How Long Should the COVID-19 Lockdown Continue?

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Heinz College

Papers on COVID-19 Lockdowns

- **Papers modeling epidemic & economy**
  - **#1: pick start & end time of lockdown**

    Recently accepted at *PLOS-ONE*.
  - #2: continuously vary intensity of lockdown
  - #3: lockdown policy between vaccine's approval and full deployment, including how allocate vaccine between workers & retirees

Balancing Loss of Jobs and (Direct) Loss of Life

- World Bank estimates that COVID-19 will push 175M people below the poverty line
- Most economic losses are caused by “lockdowns” and other efforts to combat COVID-19, not direct health harms
- Lockdowns create an equity challenge
  - Economic losses concentrated among working age
    - At least in places with fixed benefit retirement plans
  - Health benefits are concentrated among retirees

Many Indirect Effects on Health

- Benefits
  - Fewer flus and colds
  - Less air pollution and associated deaths
  - Etc.
- Harms
  - Delay of other health care
    - Even cancer screening
  - Divert scarce funds away from control of malaria and HIV/AIDS in Africa
  - Etc.

Backbone is Classic "SLIR" Model of Contagious Infection

$S(t)$: Number of susceptible individuals at time t

$L(t)$: Number of latent (asymptomatic and pre-symptomatic) individuals at time t

$I(t)$: Number of infected individuals who are showing symptoms at time t

$R(t)$: Number of recovered individuals at time t,

the SLIR state equations are:

$$\dot{S}(t) = \nu N(t) - \beta \frac{S(t)(I(t) + fL(t))}{N(t)} - \mu S(t) \tag{1a}$$

$$\dot{L}(t) = \beta \frac{S(t)(I(t) + fL(t))}{N(t)} - (\mu + \varphi)L(t) \tag{1b}$$

$$\dot{I}(t) = \omega\varphi L(t) - (\alpha + \mu + \mu_I)I(t) \tag{1c}$$

$$\dot{R}(t) = (1 - \omega)\varphi L(t) + \alpha I(t) - \mu R(t) \tag{1d}$$

$$\beta := R_{\text{eff}}(t, \tau_1, \tau_2)\alpha \tag{1e}$$

$$N(t) := S(t) + L(t) + I(t) + R(t).$$

Objective Function

Deaths of people who do and do not receive needed critical care.

Cobb-Douglas economic production reduced by lockdown.

$$V(X_0, \tau_1, \tau_2) := \tag{2a}$$

$$\int_0^T \Big(M(\xi_1 pI(t) + \xi_2 \max(\{0, pI(t) - H_{\max}\}, \zeta)) - K\gamma(t, \tau_1, \tau_2)^\sigma W(t)^\sigma \Big) dt + \tag{2b}$$

$$(T + \Gamma) K W(0)^\sigma \gamma(0, \tau_1, \tau_2)^\sigma - \Gamma K W(T)^\sigma \gamma(T, \tau_1, \tau_2)^\sigma \tag{2c}$$

$$V^*(X_0) := \min_{\tau_1, \tau_2} V(X_0, \tau_1, \tau_2), \quad X := (S, L, I, R), \quad W := S + L + R. \tag{2d}$$

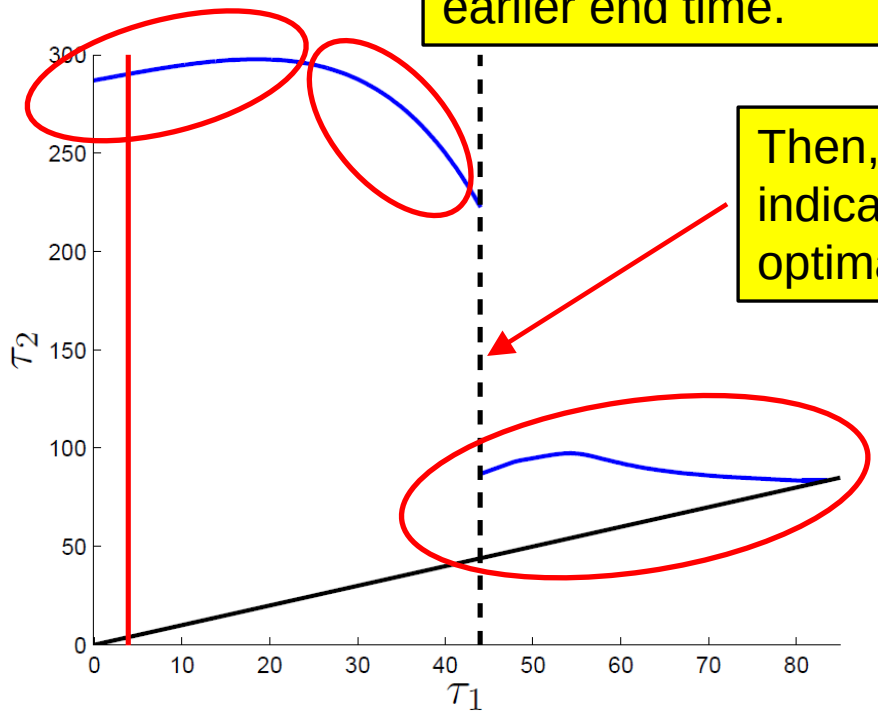
M is a key parameter. It is the cost of a premature death expressed as a multiple of daily GDP per capita. E.g., if premature death is valued at 20X GDP per capita, then M = 7,300. We consider range of 10-150X, i.e. 3,650 < M < 54,750.

Additional economic loss from delay returning to full employment after vaccine.

Optimizing the lockdown's end time (τ_2) for various start times (τ_1)

Initially, later start goes with later end time for lockdown.

Then, surprisingly, later start goes with earlier end time.

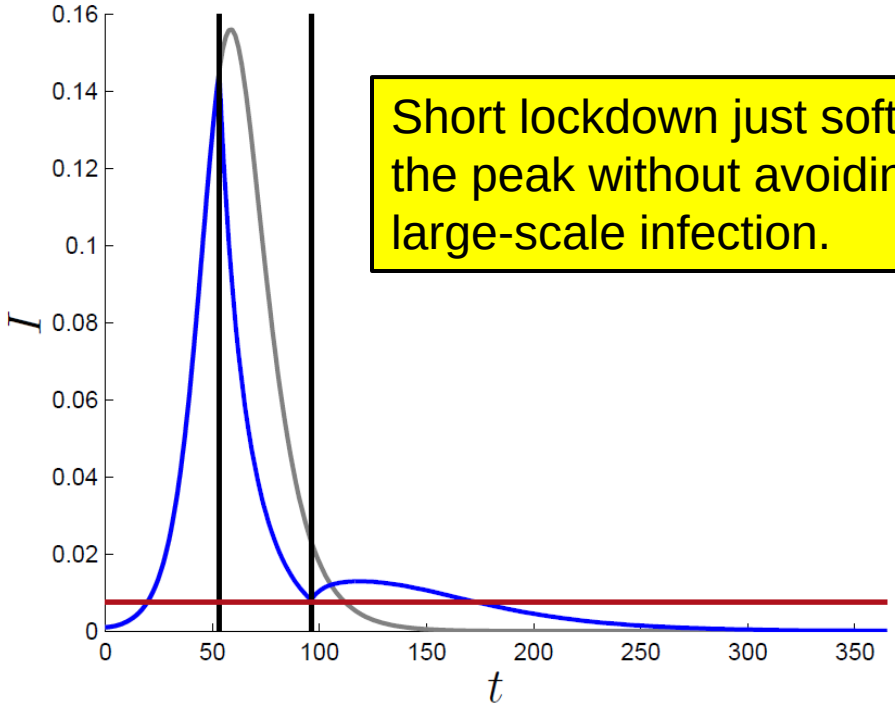


Then, a discontinuity indicates two alternate optimal solutions.

If lockdown starts very late it should be short; "horse it out of the barn".

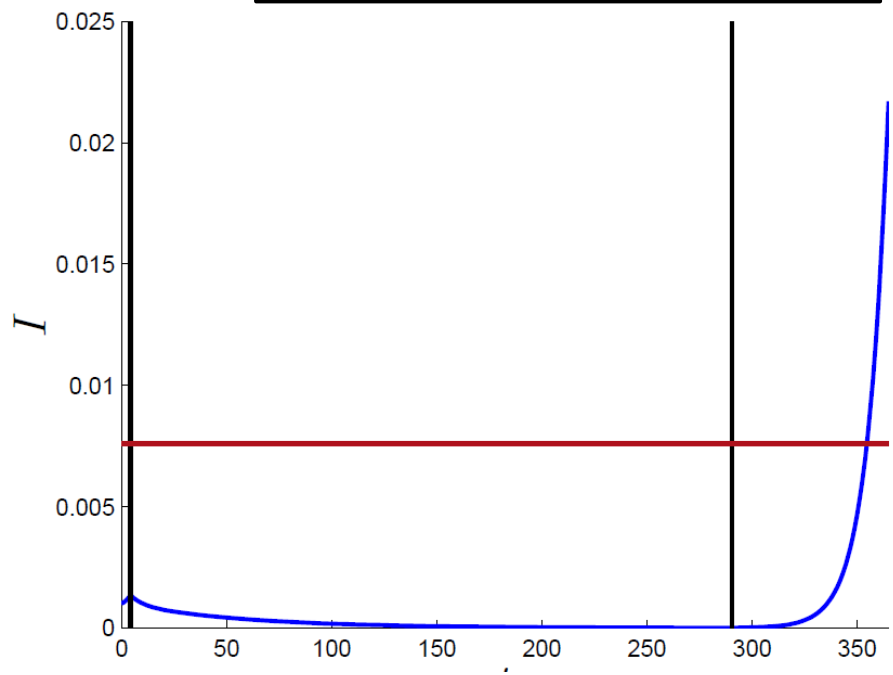
Fig 7. Fixed initial lockdown time τ_1 and optimally chosen time τ_2. For $\tau_1 = 44$ there exists a Skiba solution, i.e. there are two different solution paths which deliver the same objective value.

Different Strategies Lead to Very Different Infection Trajectories



Short lockdown just softens the peak without avoiding large-scale infection.

Prolonged lockdown keeps infections low (“surge” at end is in anticipation of vaccine’s deployment)



Optimal Strategy Depends on M, the Value of Preventing a COVID Death

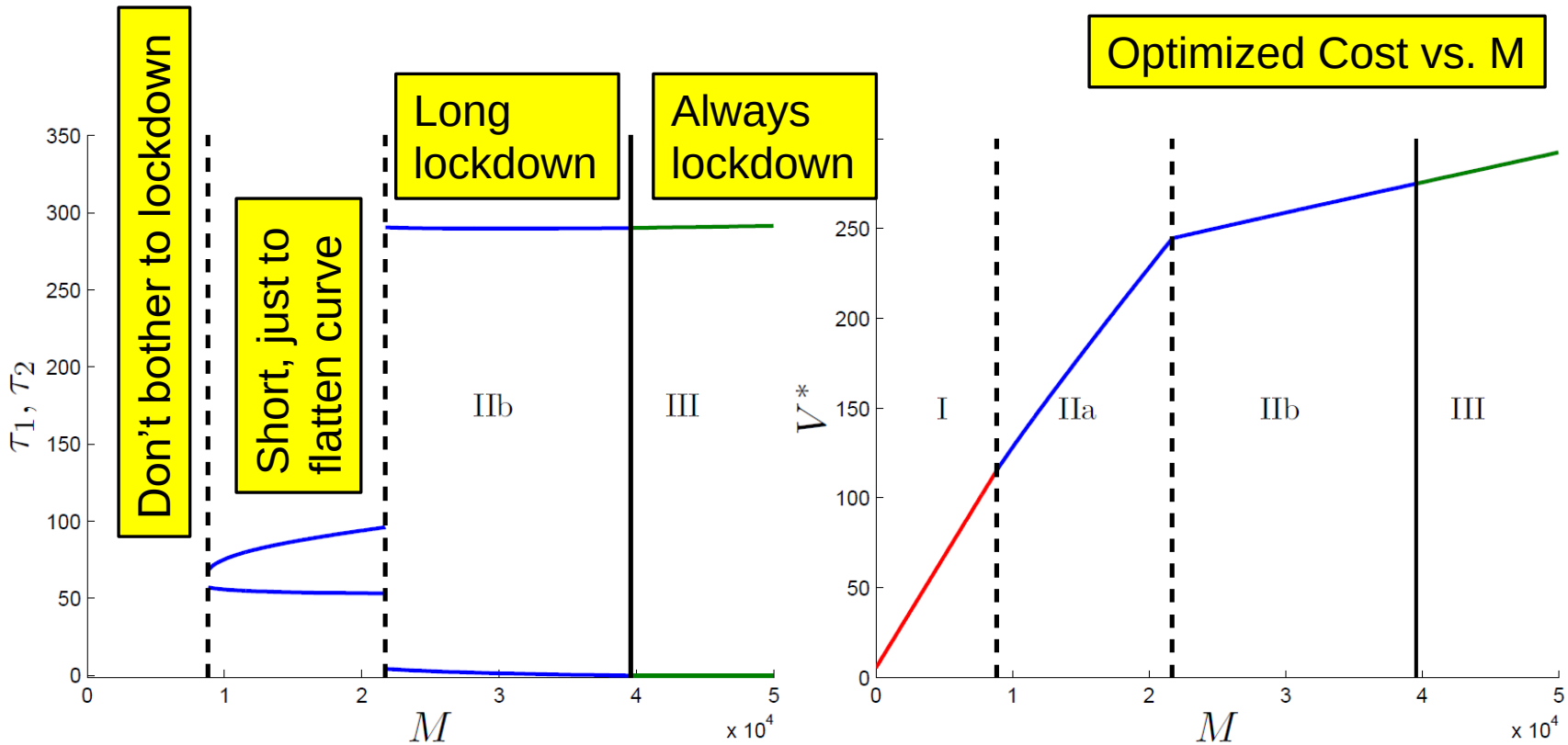
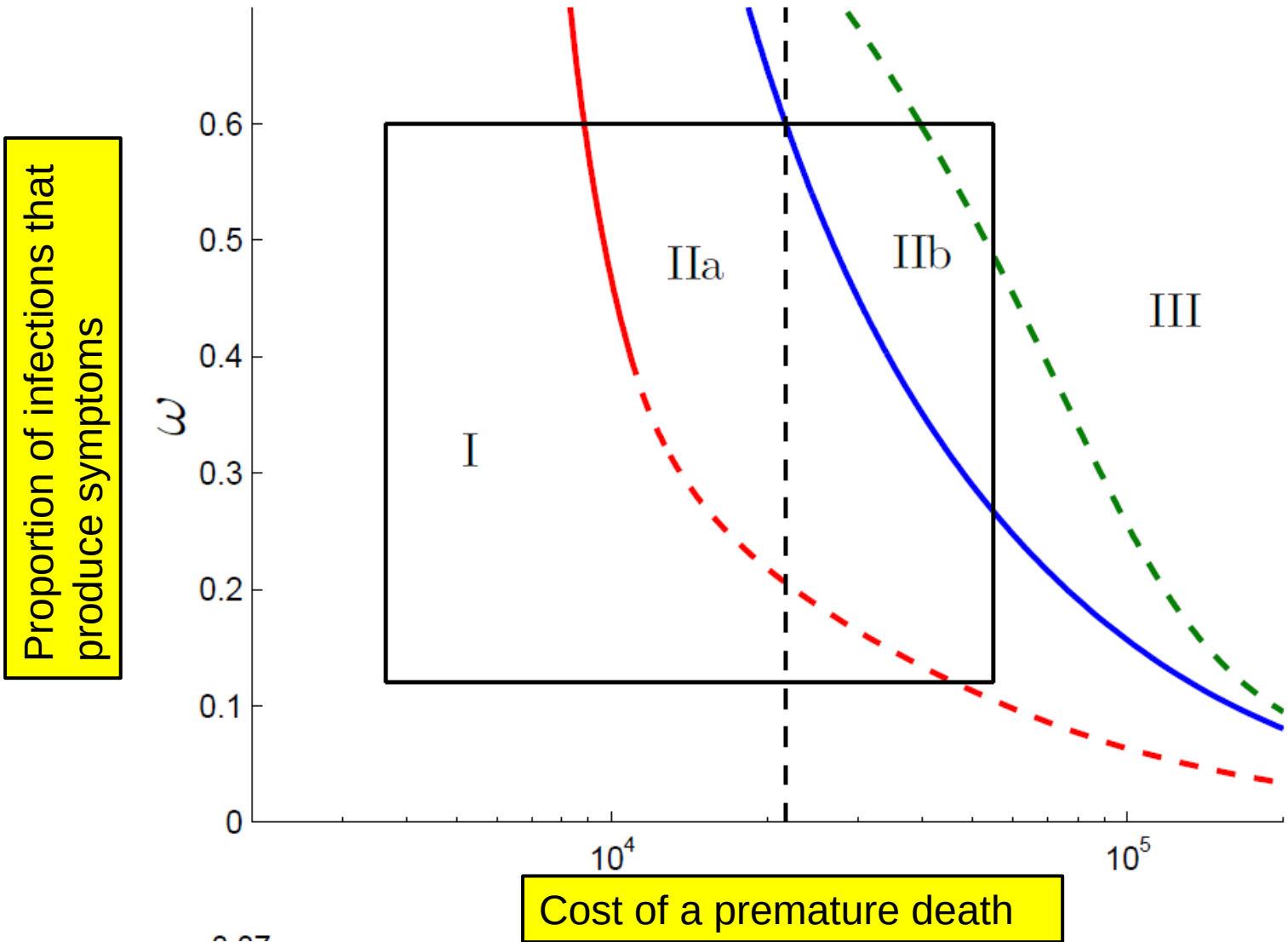


Fig 8. Figure showing the different regimes for varying M. The other parameter values are taken from Table 1. Mathematical description of the three regimes: Regime I: no lockdown, i.e. $\dot{X}(t) = \mathrm{SLIR}_1(t), 0 \leq t \leq 365$, Regime II: lockdown in interval $(0, 365)$, i.e. $0 < \tau_1 < \tau_2 < 365$, Regime III, lockdown starts immediately, i.e. $0 = \tau_1 < \tau_2 < 365$.

Plausible Variation in Two Unknown Parameters Alters Strategy



Conclusion of Paper #1

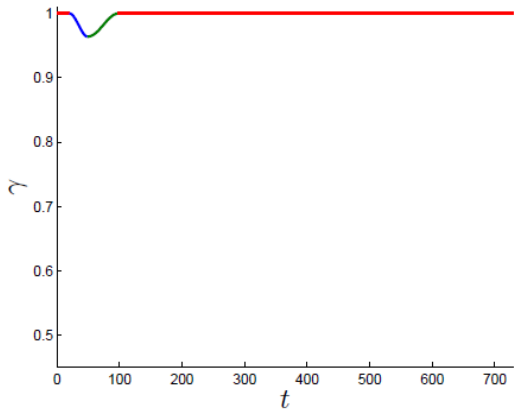
- Two people with the same understanding of the "science" and very similar – even identical – values can still favor very different policies.
- Plausible variation in two key parameters can alter dramatically what policy is optimal.

- Moral: A little more humility and a little less rancor may be appropriate when arguing over COVID-19 lockdown policies.

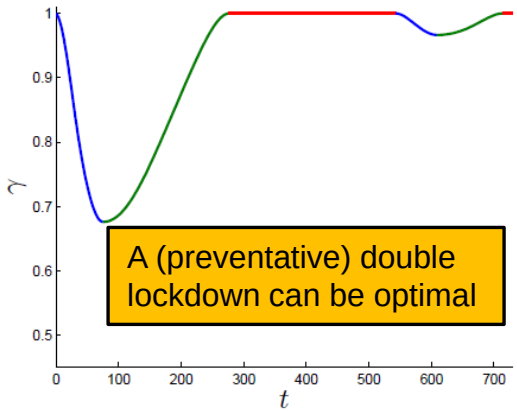
2nd Paper Allows Lockdown to Vary in Intensity & to Create "Fatigue"

Three types of strategies:

γ(t) measures employment

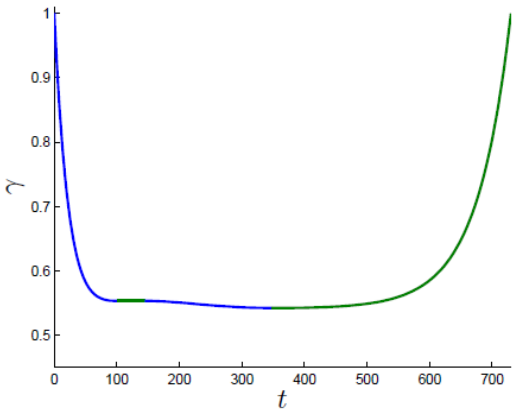


Brief lockdown



A (preventative) double lockdown can be optimal

Double lockdown

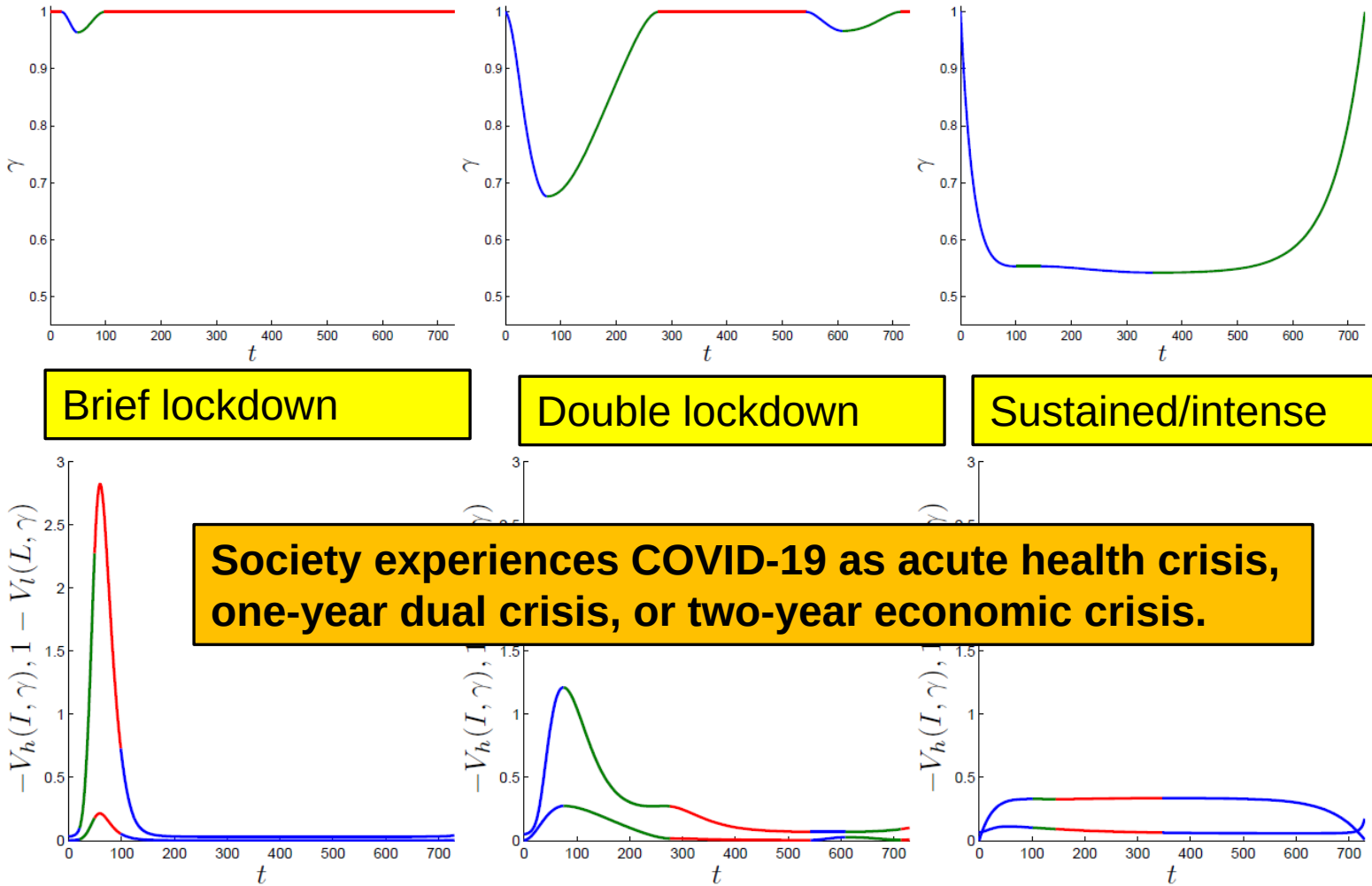


Sustained/intense

Alternate Optimal Strategies Are Very Different!

Three types of strategies:

Health & Econ Costs



Brief lockdown

Double lockdown

Sustained/intense

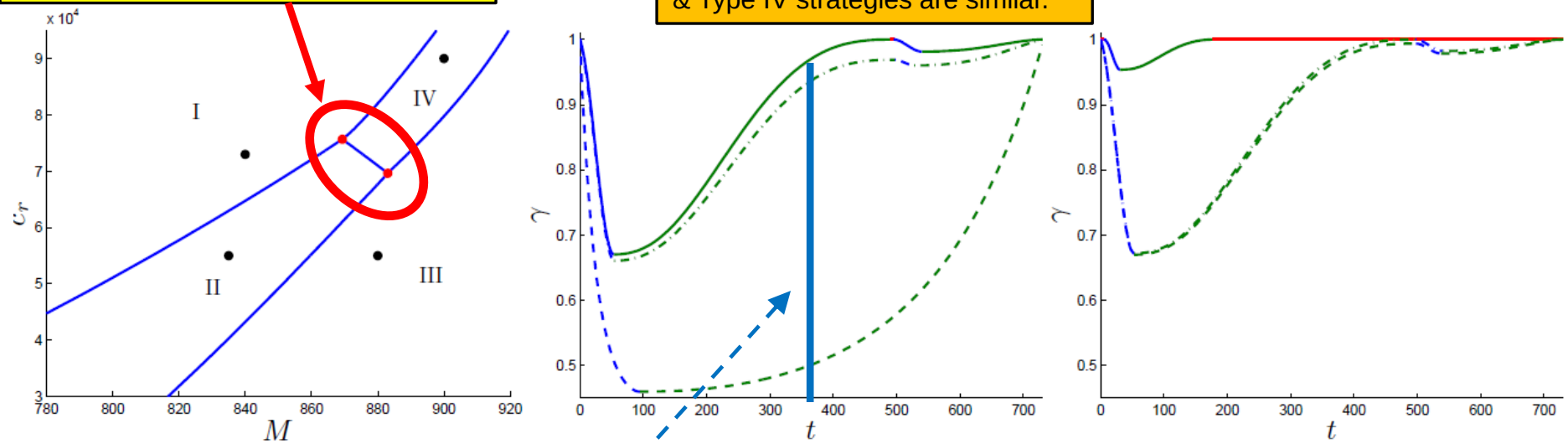
Society experiences COVID-19 as acute health crisis, one-year dual crisis, or two-year economic crisis.

(d) Regime I (e) Regime II (f) Regime III

Formally There Is A 4th Strategy: Two Lockdowns Separated by Full Employment

Two Triple Skiba Points

For these parameters, the Type II & Type IV strategies are similar.



(a) (b) $c_r = 69632.7, M = 883$ (c) $c_r = 75672.5, M = 869$

At the end of year 1, there are optimal strategies with employment at 50%, 90%, and 95%, but not any intermediate levels.

Imagine seven identical countries, that at day #365 are rank ordered by intensity of lockdown. It could be that countries #2, #4, and #6 are behaving optimally, while #1, #3, #5, and #7 are not.

Conclusion Overall

- Modeling the balance of health & economic objectives during a pandemic is a rich area for research.