a vaccine.

The Trade off: Costs of the Pandemic and Measures Restraining It

Costs of the Pandemic Include:

- Health care costs of treating the ill, at home or in hospital
- Mortality: Quality Adjusted Life Years (QALYs) lost per fatality.
- Morbidity (Survivors):
  - Short term costs include lost hours, suffering due to illness.
  - Long-term effects on survivors might include respiratory, renal, cardiological and neurological problems. They might lead in the long term to more lost QALYs than mortality. And they affect productivity.

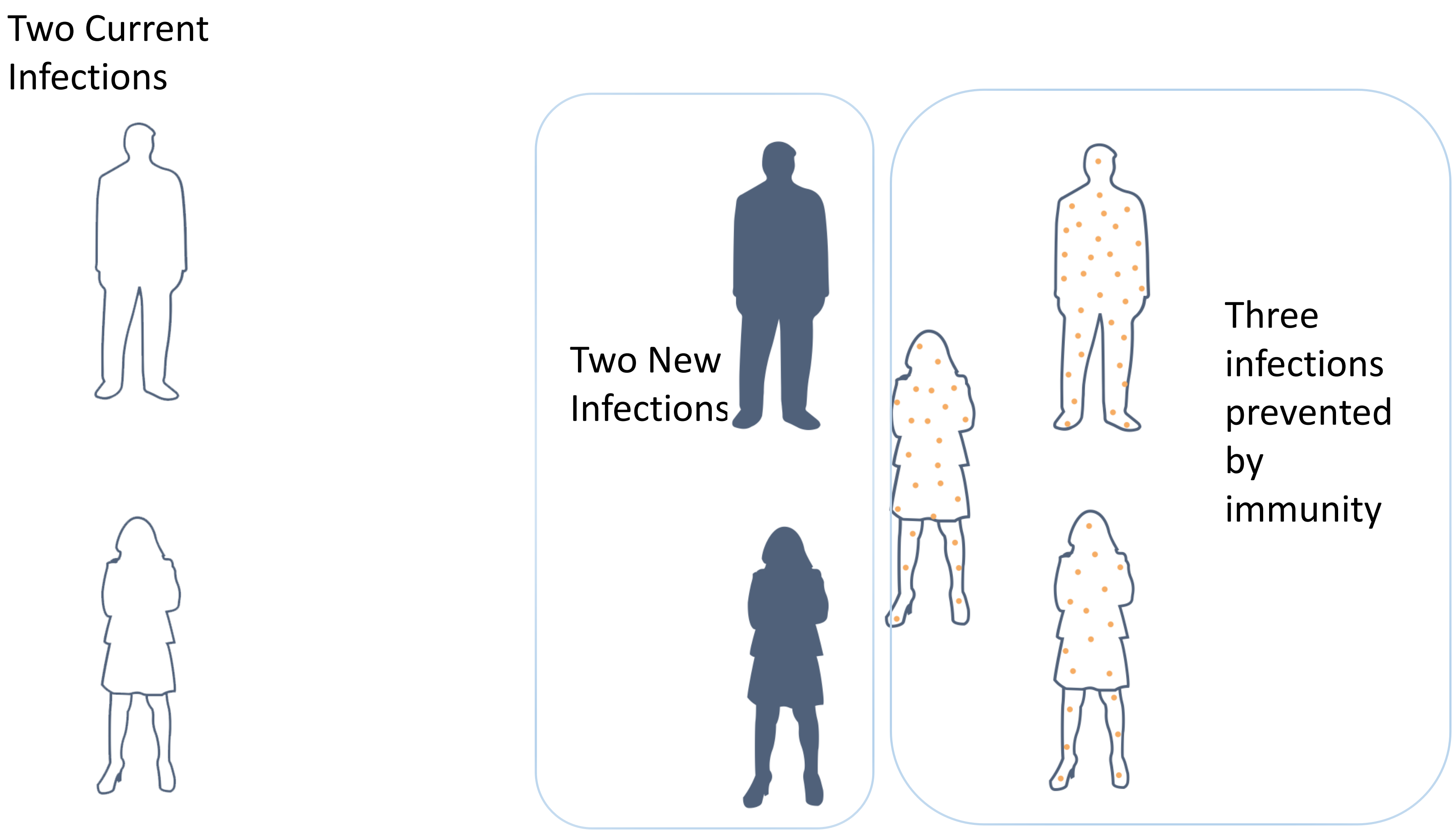
Cost of Measures Restraining It Include:

- Lost economic activity: approximately 10 percent of GDP in second quarter of 2020.
- Lost educational time / effectiveness.
- Lost hours of caregivers from school closings.
- Long term scarring effects on unemployed, in particular on recent graduates.

Epidemiological Concepts

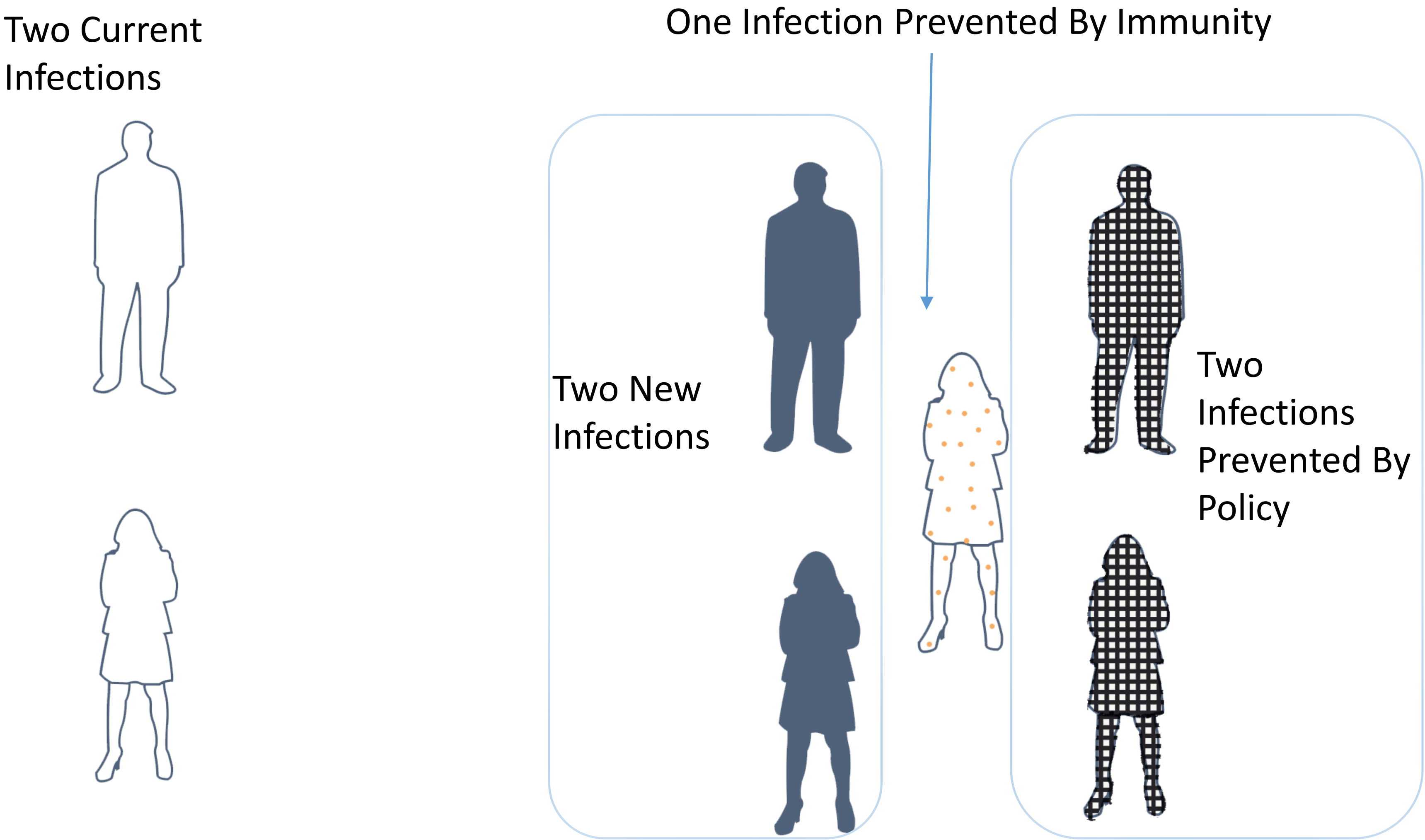
R0, Herd Immunity, the Attack Rate and Policy Effects

R0 = 2.5, Three Fifths Immune: Herd Immunity Threshold is Reached

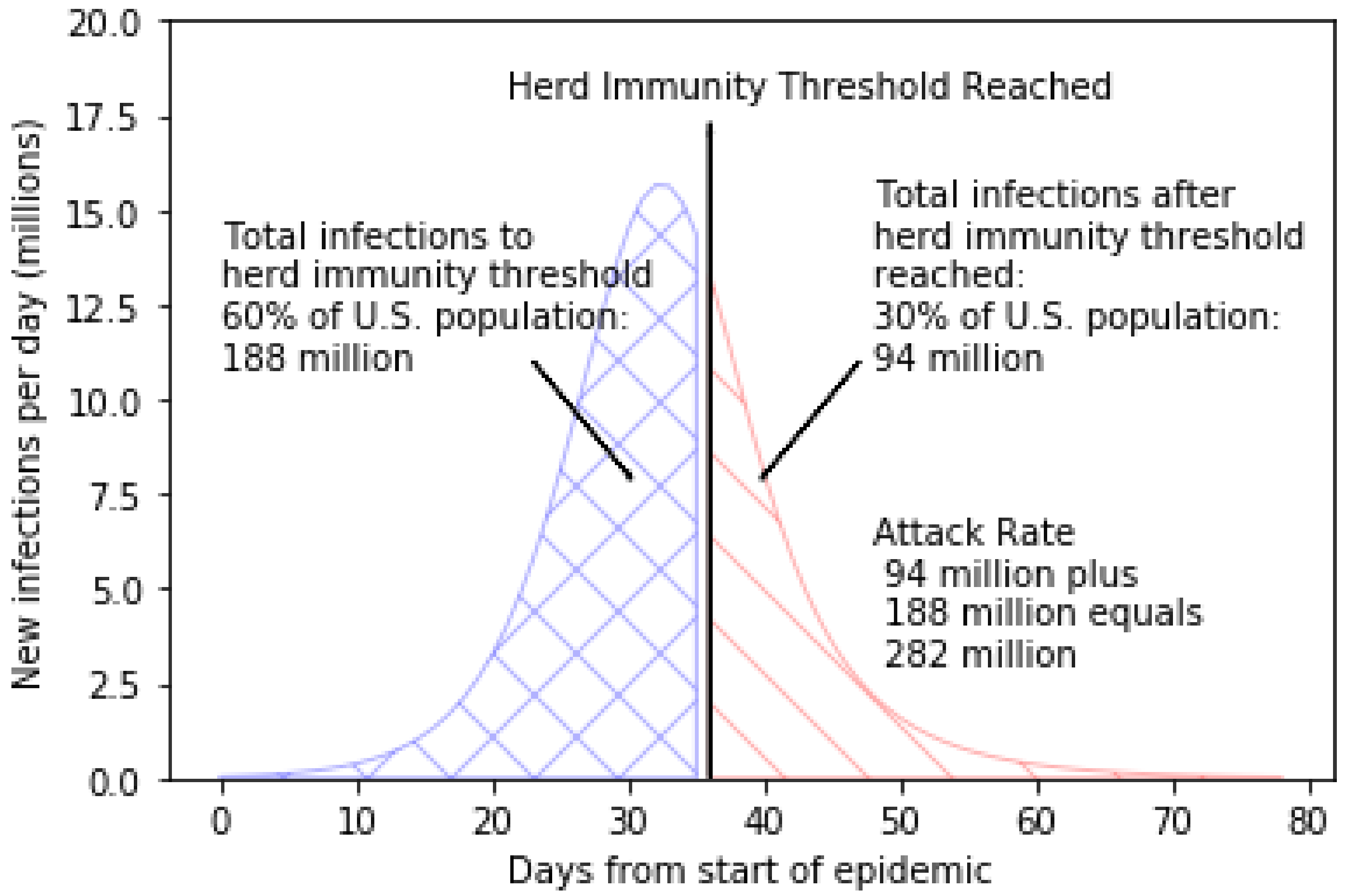


Herd immunity threshold is reached when the immune share of the population reaches 1-1/R_0, three fifths in this case.

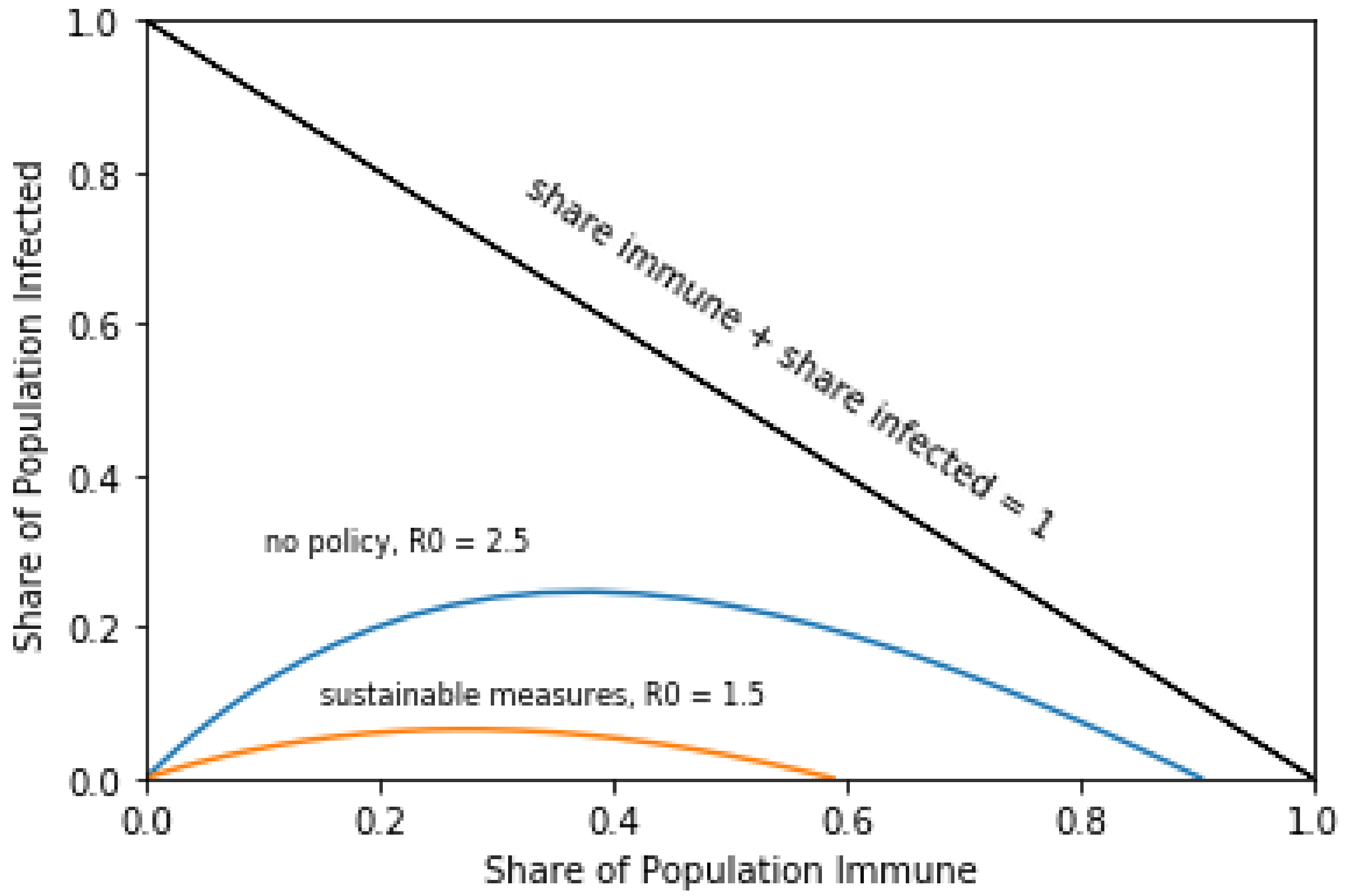
Effective R0 = 1.5, One Third of Population Immune, Epidemic Stops Growing



Policy and immunity can combine to stop the epidemic from growing. Effective herd immunity threshold is one third.



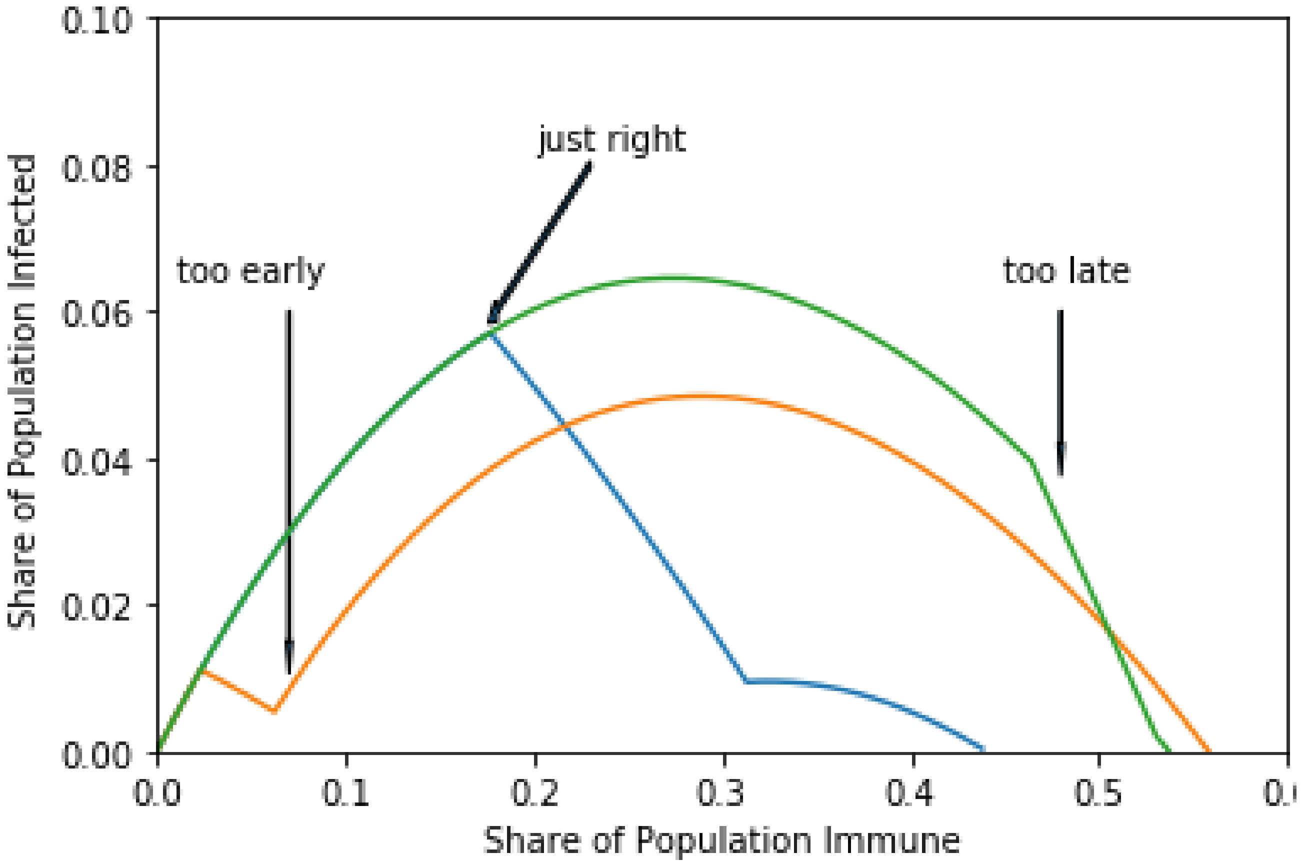
Infections Under "Do Nothing" Overshoot the Herd Immunity Threshold (R0 = 2.5)



Capturing the state of the epidemic as the share of the population that is immune or infected

Finding the Cost Minimizing Policy Sequence

Three alternative times for applying temporary restrictive measures



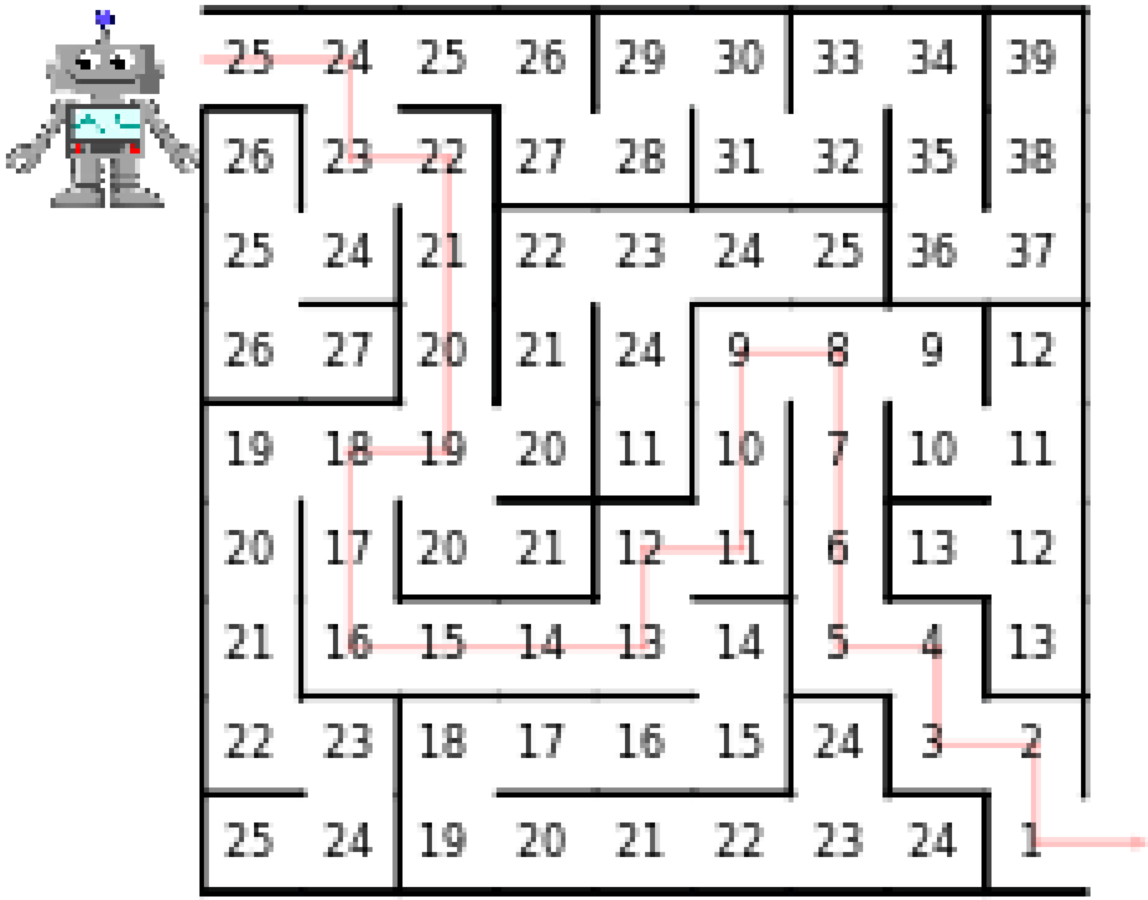
- All three scenarios combine a sustained policy resulting in an effective R0 of 1.5, with a 30-day burst of temporary restrictive measures, with an effective R0 of 0.9. The difference between the three scenarios is in the timing of the burst.
- Applying the restrictive measures well before or after peak infections does not reduce ultimate infections by as much as applying them as the epidemic approaches the peak.

Finding the sequence that gives the lowest cost

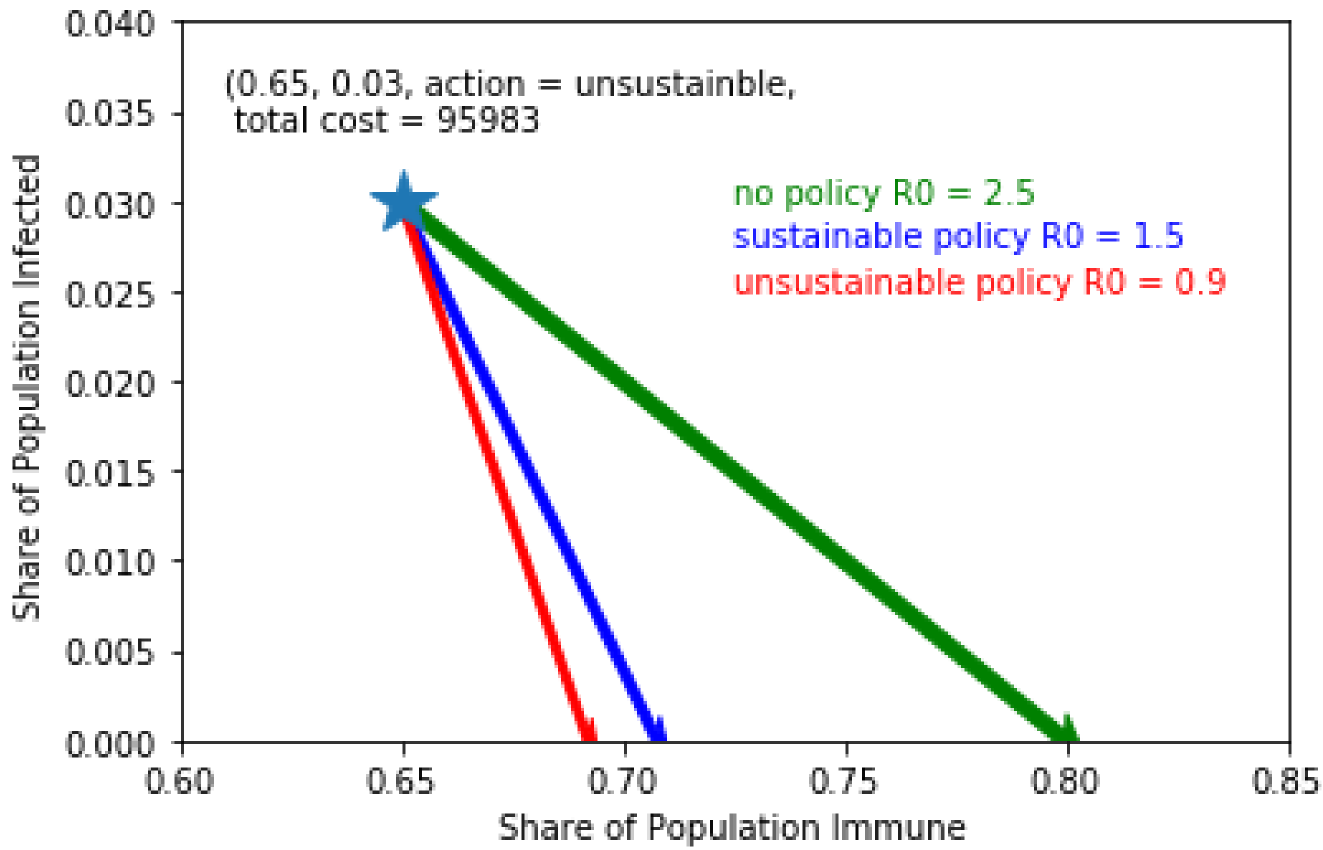
- Develop a menu of potential policies which for each includes:
  - The effective R0: the initial rate of transmission that would occur if that policy were in place.
  - The daily comprehensive cost of maintaining the policy, measured in dollars: the direct cost of policy measures (the cost of tests and glass plates and so on), plus economic activity lost, plus willingness to pay for amenity of not wearing a mask, and so on.
- Estimate costs of mortality and morbidity for the disease to be traded off against the policy costs, converted to dollars (using QALY and so forth).
- Assume a probability of a vaccine being developed at each time.
- Work backwards from the end of the epidemic.

Example of Backwards Optimization: Robot Finding Fastest Way Through Maze

- Start at the end of the problem (bottom right) and work backwards (1 step from exit, 2 steps from exit).
- Fill the entire state space with a cost measure (in this example: distance from exit)
- When faced with choices, make decisions based on what action leads to the lowest cost: for example at space labeled 24 turn down to the “23” rather than continuing right to the 25.

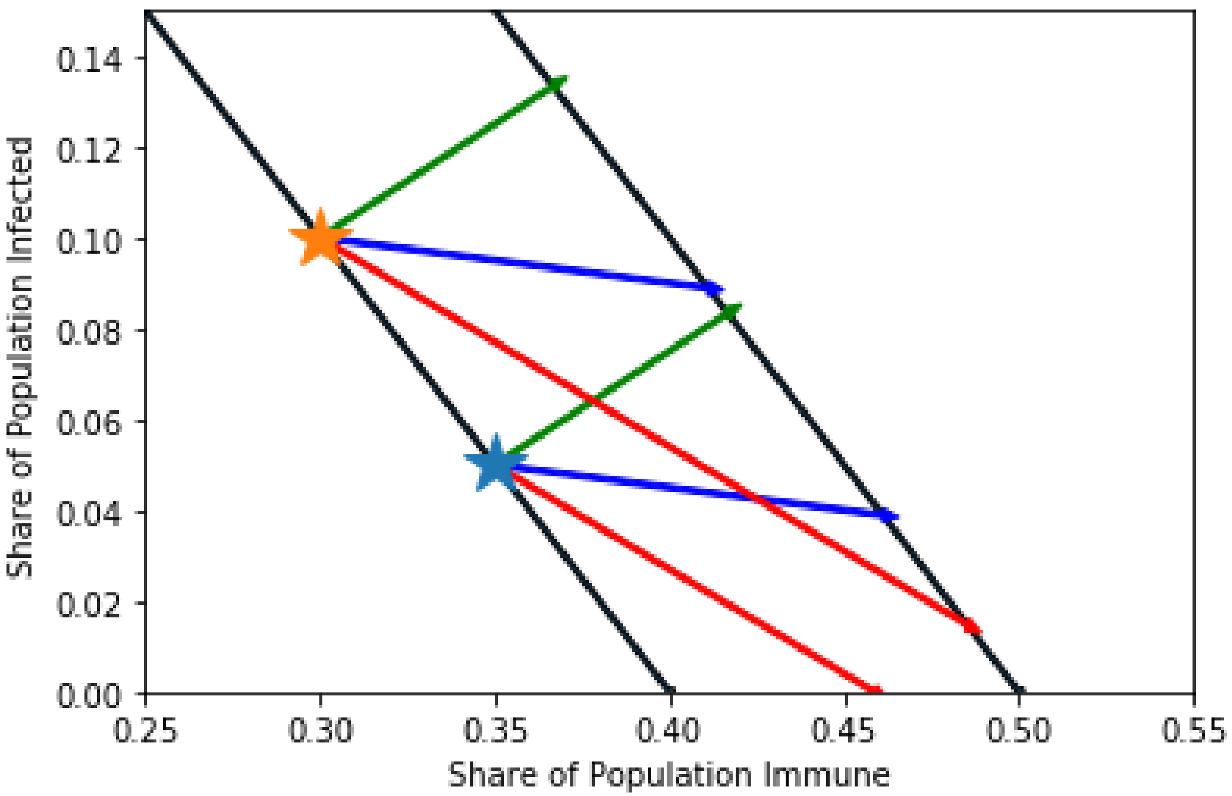


Working backwards in the epidemic state-space



Policy	None	Sustainable	Unsustainable
Deaths	281,700	108,346	79,129
Days	60	23	17
Daily Cost of maintaining policy (equivalent deaths)	0	5	1000
Total Cost	281,700	108,461	95,983

Backwards induction through the state-space

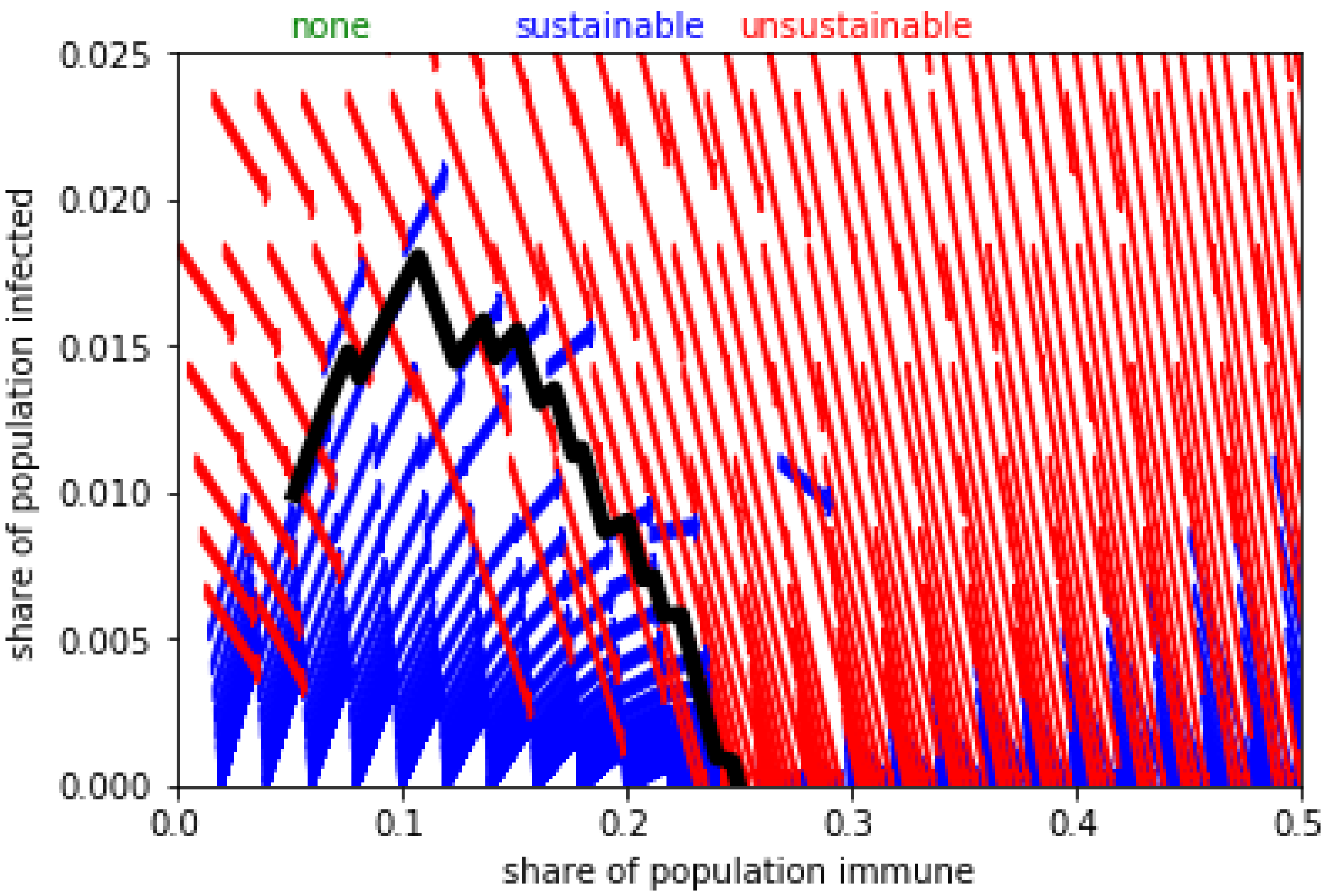


- To solve backwards through the state / space calculate the total cost at nodes along diagonal lines where share infected + share immune = k by:
  - Find the path to the next diagonal line associated with each action.
  - Calculate the cost of taking that path.
  - Add it cost associated with the destination point on the next line (requires interpolation)

Following the map through the state space: example where effective R0 =1.3 for sustainable policies

- The arrows show the optimal policy at each point in the state space and the direction that policy takes the epidemic.
- The projected path through the state space find the nearest arrow and follows it until another arrow come closer.
- The arrows in this case steer the epidemic towards the effective herd immunity threshold associated with sustainable policy:

(1 – 1 / 1.3) = 0.23



Projections under the cost minimizing policy sequence

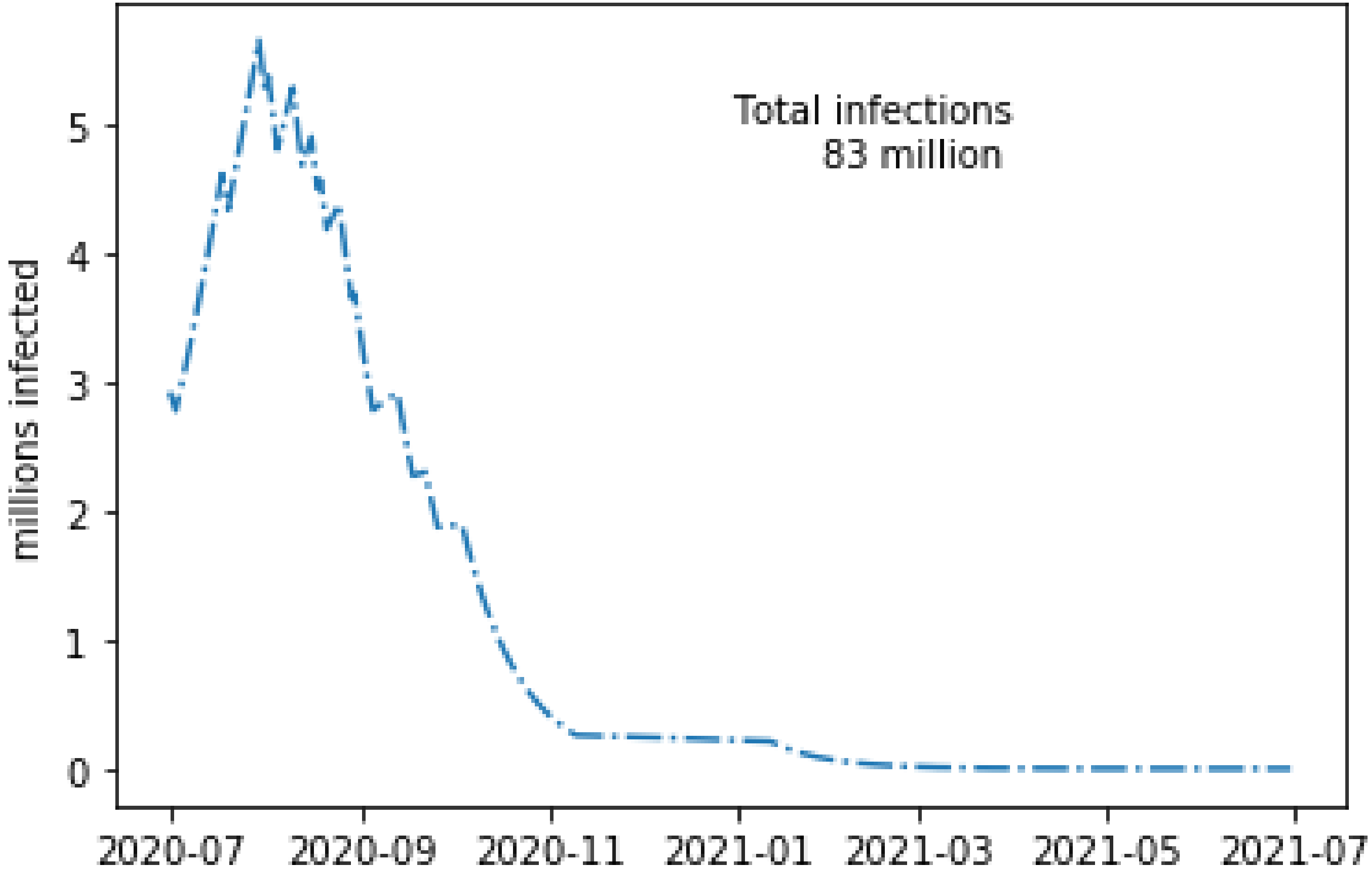
Benchmark Projection Assumptions (illustrative parameters)

- Three policy options:
  - “None” (R0 = 2.5),
  - “Sustainable” effective R0 = 1.3/1.6, daily cost = $50 million (18 billion / year)
  - “Unsustainable” effective R0 = 0.9, daily cost = $5 billion (1.8 trillion / year)
- Serial interval: 6 days
- Fatality rate = 0.6 percent.
- Health care capacity: 7 million active infections
- Cost per fatality = $5 million (includes survivor health effects)
- Time to vaccine = 1.5 years on average, probabilistic

The model also assumes homogeneity, complete adherence to policy, and that the disease confers immunity. Policy leads to the same effective R0 (but different Rt) no matter where you are in the state space.

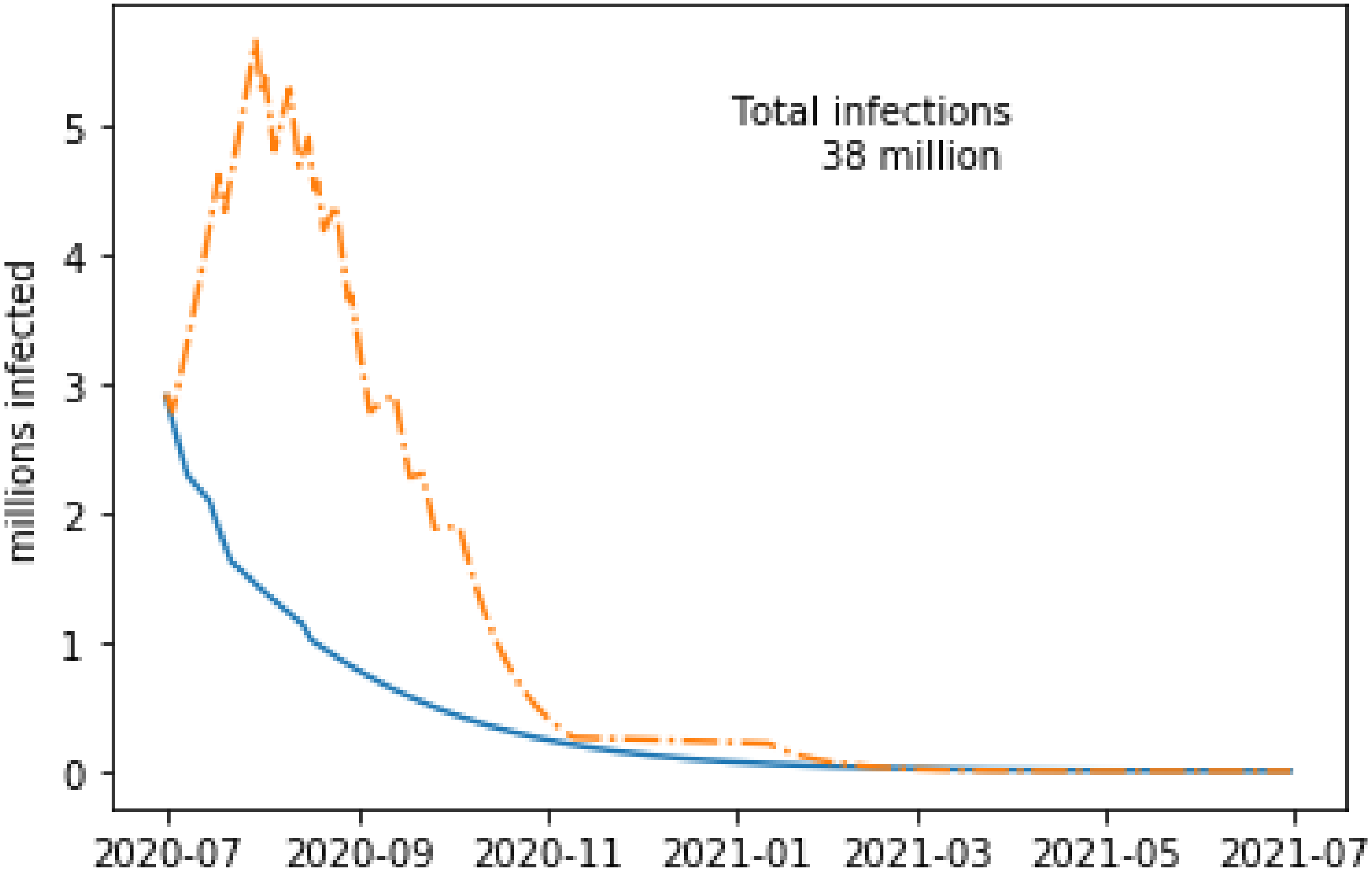
Benchmark Projection (sustained R0 = 1.3, temporary R0 = 0.9)

Managed path to effective herd immunity threshold (23 percent of population)



Containment (sustained R0 = 0.99, temporary R0 = 0.9)

The epidemic can be contained under sustainable measures



On and off mitigation (sustained R0 = 1.6, temporary R0 = 0.9, higher cost of mortality and morbidity, vaccine coming sooner)

The epidemic can only be contained under temporary measures, which are turned on and off to avoid reaching herd immunity threshold.