Integrating Voluntary and Policy-Induced Behaviours into Epidemiological Models

Eli P. Fenichel
Knobloch Family Professor of Natural Resource Economics
Yale School of the Environment

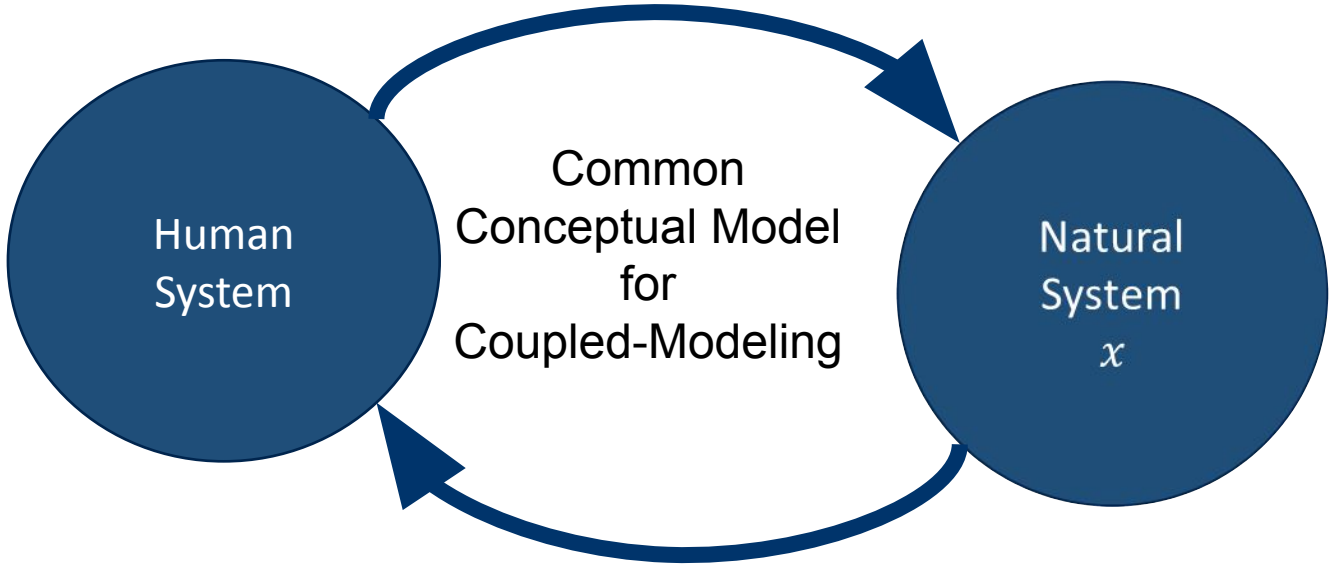
*** Disclaimers:

(1) There will be an exception to every characterization I make in this talk.

(2) A lot has happened in the last two years, and I have found it impossible to keep up.

A core challenges for connecting epidemiological models and models of socio-economic dynamics are similar to the core challenges in coupled human-natural systems

- Bounding the system
- Aggregation (from "micro" to "macro" and back again)



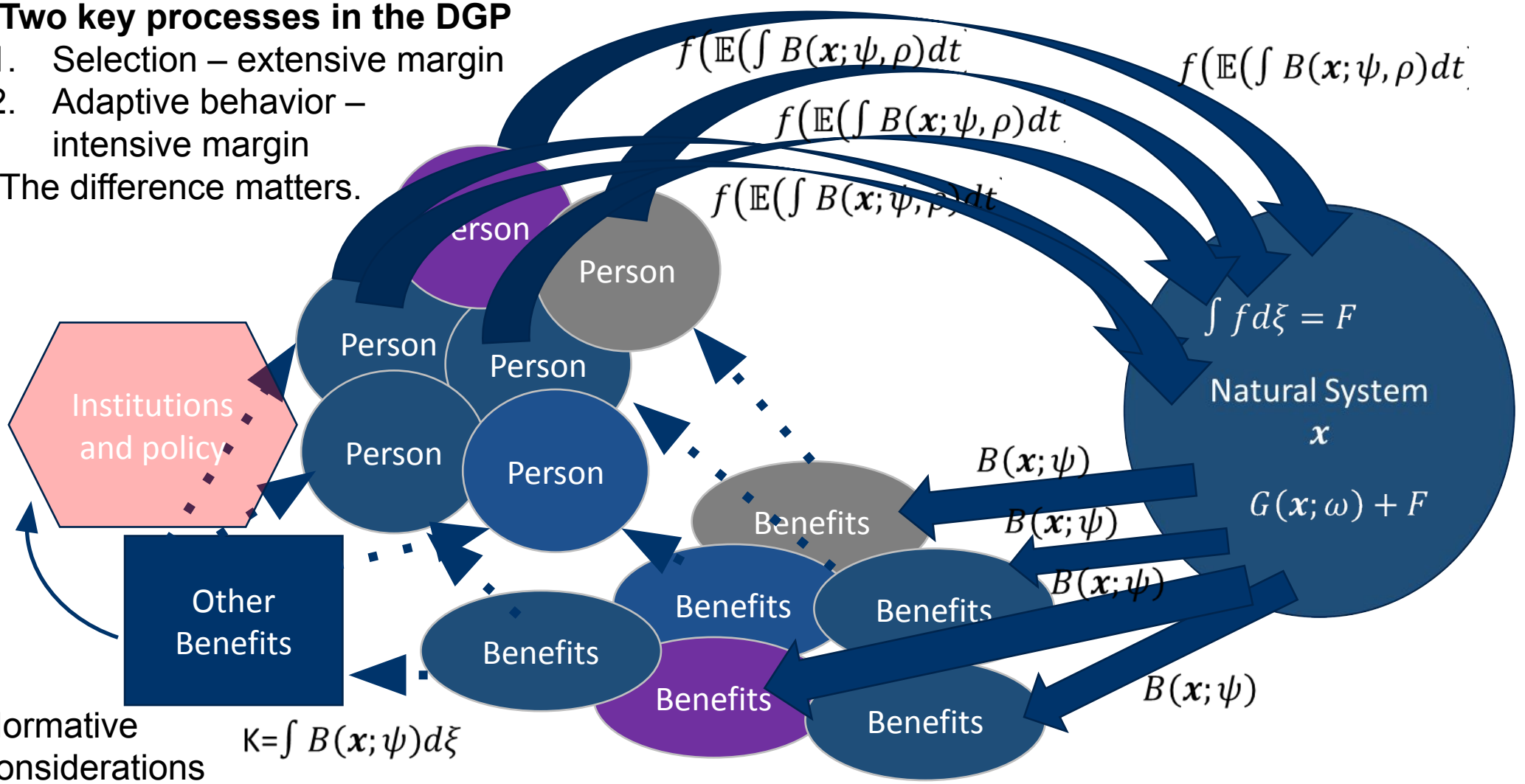
$$\text{"max"}_{\{choices\}} U(Human\ System, Natural\ System, choices)$$

$$s.t.\ \frac{d}{dt} F(Human\ System, Natural\ System, choices)$$

Two key processes in the DGP

1. Selection – extensive margin
2. Adaptive behavior – intensive margin

The difference matters.



Fenichel & Abbott 2014 (REE)
Veliov 2005 (JMB); 2008 (J Math Analysis & App)

Infectious disease modeling is built around the compartmental modeling framework.

$$\dot{S} = \alpha - F(S,I,R) - \delta S$$

$$\dot{I} = F(S,I,R) - G(I) - H(I) - \delta I$$

$$\dot{R} = G(I) - \delta R$$

With the primary focus on the transmission function $F(S,I,R)$ commonly written as $\beta(N)SI/N$, with $N = S + I + R$

Recovery and disease mortality function $G(I)$ and $H(I)$ are often defined as first order approximations gI and hI. Added classes mostly modeled similarly.

This is the βgh formation.

If β, g, and h are constants then there is no space for interesting behavior in this model.

- Confounded parametric assumptions.
- Most connections to society are via behavior changes, so what causes behavior changes.
- The βgh model cannot help evaluate behavioral-based interventions or "spillovers."
- Can't use peoples revealed preferences to evaluate alternative policies or guide normative aggregation decisions.

SARS-CoV-2 is *ad hoc* adjustments to parameters the βgh formation.

Heterogeneity (networks, ABMs, more compartments). – Behavior is just a selection process.
We warned this was a problem for flu-like pathogens in Fenichel et al. 2011 (PNAS) and Kremer discussed in the context of HIV in 1996.

βgh Breakdown – even if we only care about cases and death

Business closure

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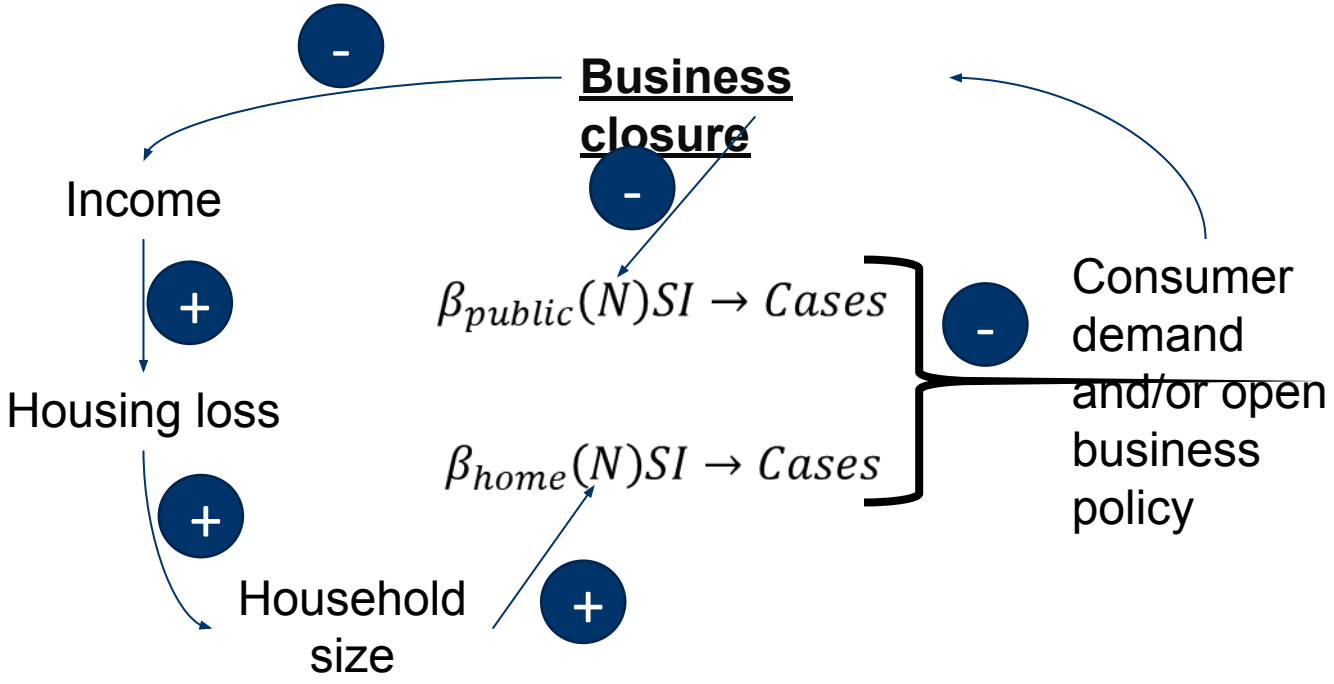
$$\beta_{public}(N)SI \rightarrow Cases$$

βgh Breakdown – even if we only care about cases and death



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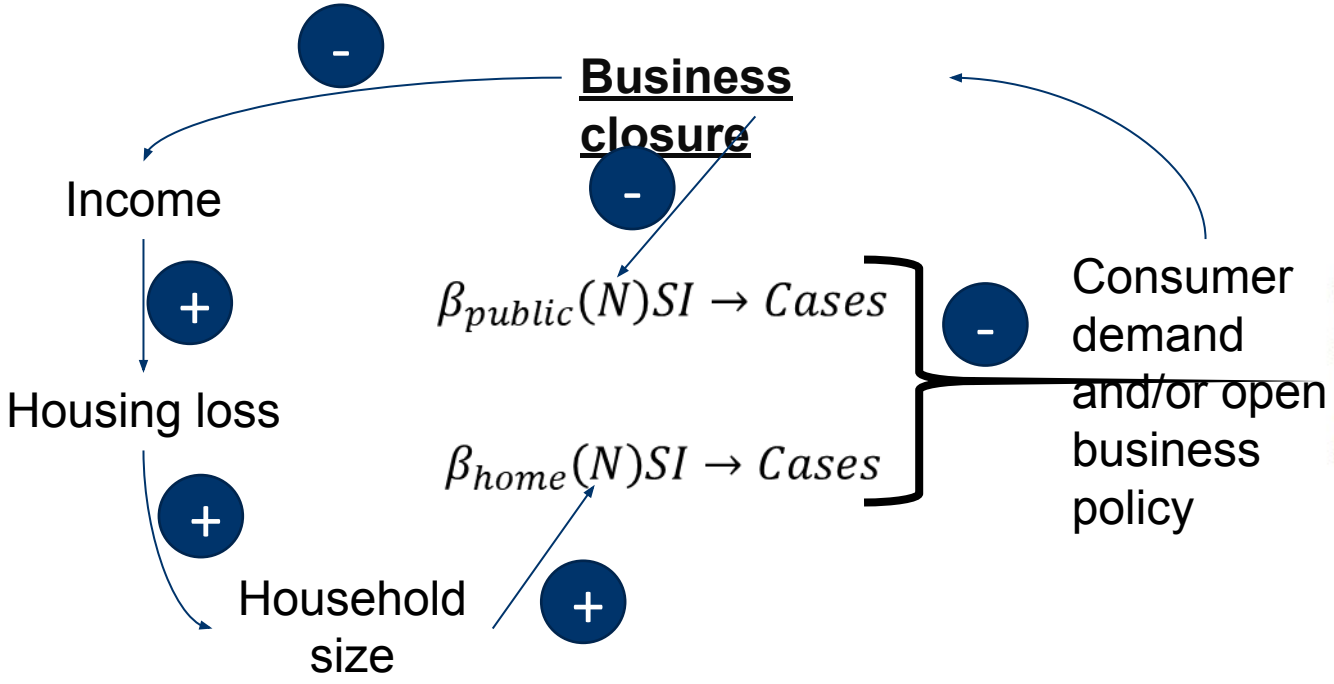
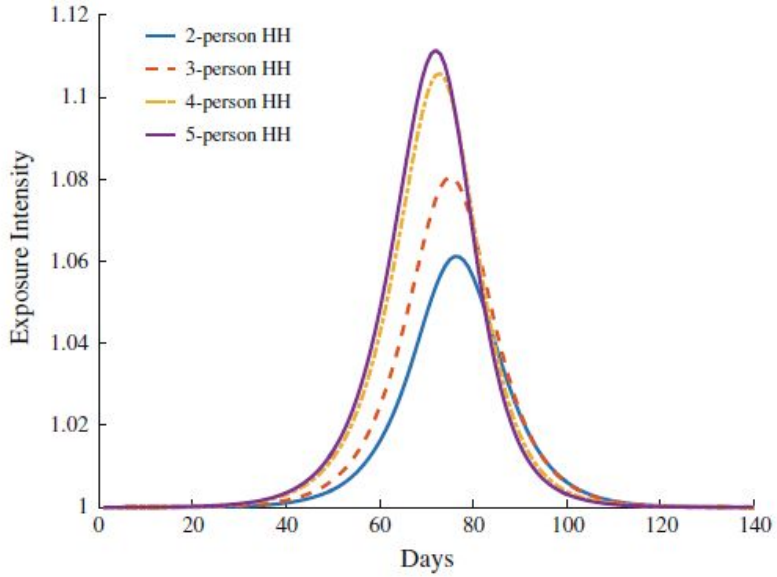


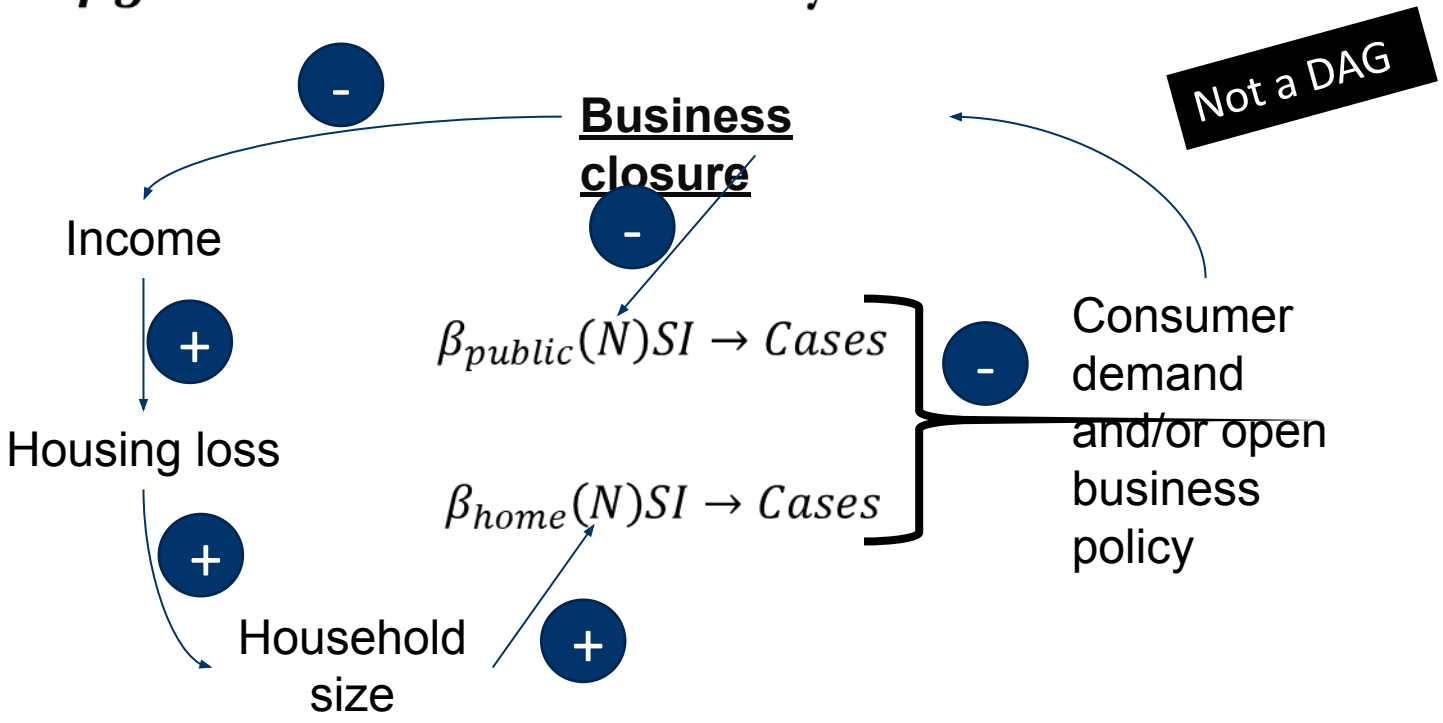


From Fenichel & Bayham (2016)

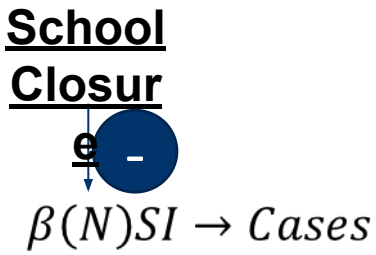
What is the net effect? – Flu based thinking:

- Ferguson et al. (2005) Nature 30% of cases are in home transmission, but these are Thailand households that large.
- Fenichel & Bayham (2016) 12-23% of US flu-ish cases are within home transmission.
- Cauchemez et al. et al. (2009) NEJM; House & Keeling (2009) Am J Epi find no increas in home relative to public transmission for the US.

βgh Breakdown – even if we only care about cases and death



βgh Breakdown – death is not 1-to-1 with cases



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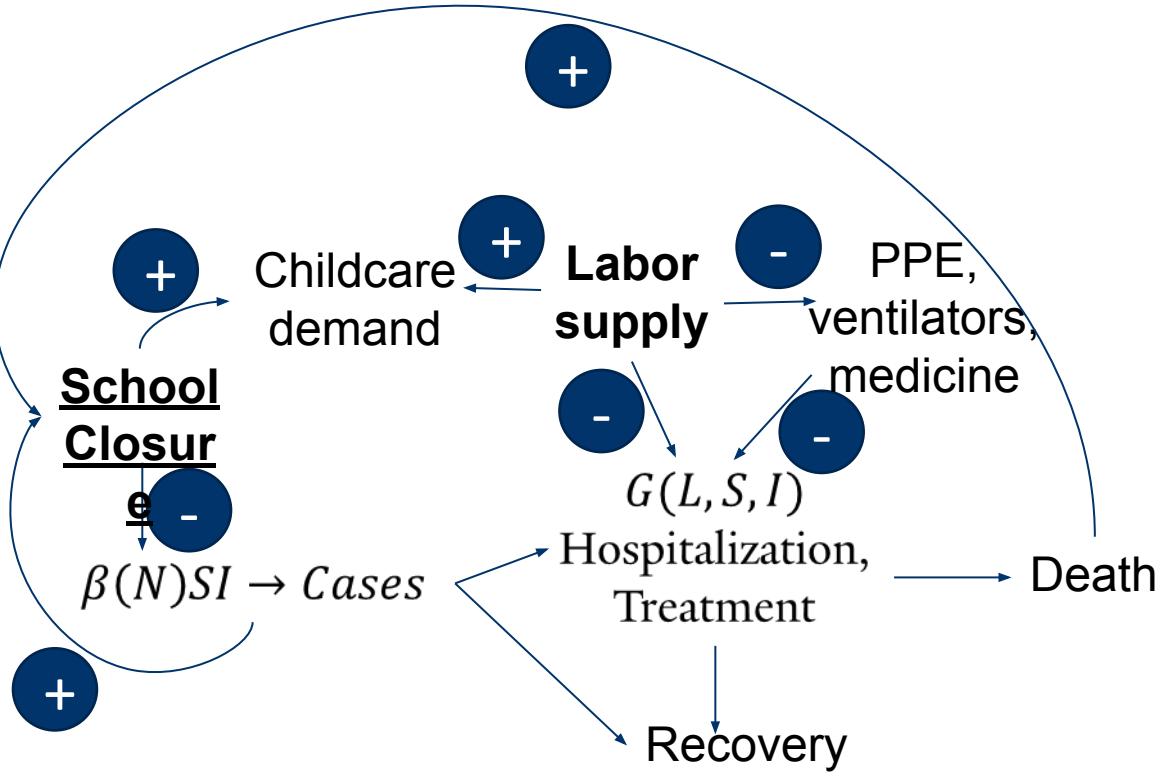

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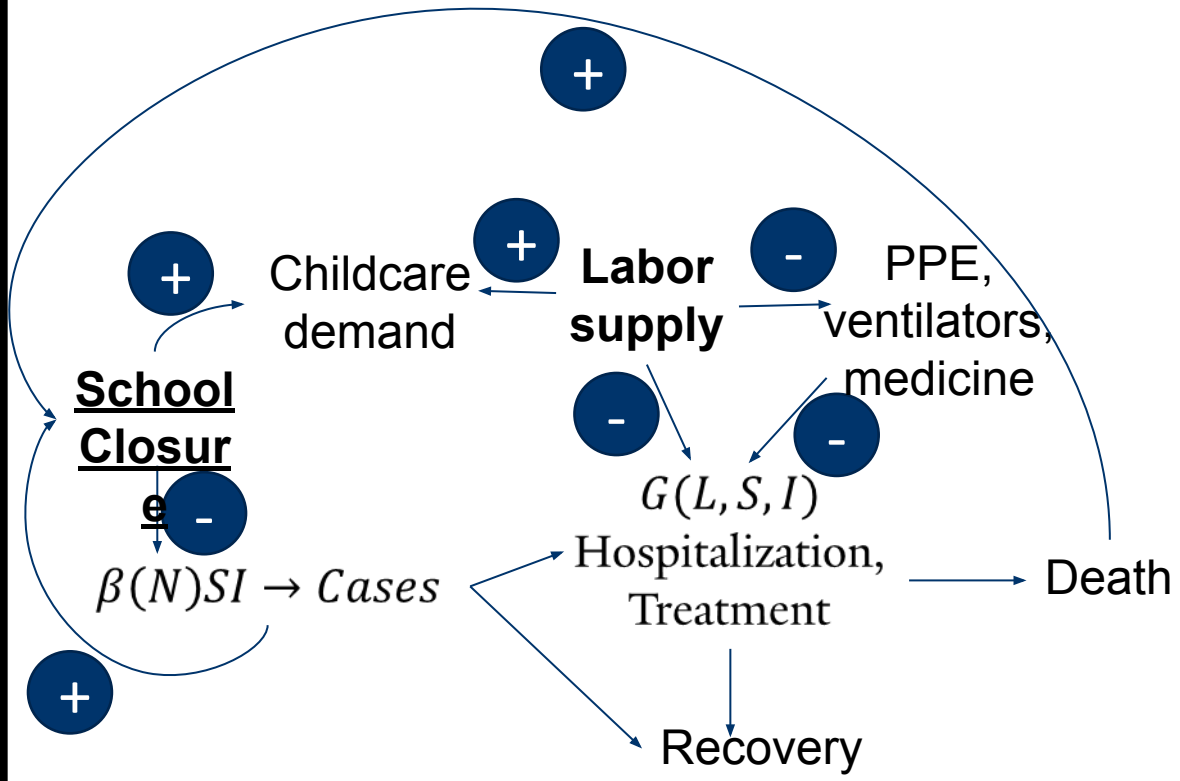
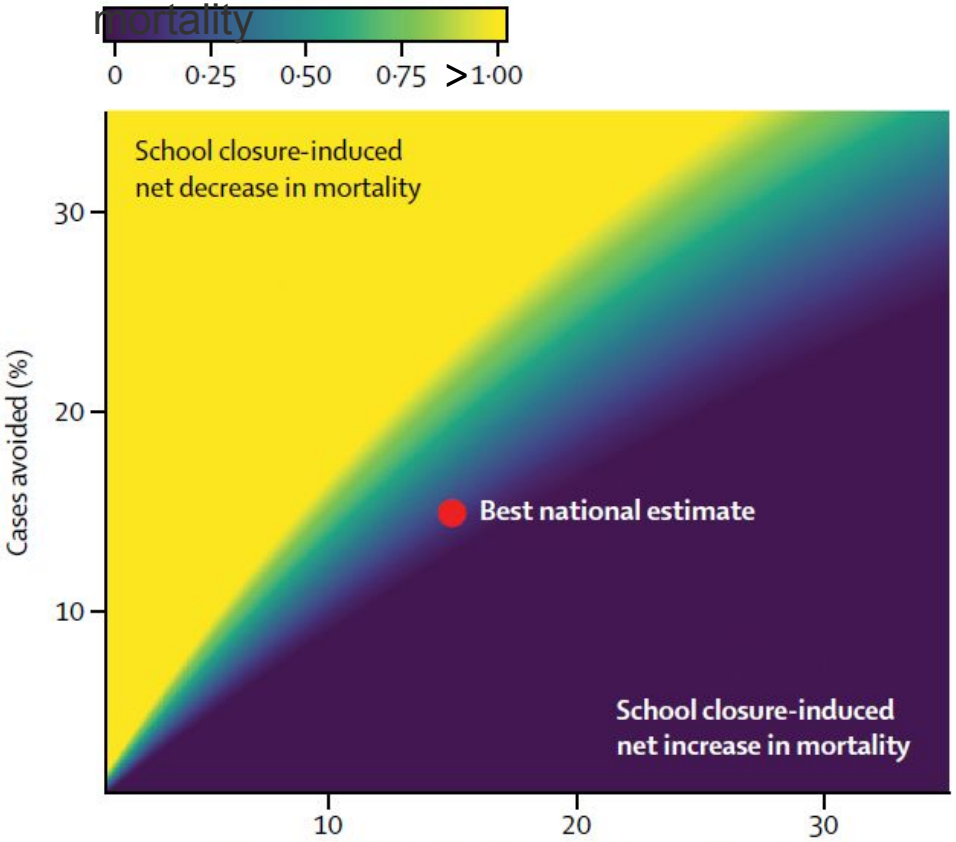


Critical level of life-saving effectiveness of health-care workers that would lead school closures to contribute to greater COVID-19 mortality



Bayham, J., & Fenichel, E. P. (2020). Lancet Public Health.

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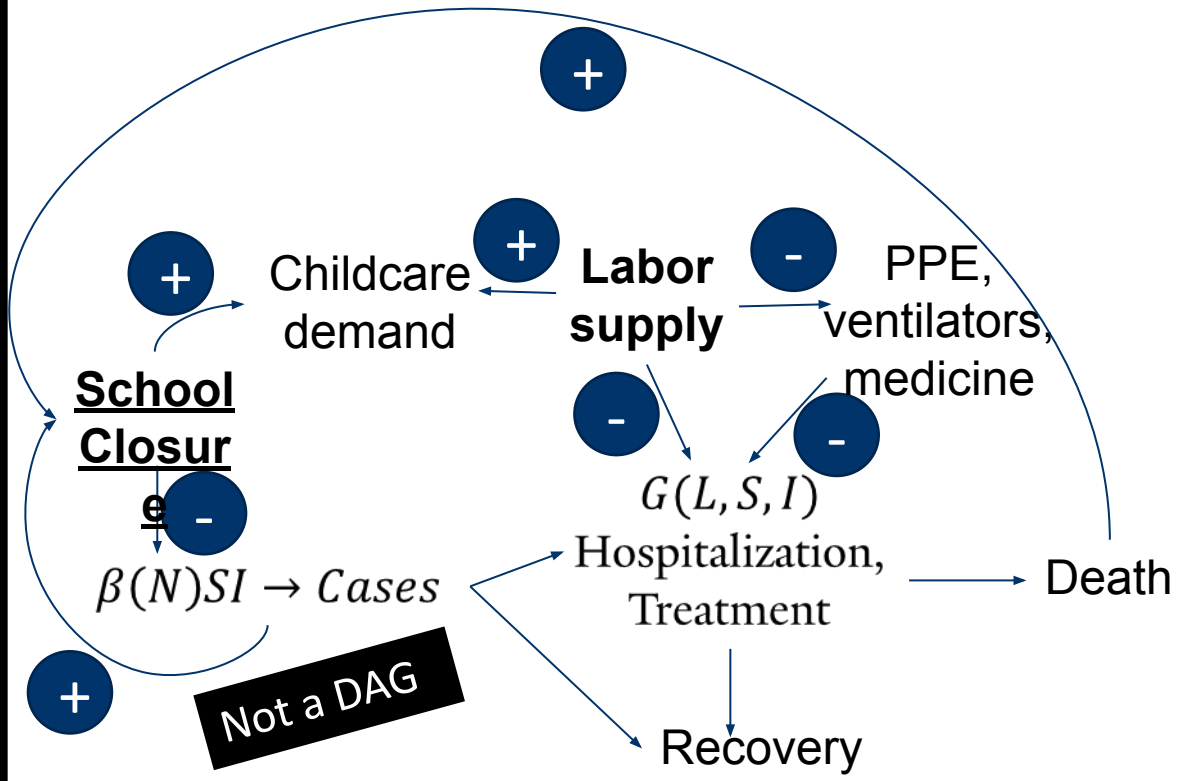

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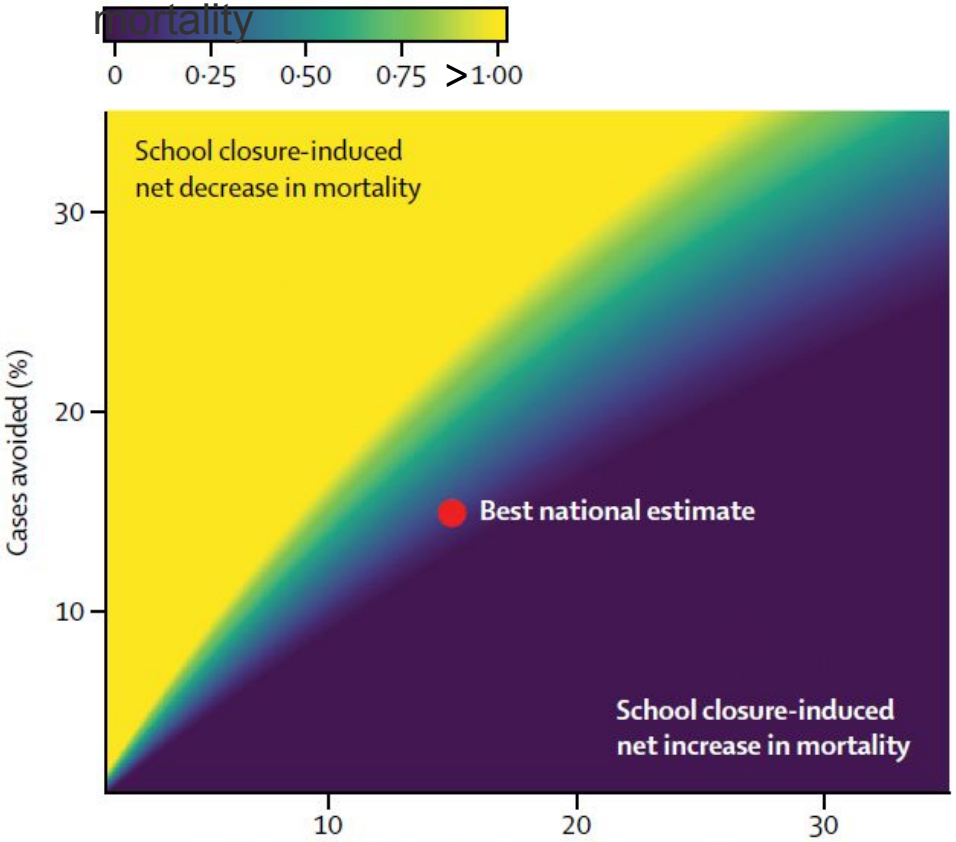

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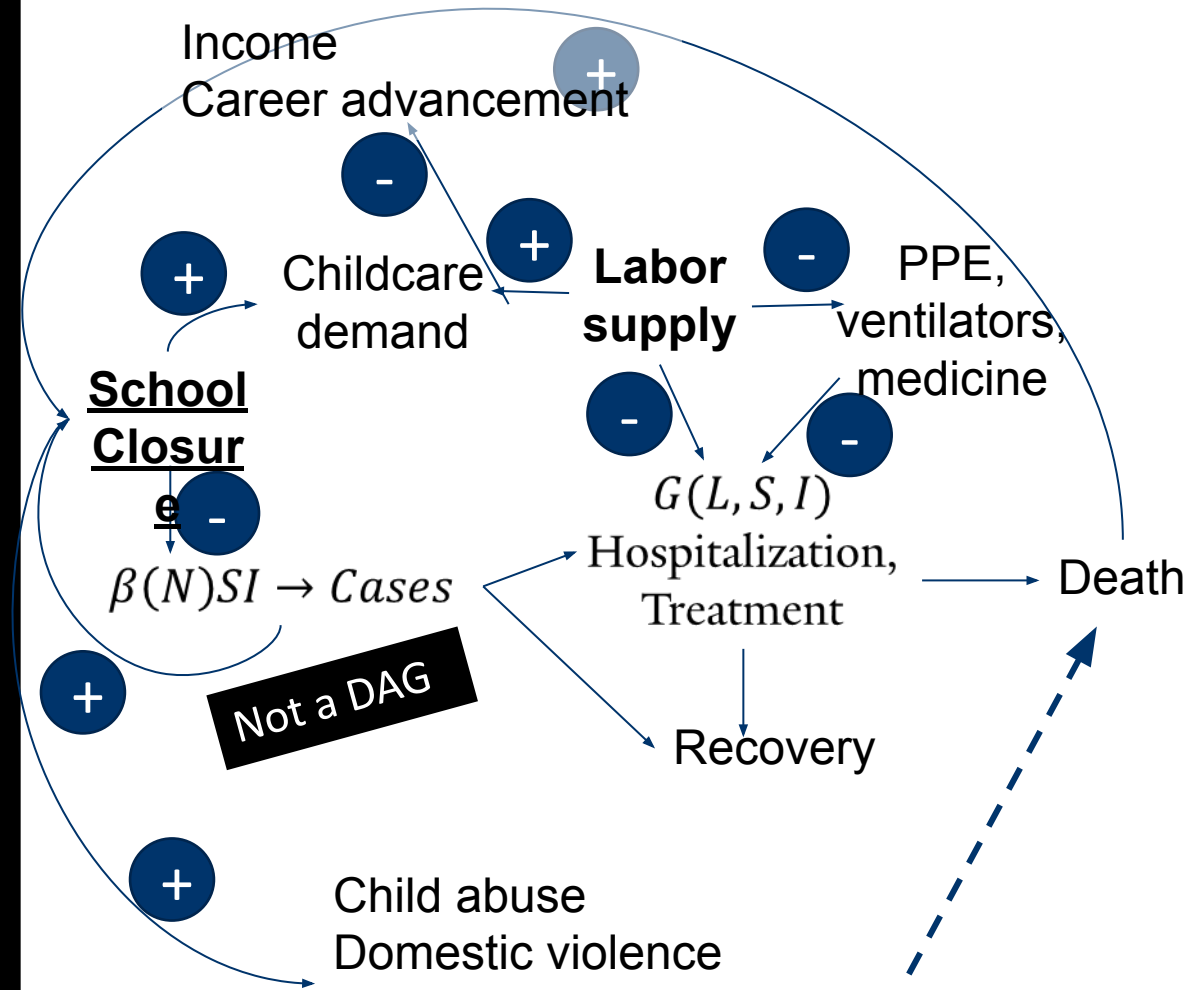

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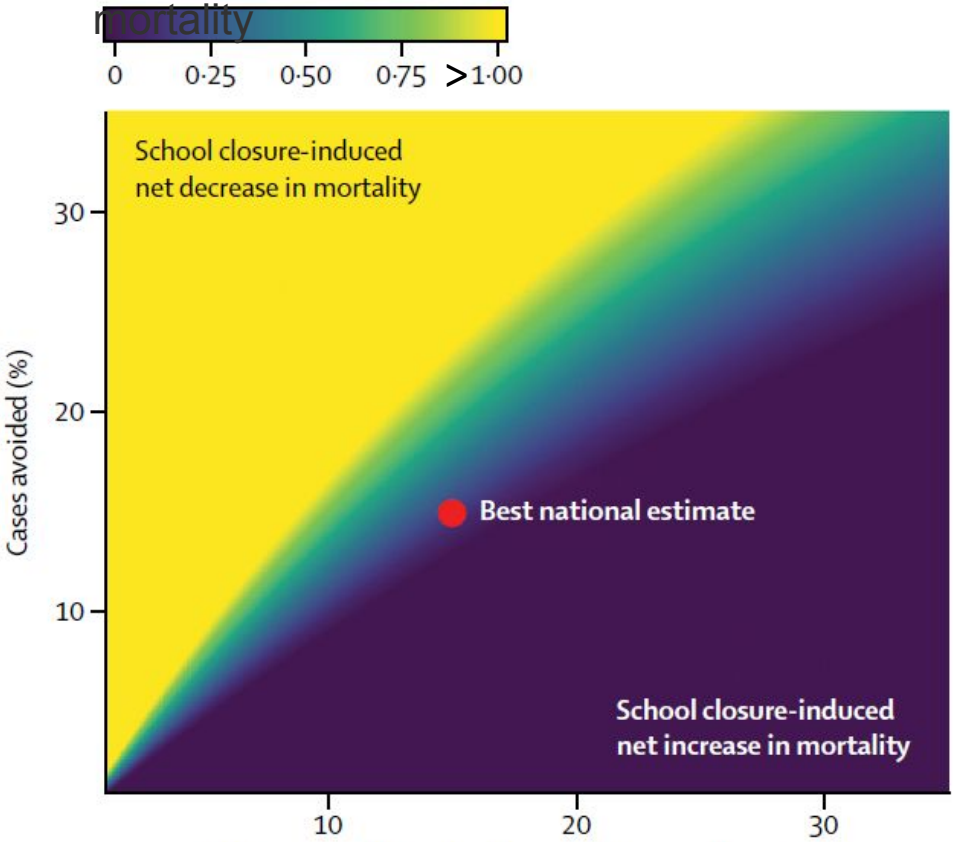

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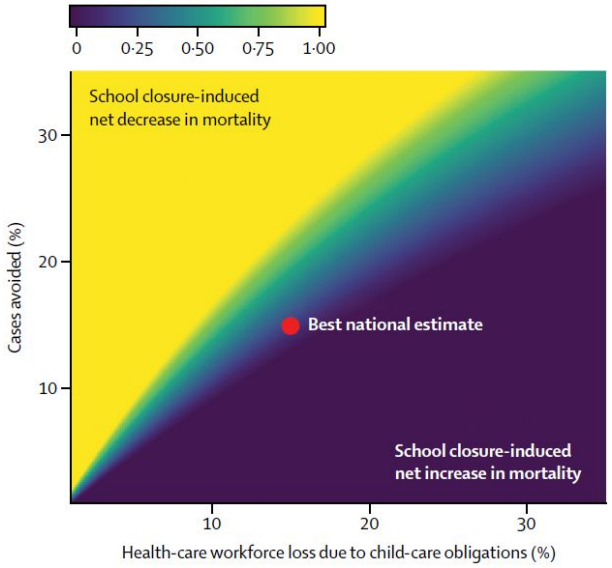
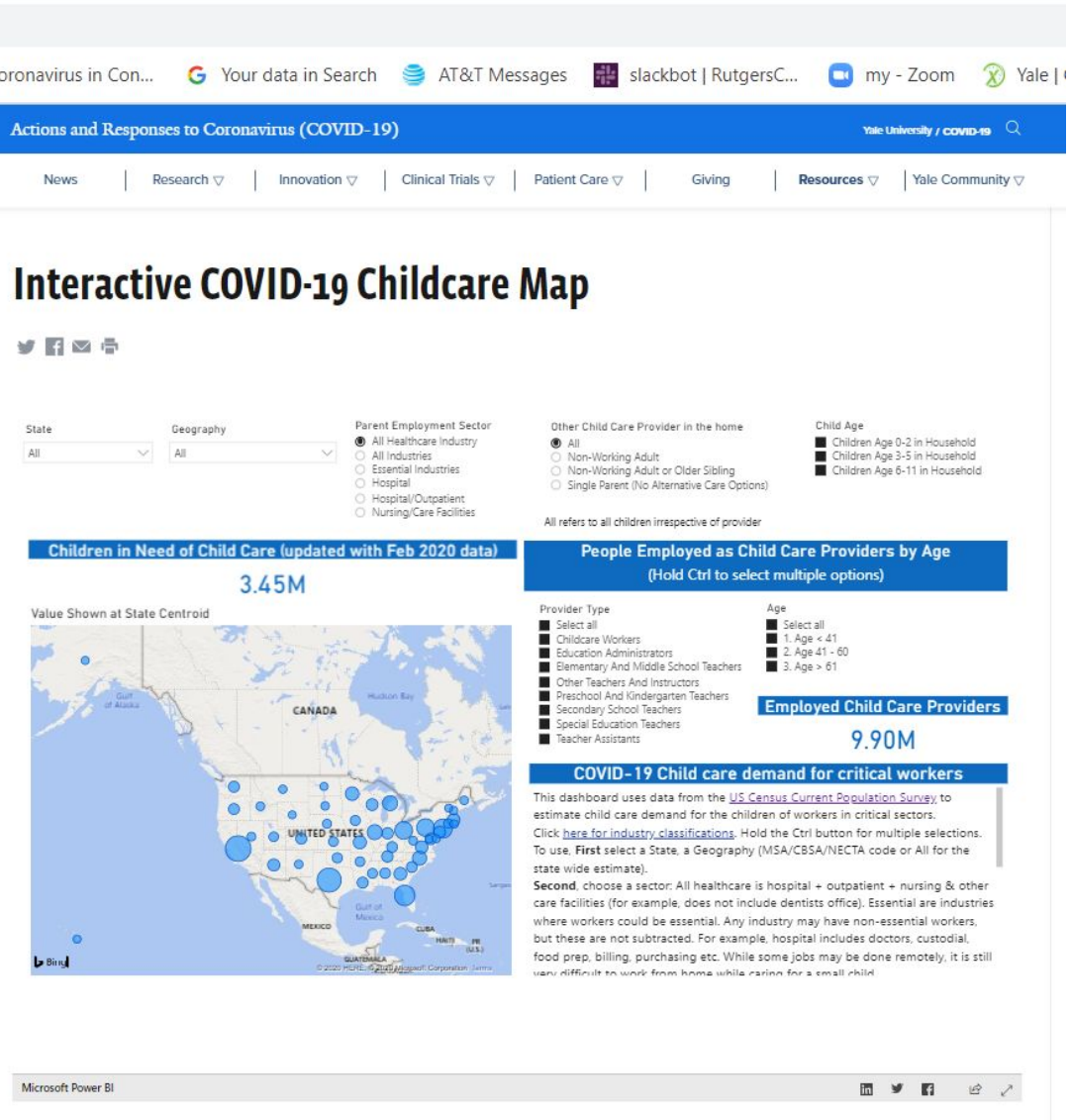
My research and views: Does not represent the views of the Biden Administration or US Government

Being Prepared for Connecting Behavior with Pandemic Policy Means Knowing (or talking to people who know) the data





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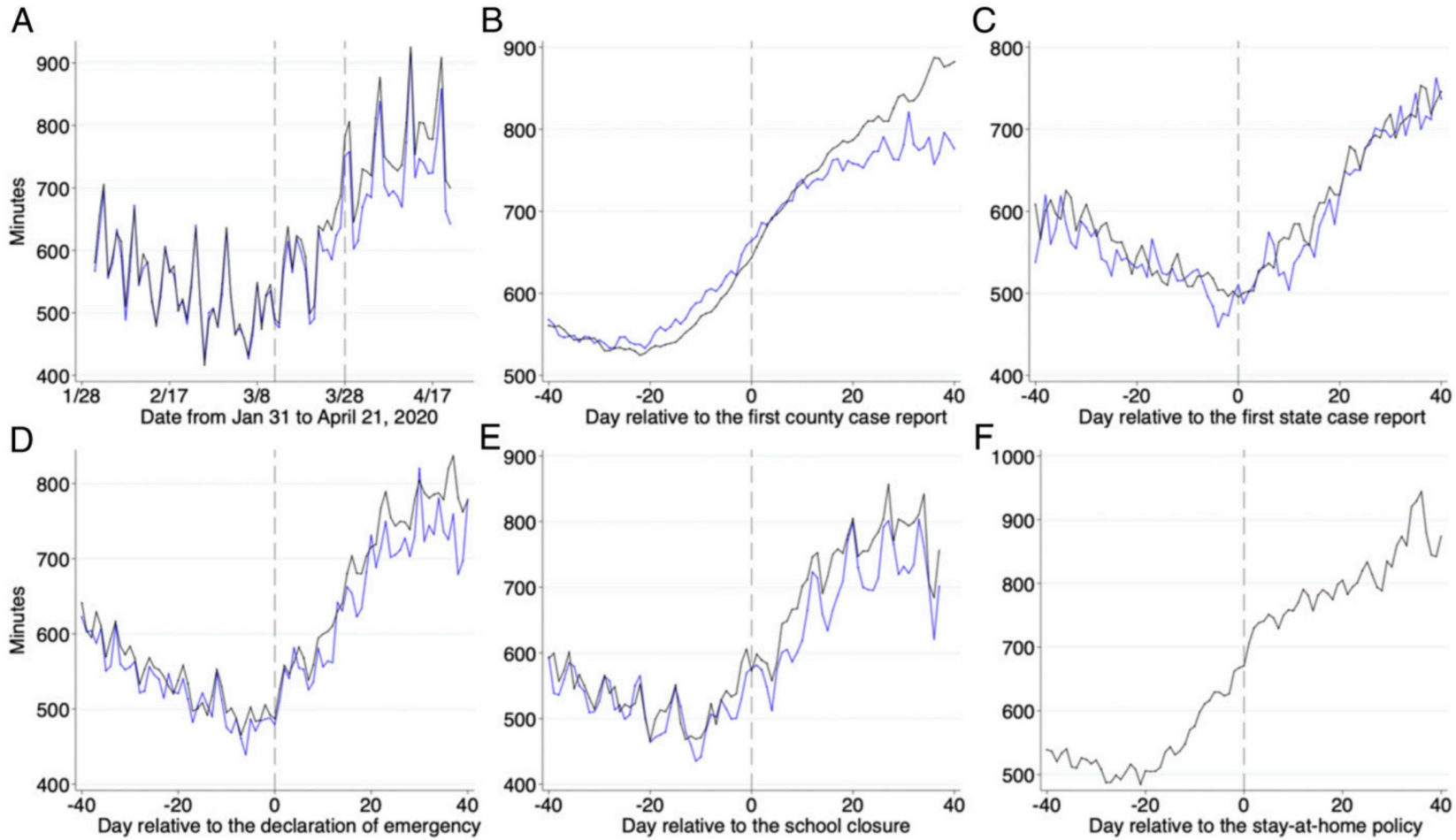
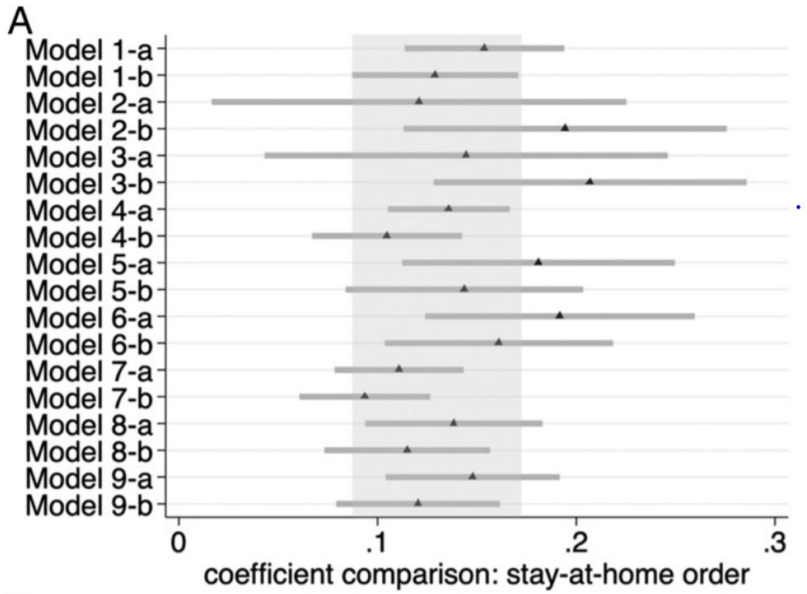
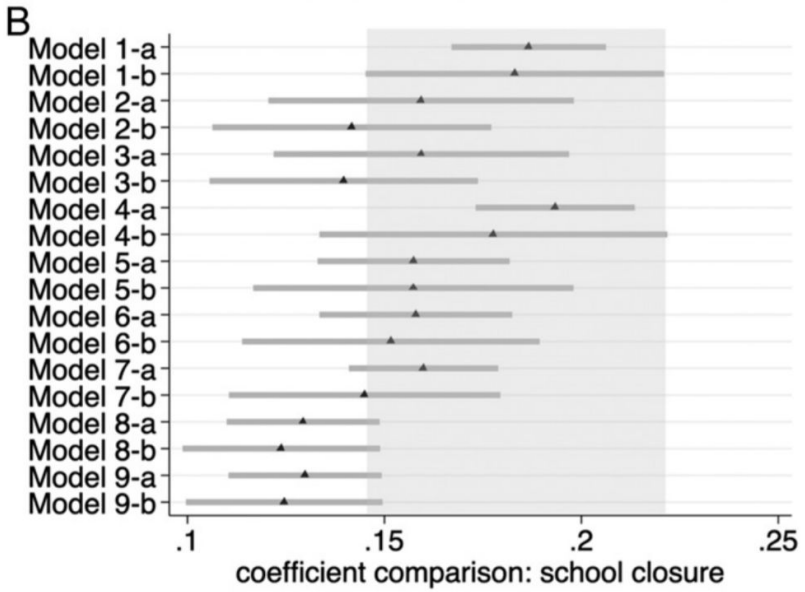
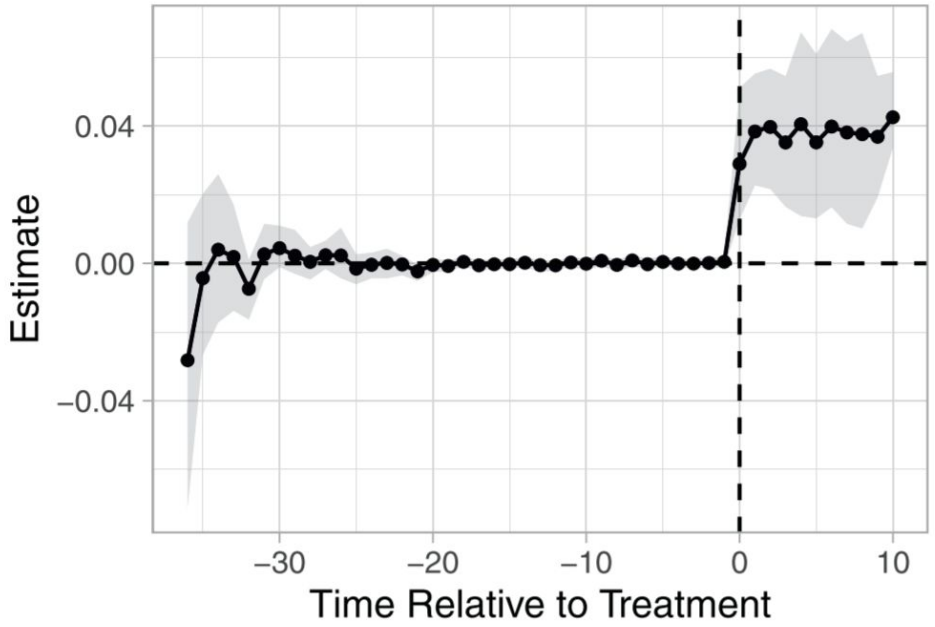
Seemed to know how to address policy, we need to separate voluntary behavior from behavior induced by a policy (Yan et al. 2021 PNAS)







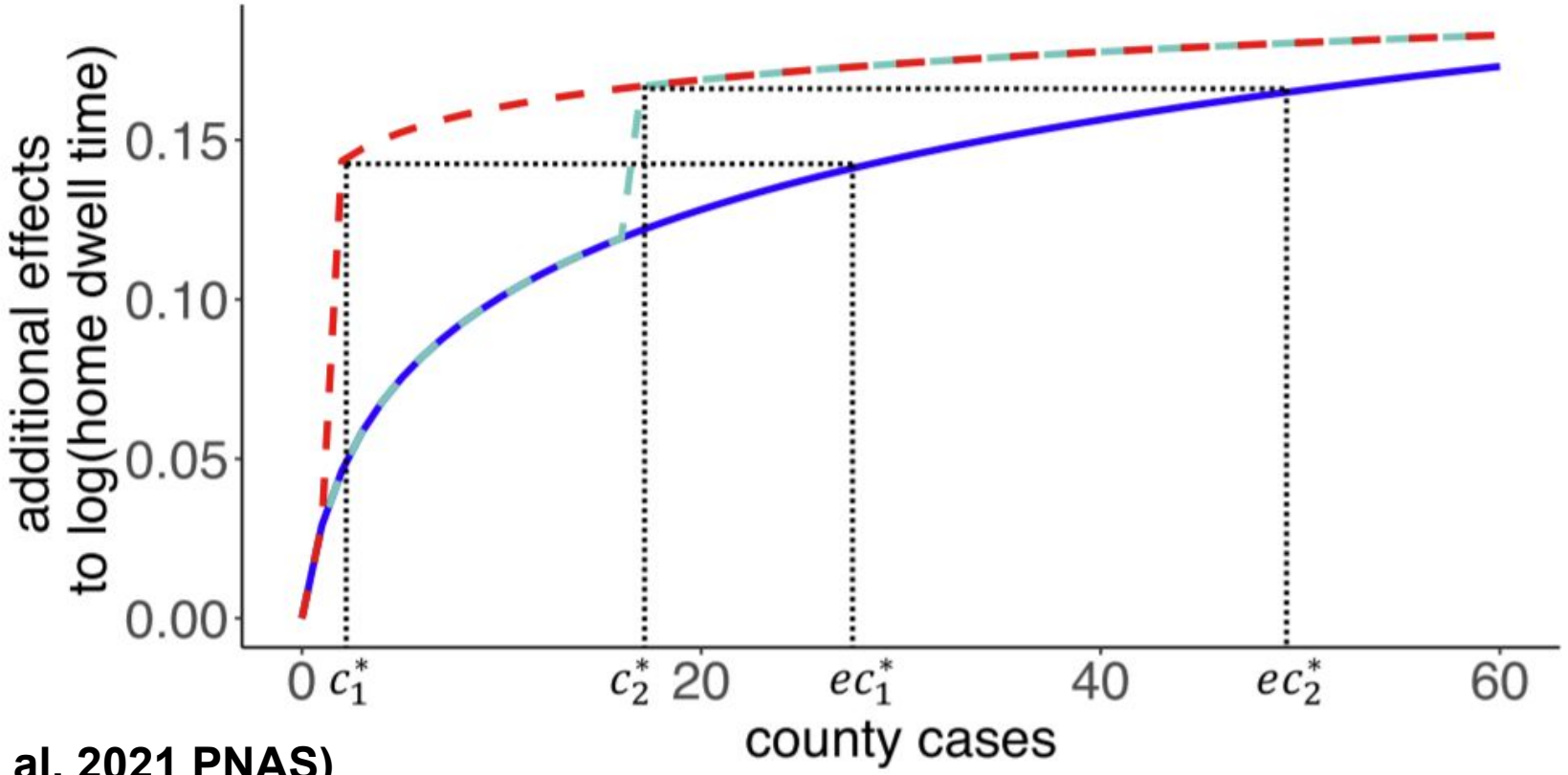


(Yan et al. 2021 PNAS)

What would cases have had to risen to to get the same behavior?

Stay-at-home policies led people in most places to stay home modestly more in the end, but they made the adjustment much earlier in the pandemic.

(They may have gotten fatigued from the pandemic earlier too – See Springborn et al. 2015 or Yan et al. 2021 Scientific Reports)



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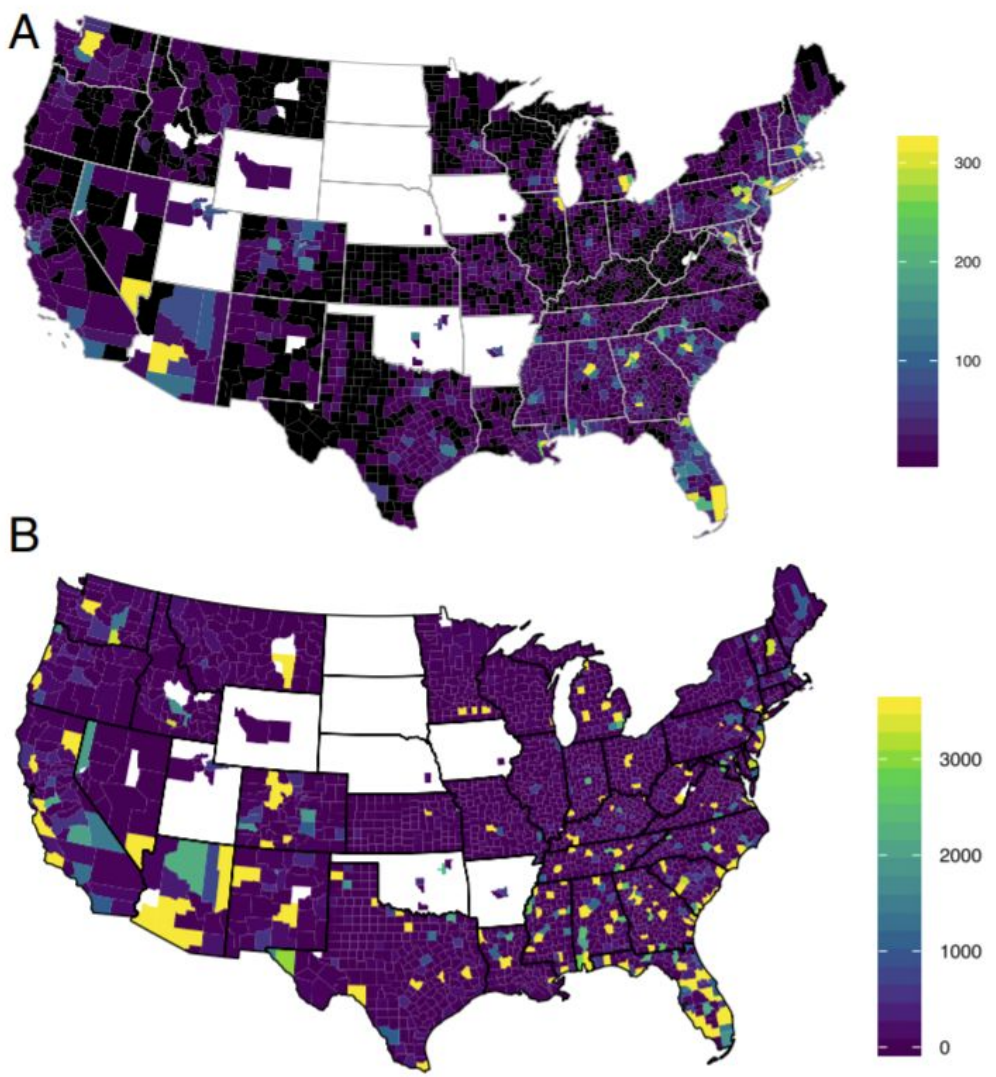


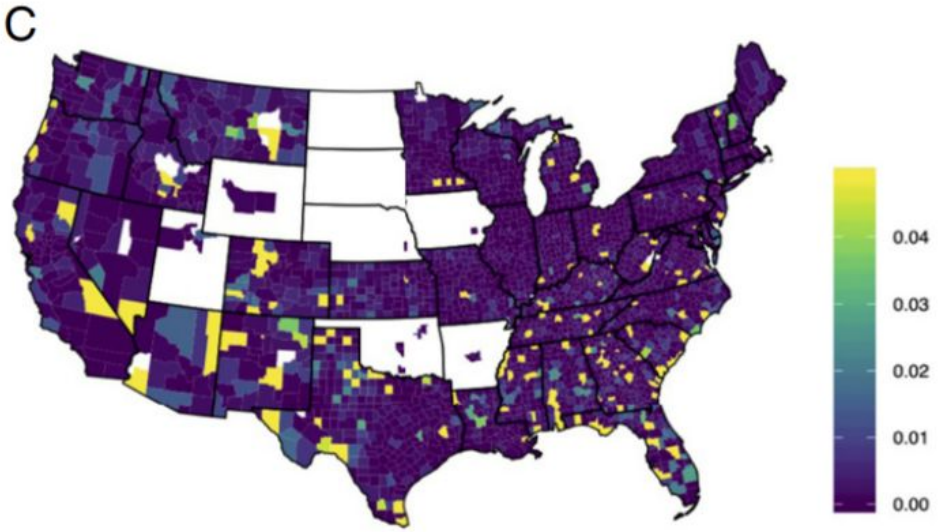


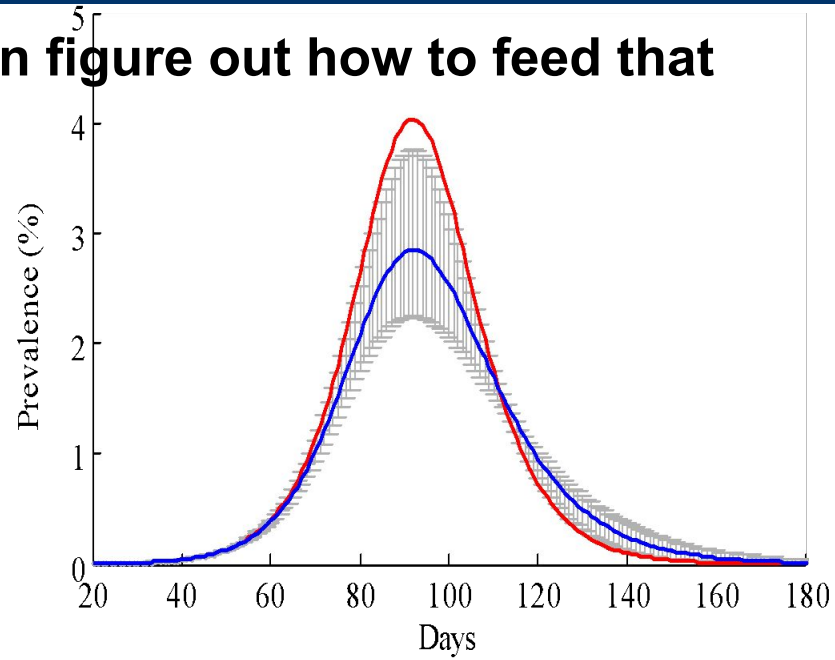
Fig. 6. (*A*) Cases in each county when the stay-at-home order was in effect (censored at 99% = 318 cases). Counties imposing stay-at-home orders with zero cases are shown in black. Missing data or those never imposing stay-at-home orders are white. (*B*) Equivalent cases to the response to the stay-at-home order (values about 95% = 3,553.7 cases are colored yellow) for each county using coefficients of column 2 in Table 1. (*C*) Equivalent cases per population by county.

(Yan et al. 2021 PNAS)

Pass back into an epi model with a home and away contact structure to evaluated the role of staty-at-home (on the first and maybe second wave)

Still we need to look a behavior and learn – then figure out how to feed that behavior back into epidemiological model.

For H1N1 we had looked at home dwell time as a risk reduction strategy and found that people spent significantly more time at home and changed their schedules, even though there were not social distancing policies in the US. We fed this back through epi models and suggested that the voluntary behavior yield about a 13% reduction in cases. (Bayham et al. 2015 Proc B).



Could we partition the additional time at home observed in spring of 2020

Policy for Pandemics Needs to Focus on Health and Wellbeing not Illness
Health & Wellbeing are Broader than the Infectious Agent of Concern

(Bayham, Chowell, Fenichel & Kuminoff forthcoming *Frontiers of Economics in China – first submitted in 2016*)

Integrated Model of an Epidemic, School Closures, and Labor

1. Worry about where do kids go when schools are closed
2. Worry how do parents alter their behavior to care for kids.
3. Deal with within-household transmission by added a separate set of transitions.
4. Break compartments into exogenous source of heterogeneity – e.g., age group, household size, income*
5. Calibrate the contact matrix (American Time Use Survey based on Bayham et al. 2015 Proc. B.).
6. Edit the contact matrix using a set of assumptions. In our work, we eliminate schools and reallocate time to proportionally to other place a representative individual visits. (most efforts make these edits arbitrarily)

School closures are only ever optimal if

(1) pharmaceuticals arrive reasonably quickly to end the epidemic (option value) or
(2) school closures create a beneficial non-proportional relationship between cases and death.

EPILOGUE:

People behavior matters more then even I ever thought, and people respond to a wider range of goals and risks (real or perceived) then I could ever imagine.

Models are abstractions, so purpose matters. What is the objective or goal?

Epi

1. Measure (Minimize) cases
2. Measure (Minimize) death
3. Measure (Minimize) probability of hitting a hospital boundary condition

Soc-Eco

4. Measure (Minimize) unemployment
5. Measure (Maximize) GDP (primarily market based economic output)
6. Measure (Maximize) household money income
7. Measure (Maximize) wellbeing or welfare (perhaps of some group within society)

Either way these are social welfare functions $SWF = \alpha_1 U_1 + \alpha_2 U_2 + \alpha_3 U_3 \ldots$
Where the welfare weights α are seldom explicit and analyst chooses each agent's utility function.

- Only care about cases U_i is zero or one, $\alpha_i = 1$.
- Household money income, e.g., $U_i = e^{-\delta(\tau - t)} f(m, h)$ and $\alpha_i = \left(\frac{\partial U}{\partial m}\right)^{-1}$