

Integrating Voluntary and Policy-Induced Behaviours into Epidemiological Models

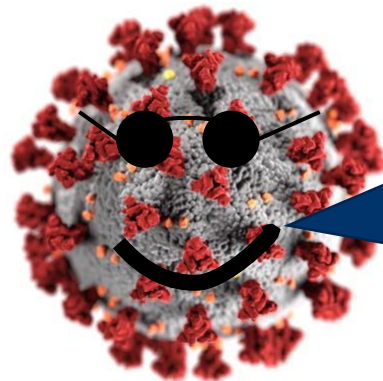
Eli P. Fenichel

Knobloch Family Professor of Natural Resource Economics

Yale School of the Environment

*** Disclaimers:

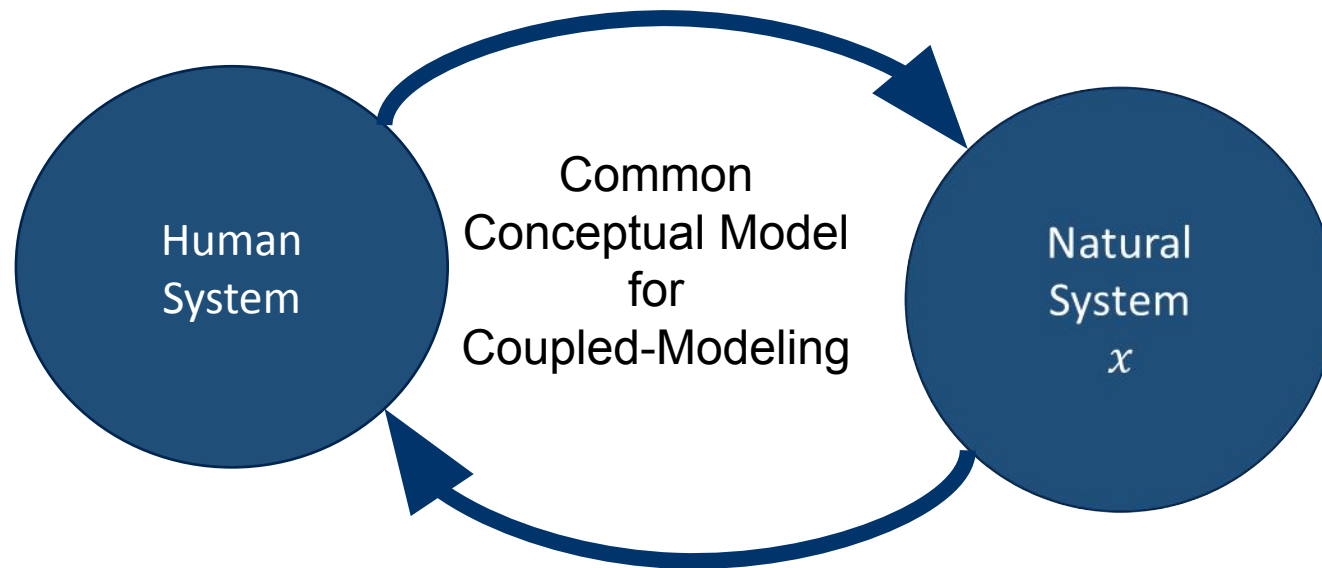
- (1) There will be an exception to every characterization I make in this talk.
- (2) A lot has happened in the last two years, and I have found it impossible to keep up.



Causing illness is not enough. I'm expanding to impact housing, schooling, labor, drug use, domestic violence...

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

- Bounding **human-natural systems**
- Aggregation (from “micro” to “macro” and back again)

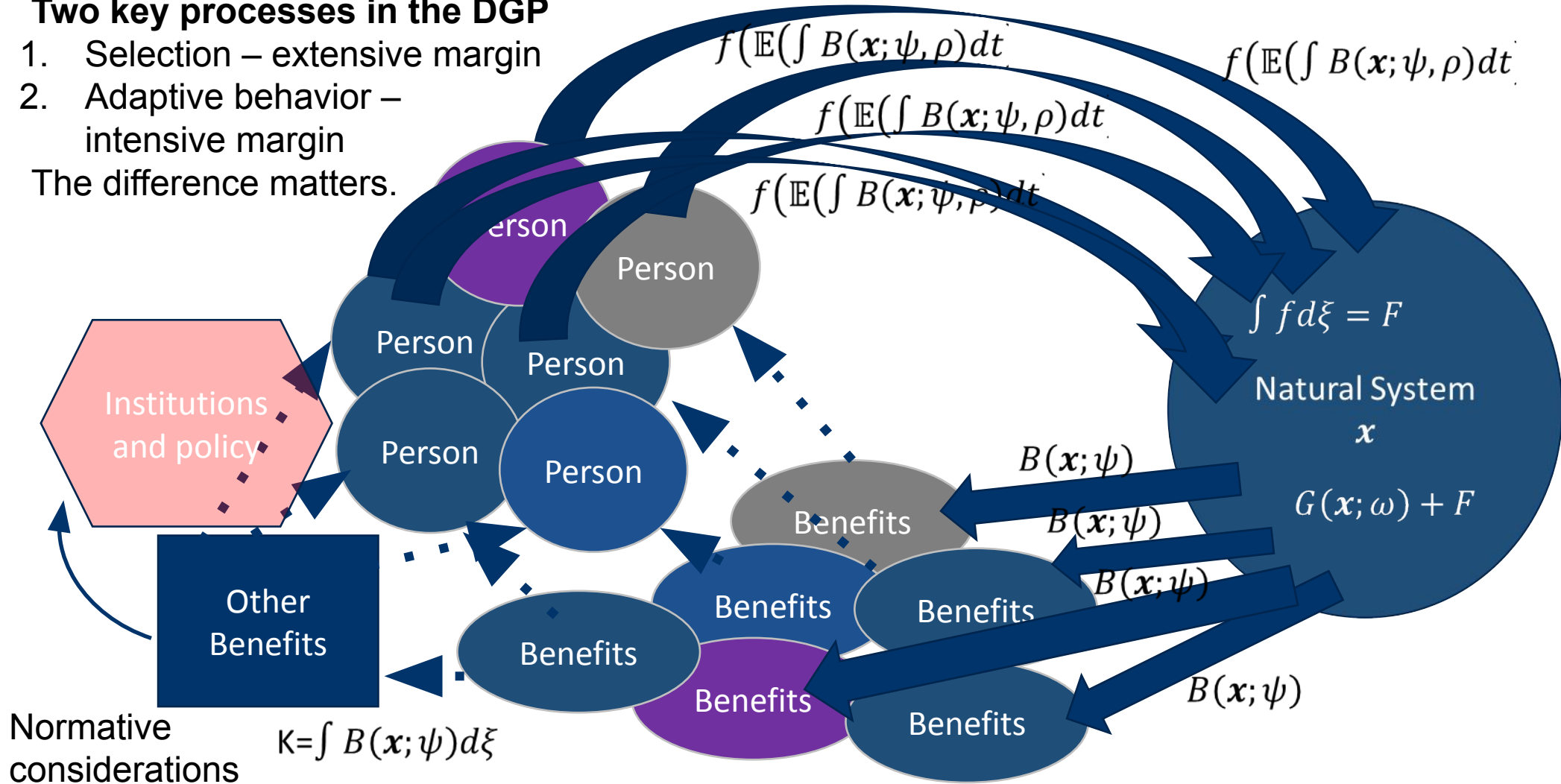


$$\text{"max"}_{\{choices\}} U(\text{Human System}, \text{Natural System}, \text{choices})$$

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

Two key processes in the DGP

1. Selection – extensive margin
 2. Adaptive behavior – intensive margin
- The difference matters.



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.

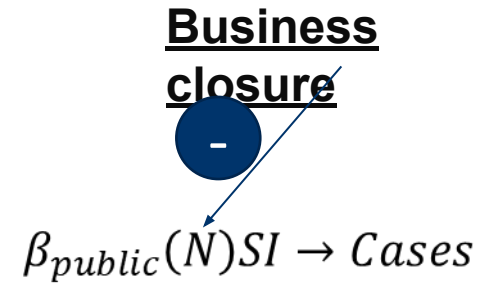
- Confounded parametric assumptions.
- Most connections to society are via behavior changes, so what causes behavior changes.
- The βgh model cannot help evaluate behavioral-based interventions or “spillovers.”
- Can’t use peoples revealed preferences to evaluate alternative policies or guide normative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

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

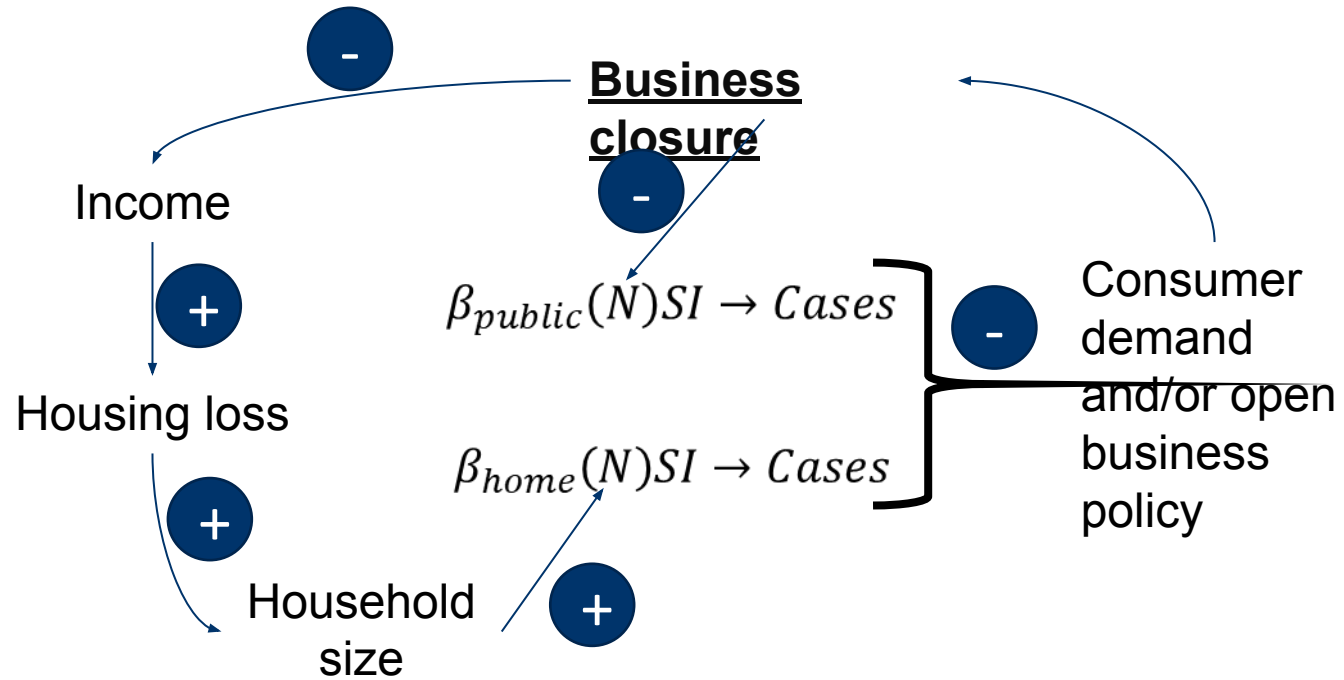
Heterogeneity (networks, ABMs, more compartments). – Behavior is just a selection process.

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.

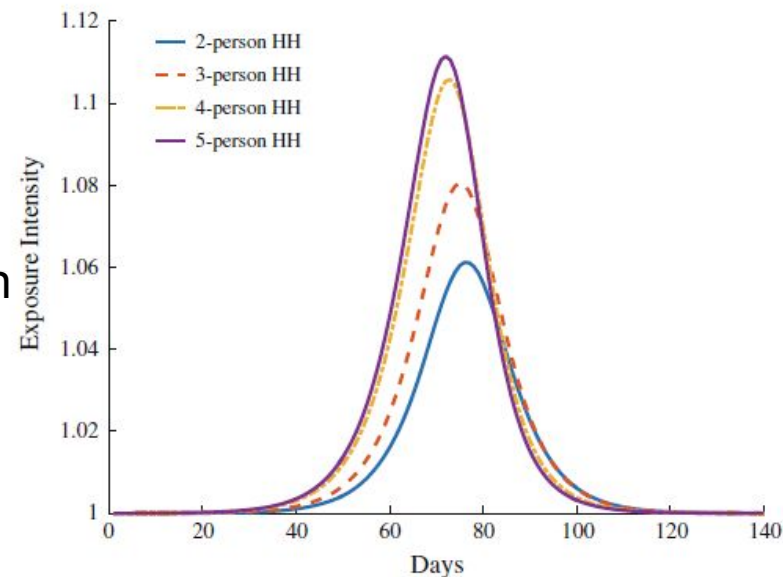
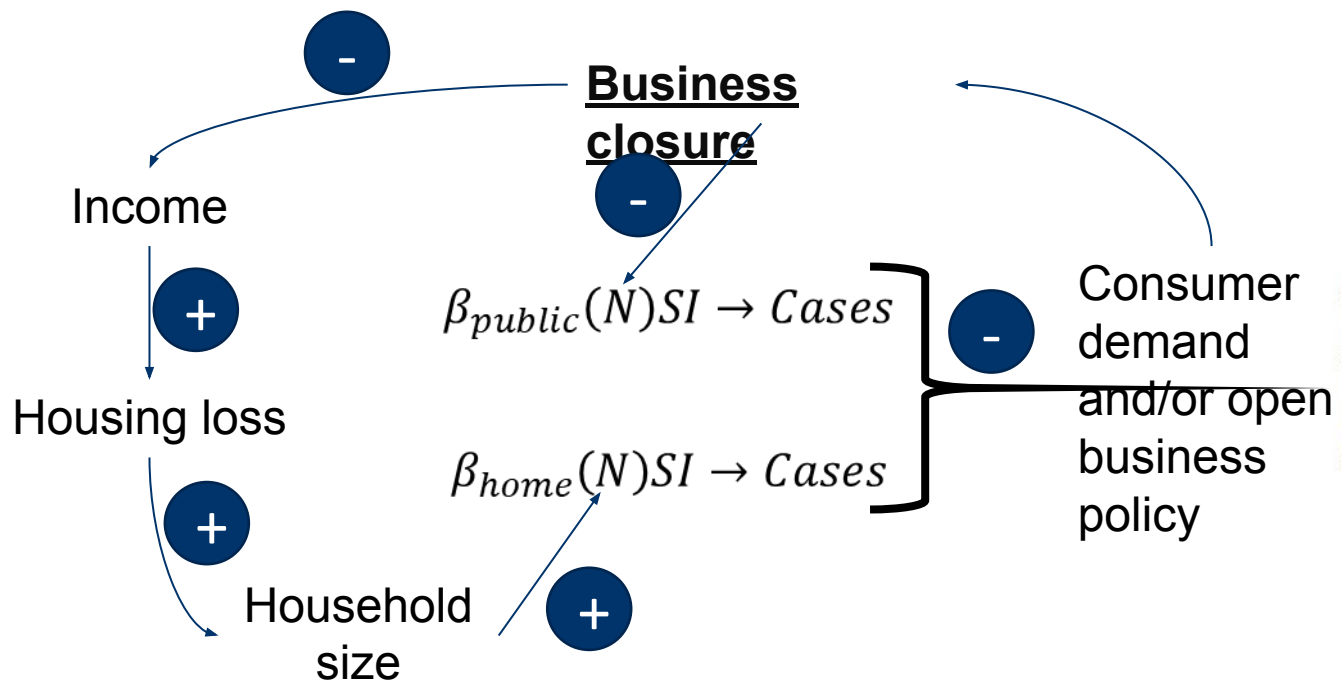
βgh Breakdown – even if we only care about cases and death



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



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

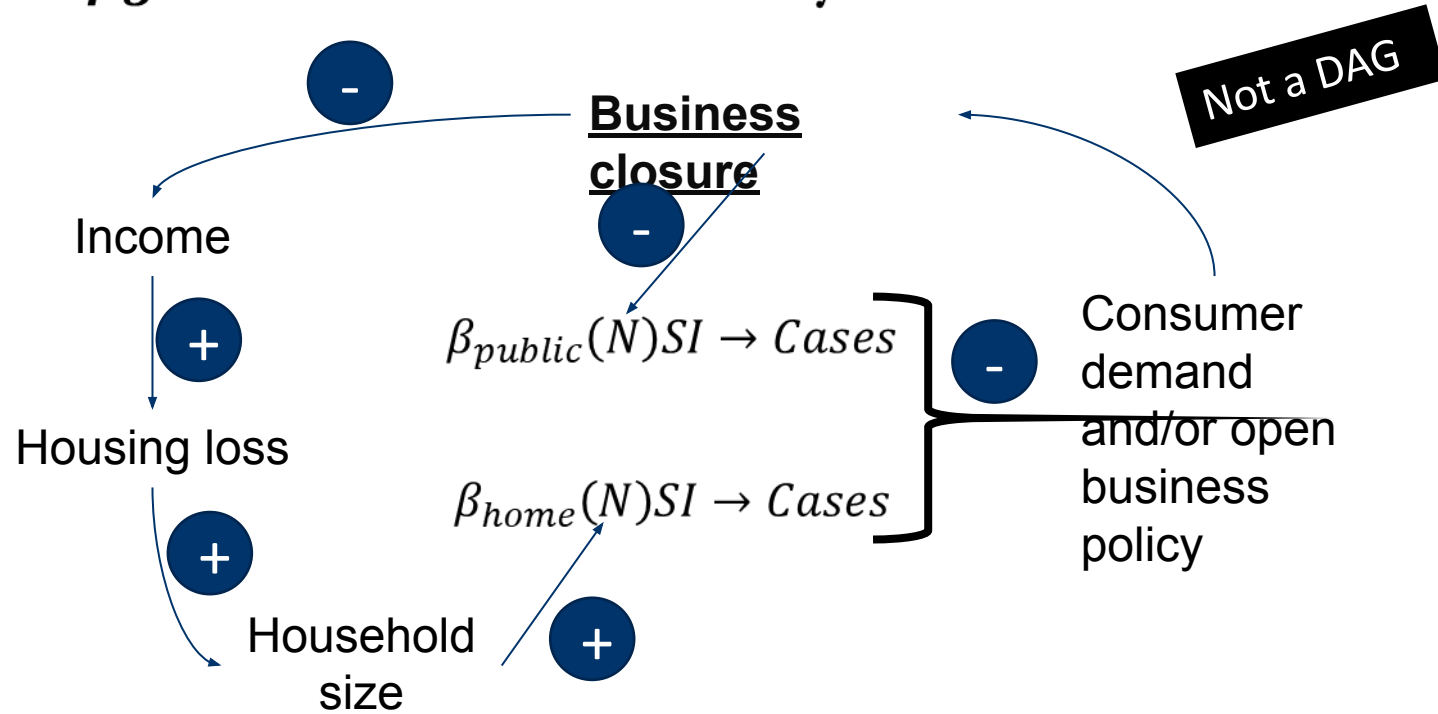


From Fenichel & Bayham (2016)

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 increase in home relative to public transmission for the US.

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



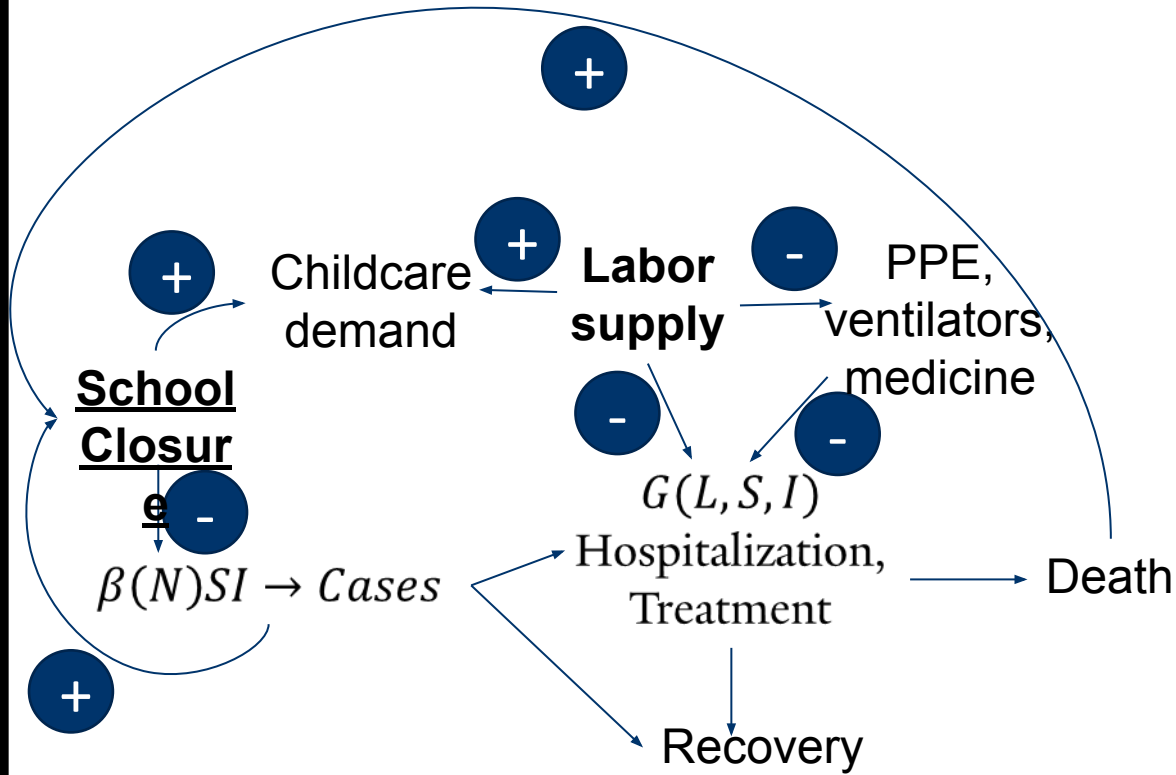
βgh Breakdown – death is not 1-to-1 with cases

School
Closur

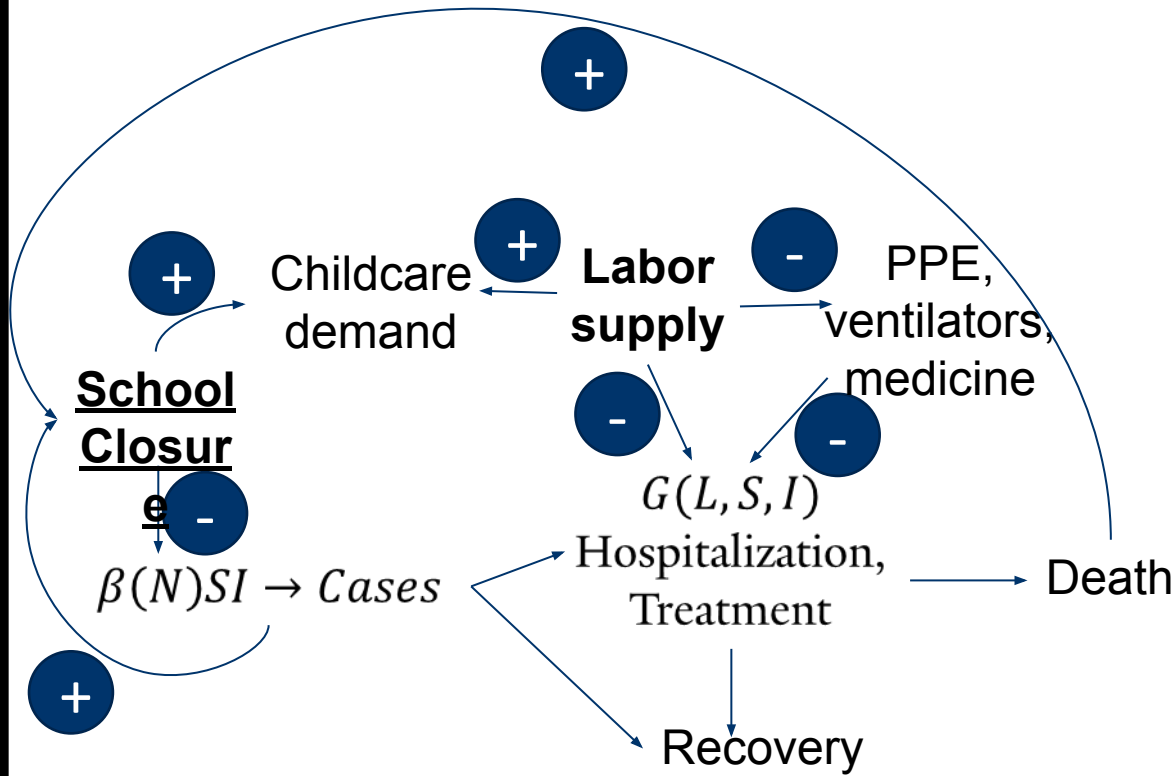


$\beta(N)SI \rightarrow \text{Cases}$

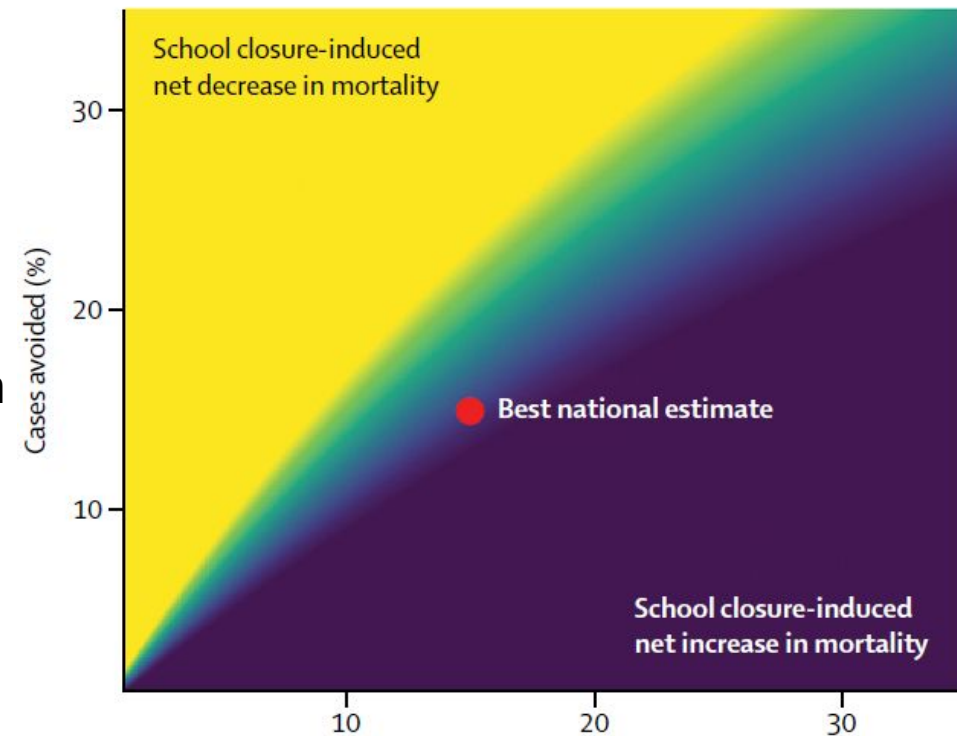
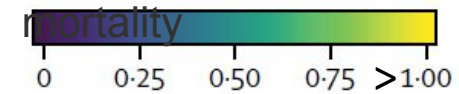
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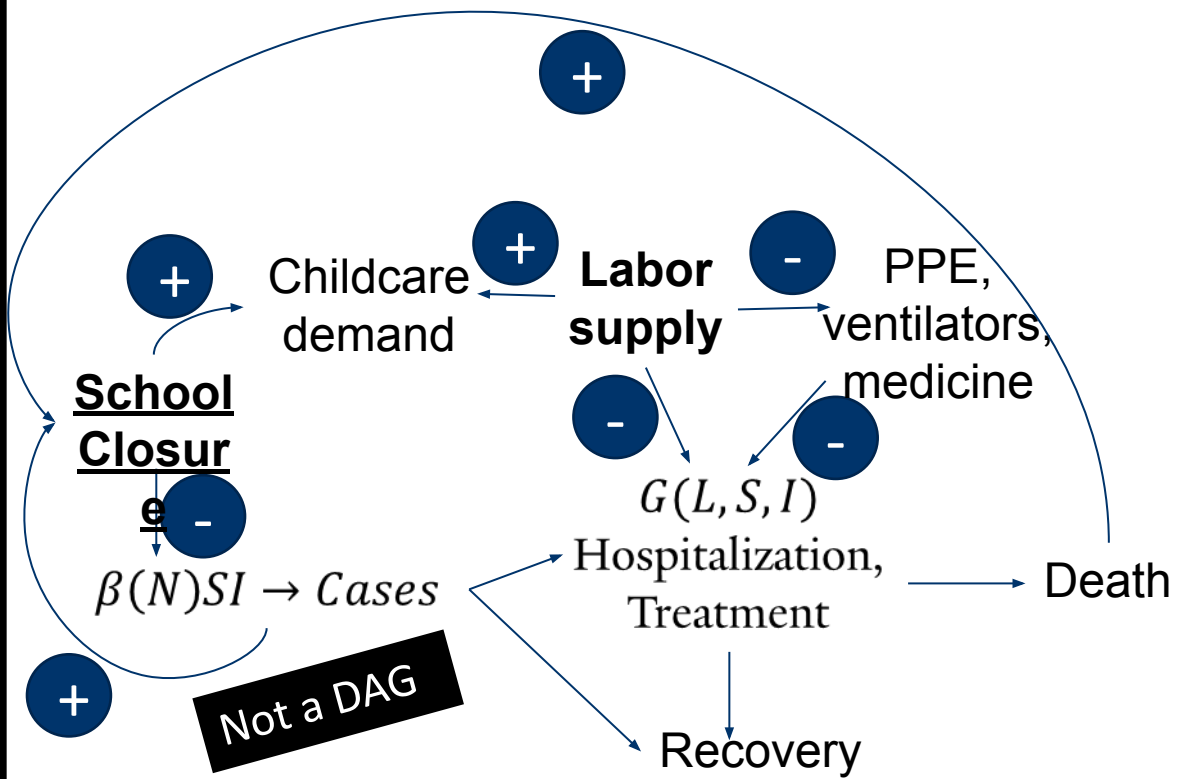


Critical level of life-saving effectiveness of health-care workers that would lead school closures to contribute to greater COVID-19

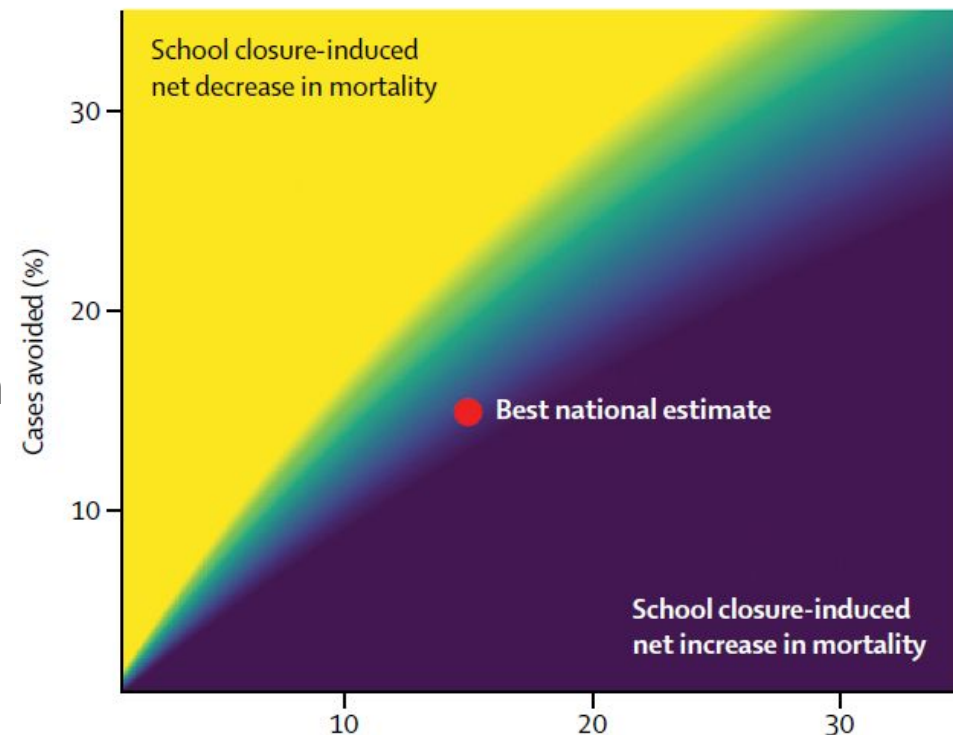
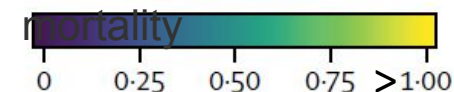


Health-care workforce loss due to child-care obligations (%)
 Bayham, J., & Fenichel, E. P. (2020). Lancet Public Health.

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

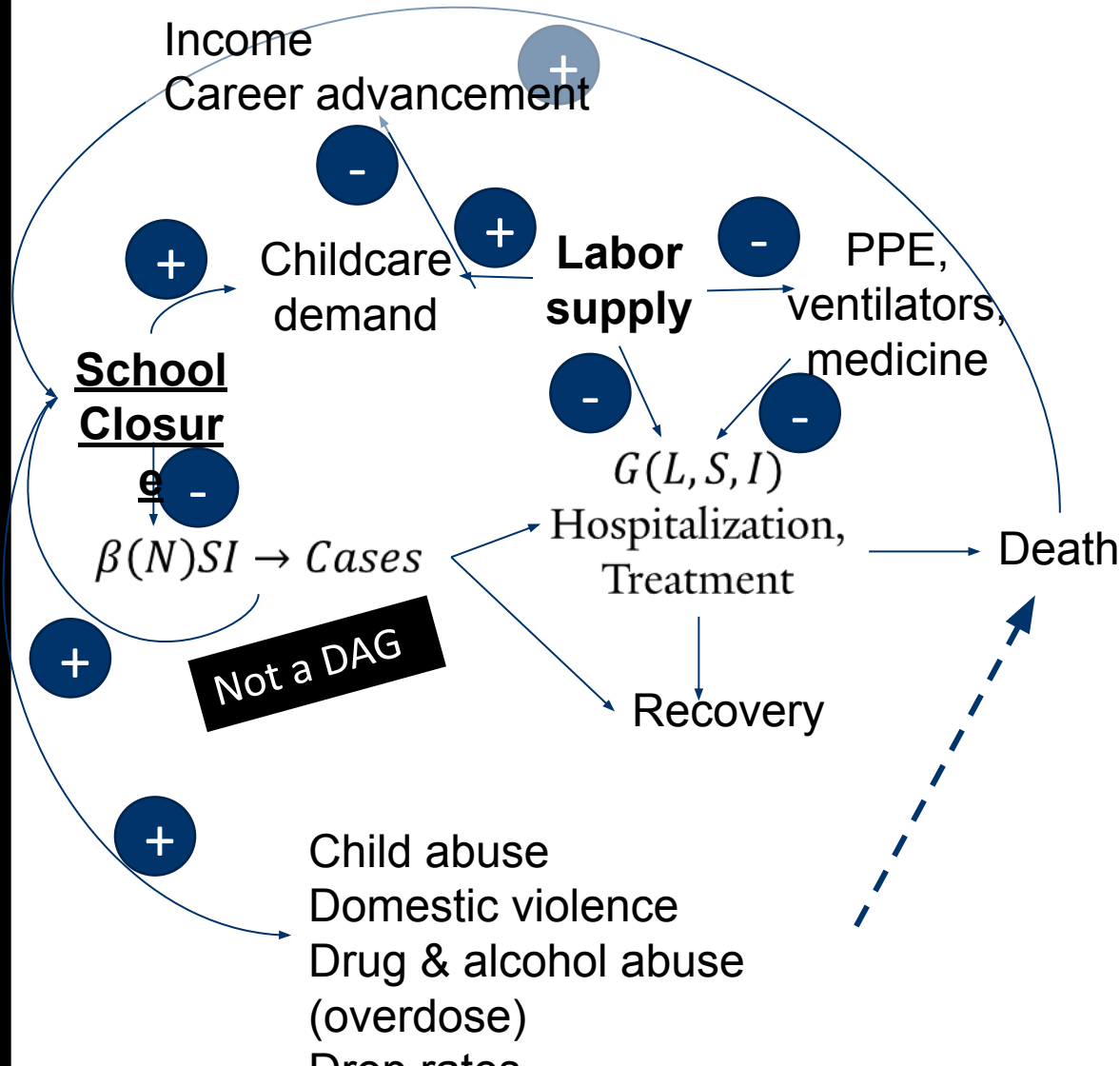


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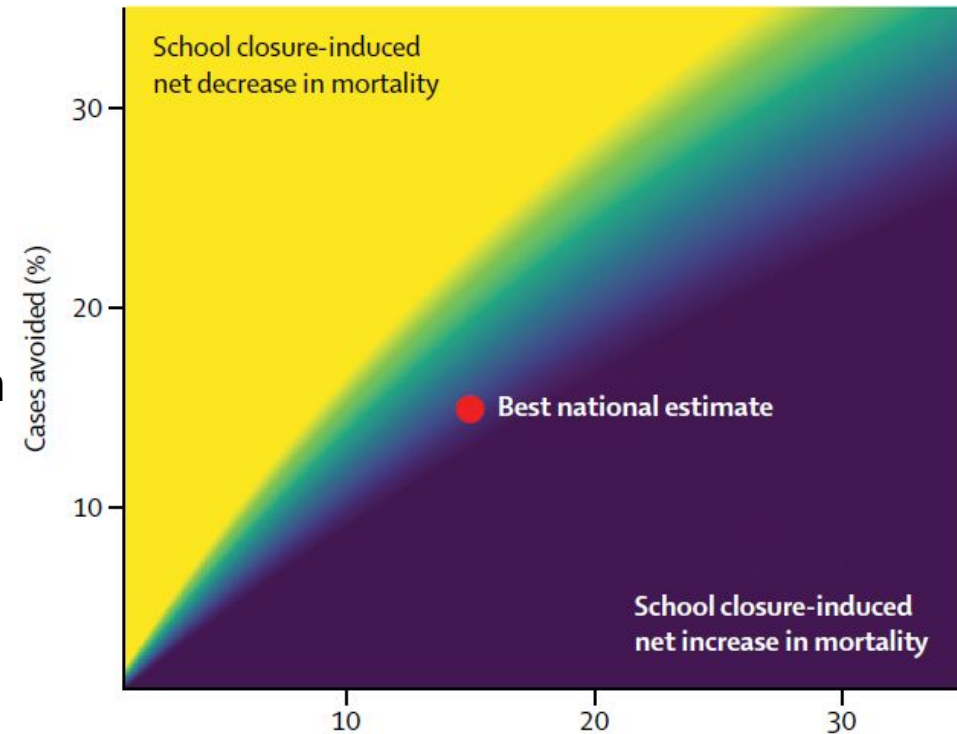
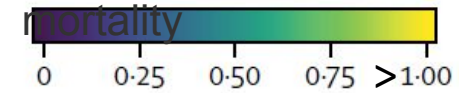


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Critical level of life-saving effectiveness of health-care workers that would lead school closures to contribute to greater COVID-19



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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

covid.yale.edu/other/childcare/

Coronavirus Updat... Coronavirus COVID... NIA Coronavirus in Con... Your data in Search AT&T Messages slackbot | RutgersC... my - Zoom Yale |

Actions and Responses to Coronavirus (COVID-19) Yale University / COVID-19

News | Research | Innovation | Clinical Trials | Patient Care | Giving | Resources | Yale Community

Cases avoided (%)

Health-care workforce loss due to child-care obligations (%)

School closure-induced net decrease in mortality

Best national estimate

School closure-induced net increase in mortality

Interactive COVID-19 Childcare Map

State: All Geography: All

Parent Employment Sector: All Healthcare Industry

Other Child Care Provider in the home: All

Child Age: Children Age 0-2 in Household, Children Age 3-5 in Household, Children Age 6-11 in Household

Children in Need of Child Care (updated with Feb 2020 data): 3.45M

Value Shown at State Centroid

People Employed as Child Care Providers by Age (Hold Ctrl to select multiple options): 9.90M

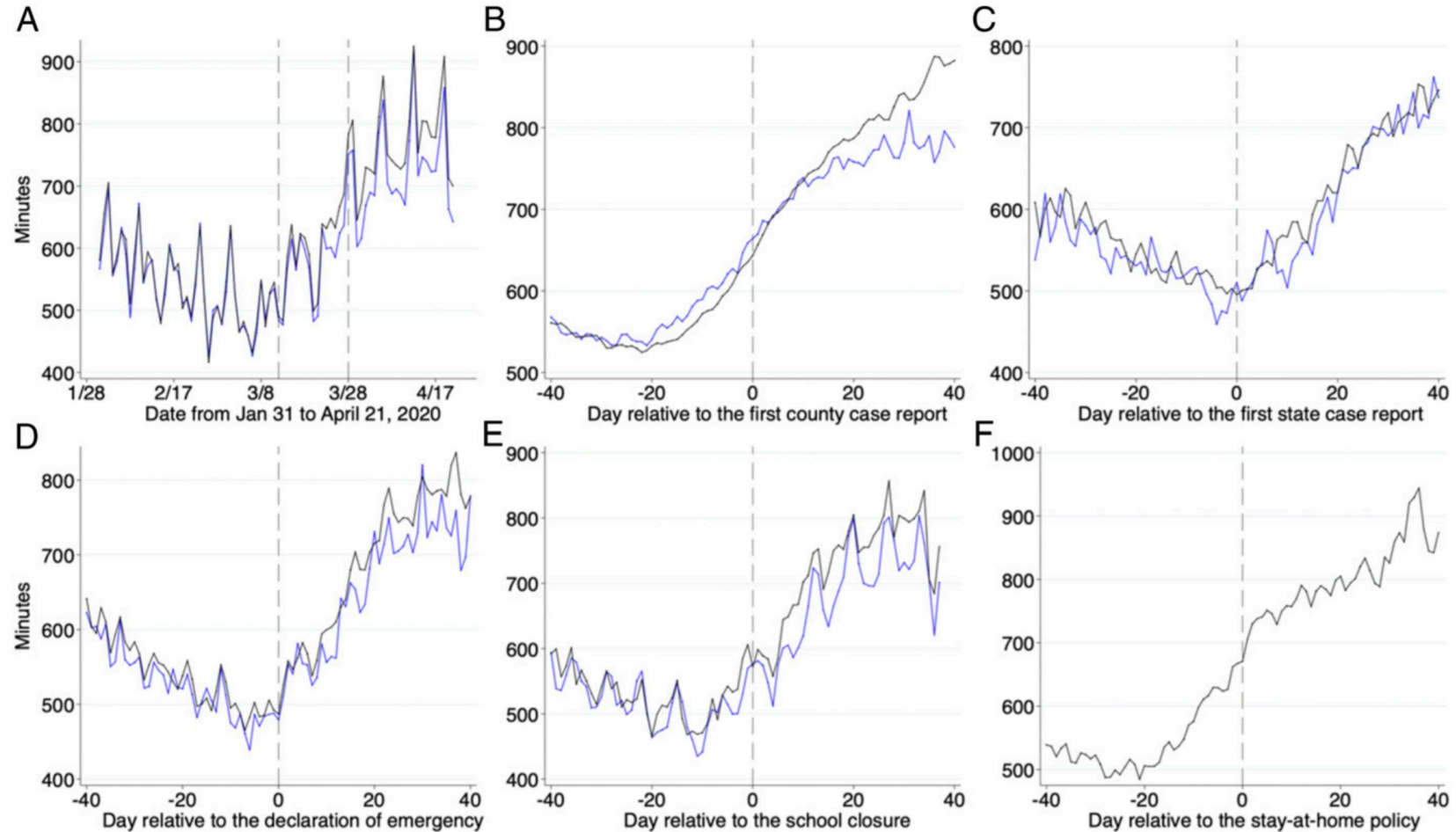
Employed Child Care Providers: 9.90M

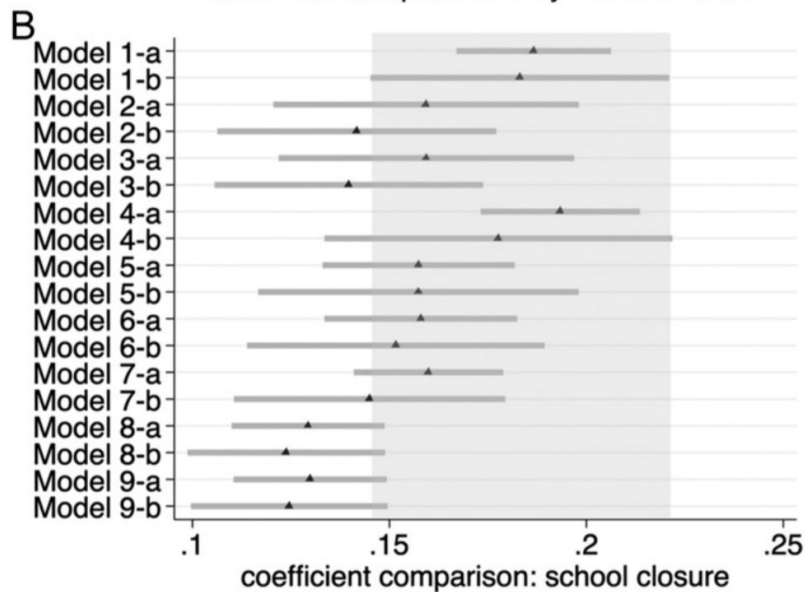
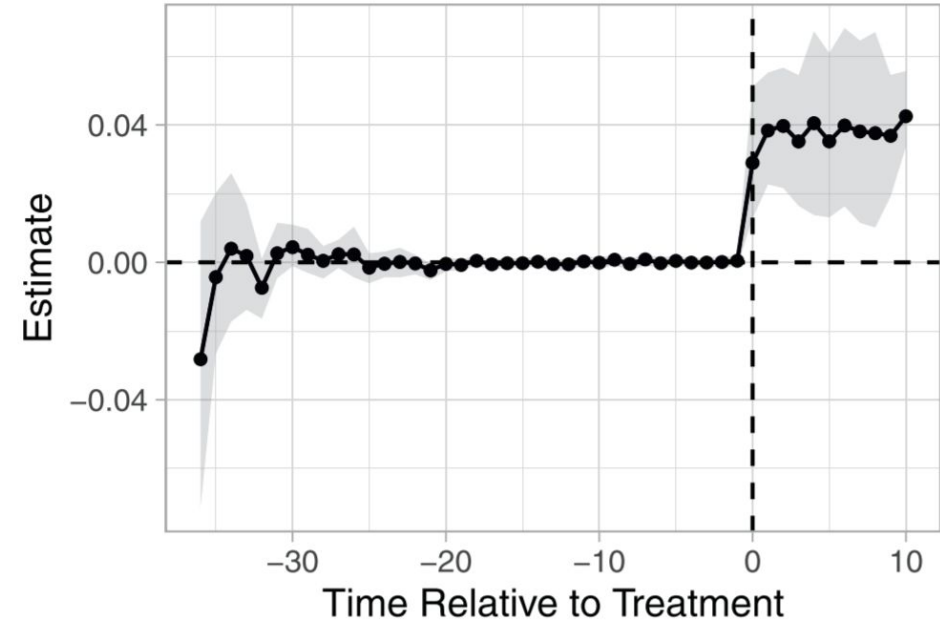
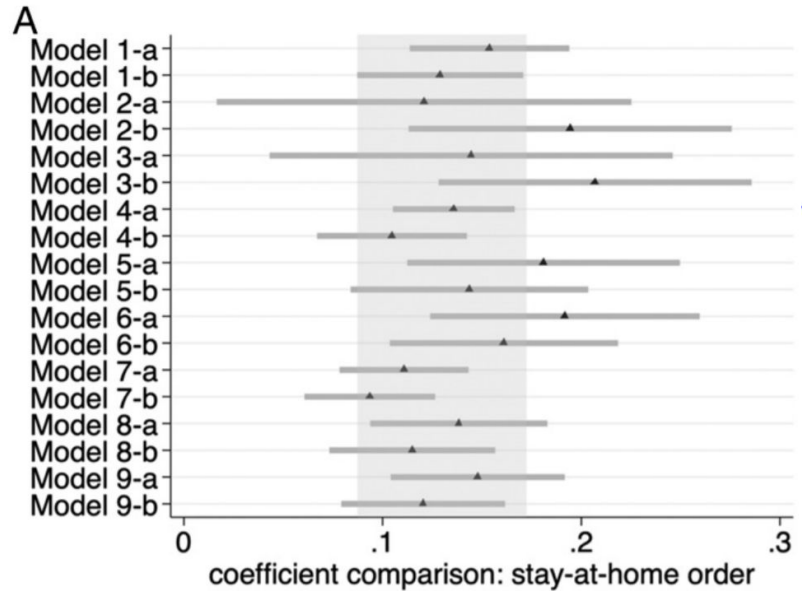
COVID-19 Child care demand for critical workers

This dashboard uses data from the [US Census Current Population Survey](#), to estimate child care demand for the children of workers in critical sectors. Click [here for industry classifications](#). Hold the Ctrl button for multiple selections. To use, **First** select a State, a Geography (MSA/CBSA/NECTA code or All for the state wide estimate). **Second**, choose a sector; All healthcare is hospital + outpatient + nursing & other care facilities (for example, does not include dentists office). Essential are industries where workers could be essential. Any industry may have non-essential workers, but these are not subtracted. For example, hospital includes doctors, custodial, food prep, billing, purchasing etc. While some jobs may be done remotely, it is still very difficult to work from home while caring for a small child.

Microsoft Power BI

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

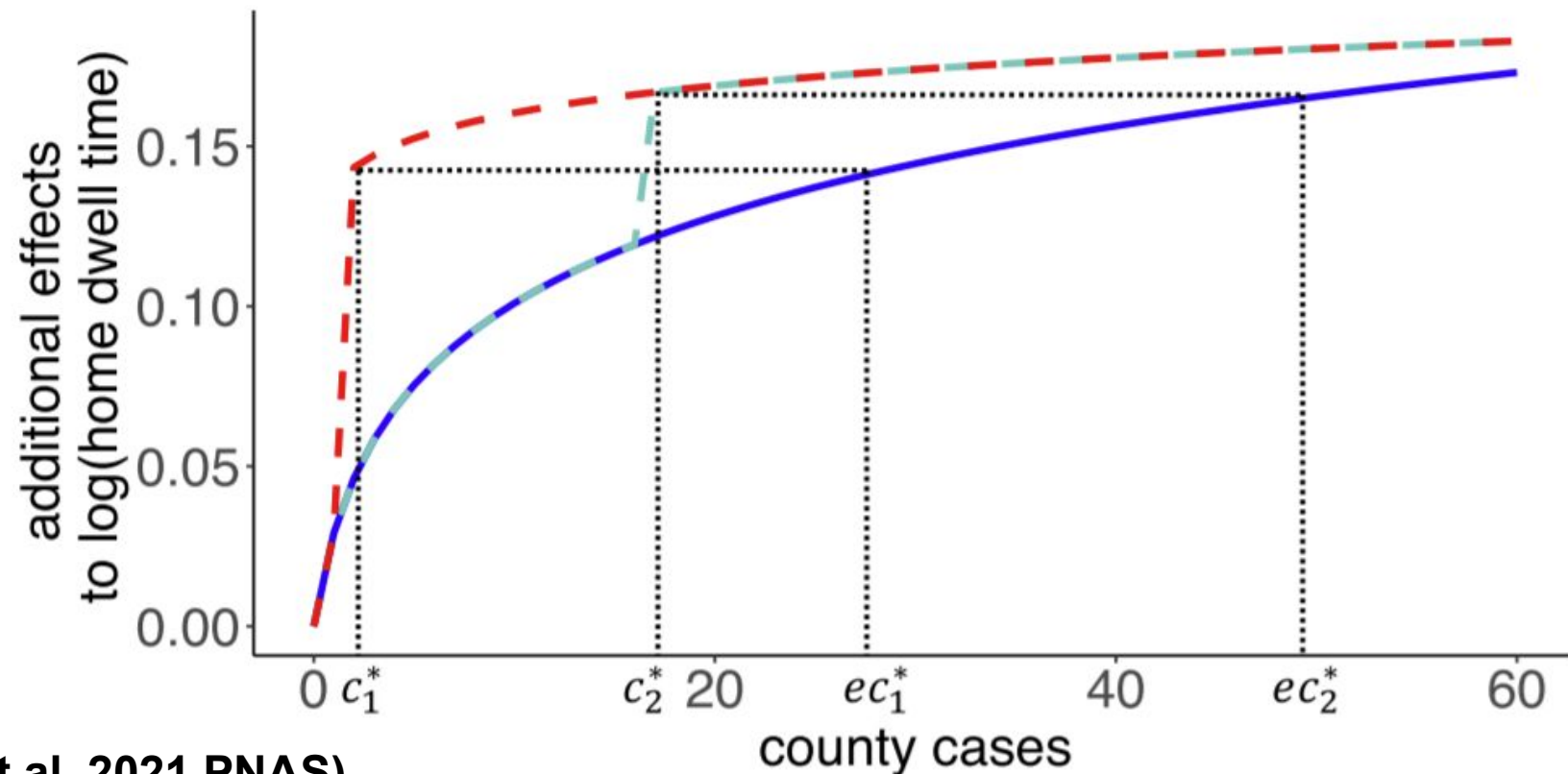




What would cases have had to risen to to get the same behavior?

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)



(Yan et al. 2021 PNAS)

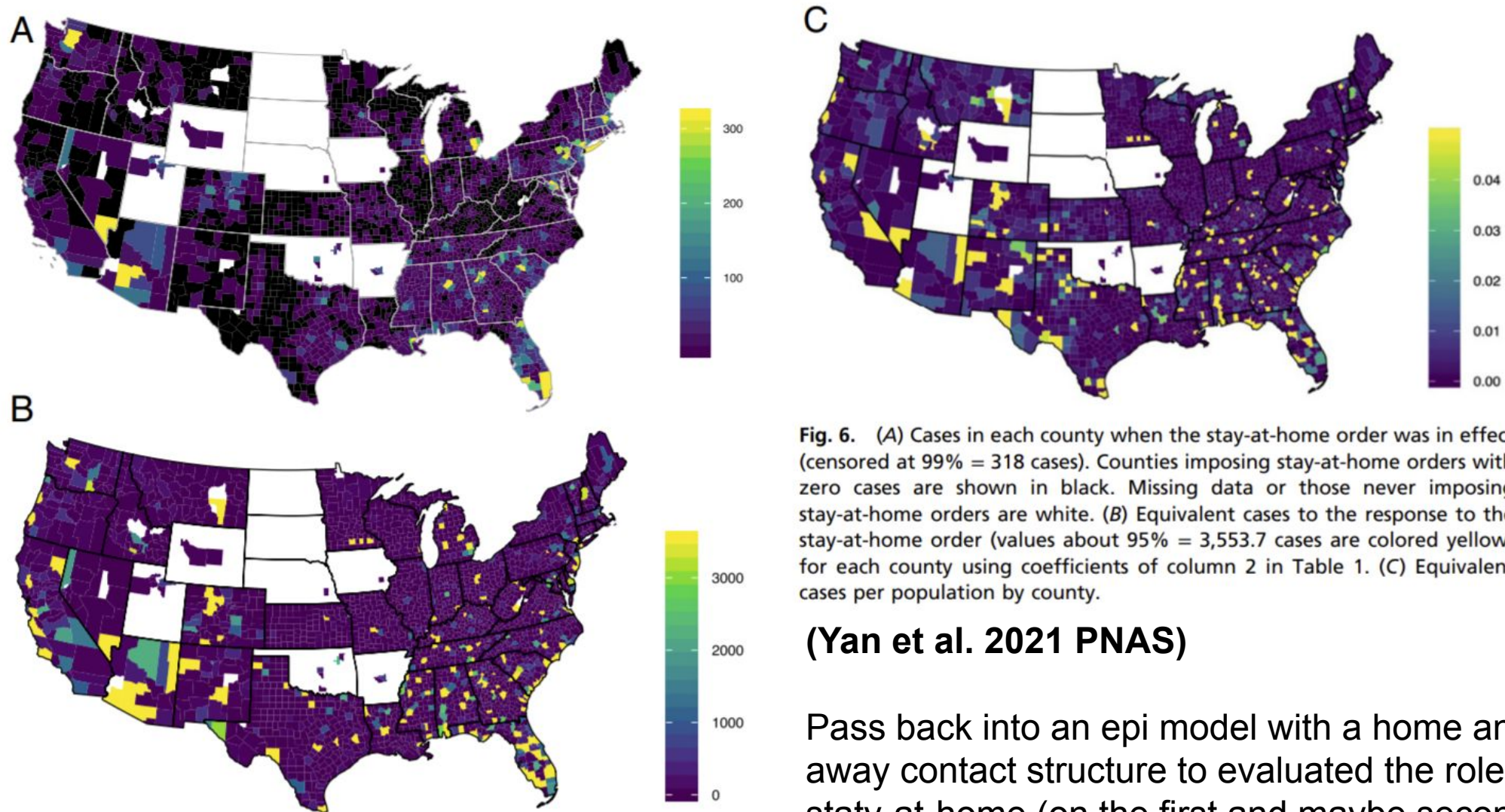


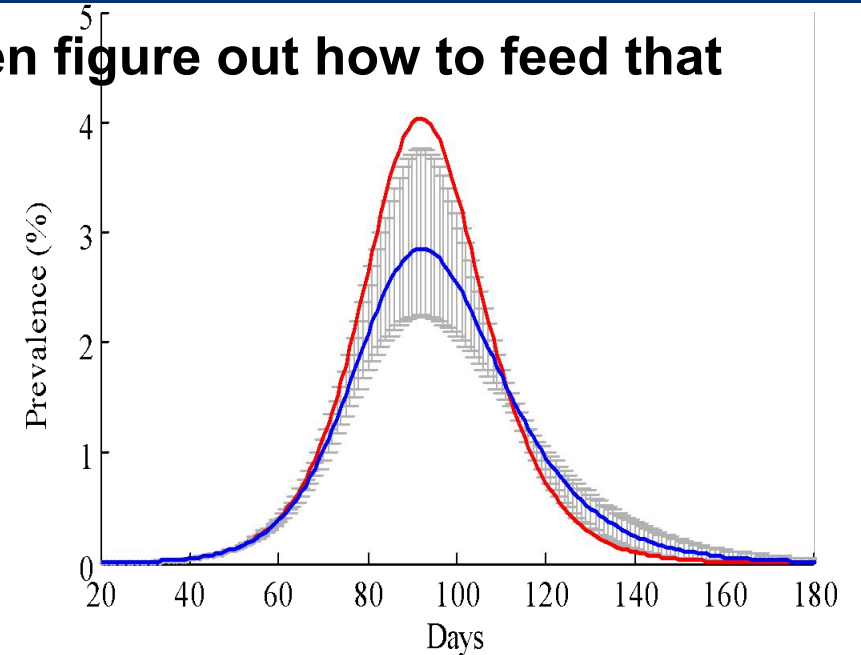
Fig. 6. (A) Cases in each county when the stay-at-home order was in effect (censored at 99% = 318 cases). Counties imposing stay-at-home orders with zero cases are shown in black. Missing data or those never imposing stay-at-home orders are white. (B) Equivalent cases to the response to the stay-at-home 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 evaluate the role of stay-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 school closures only ever optimal if
~~these 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 | <ol style="list-style-type: none"> 1. Measure (Minimize) cases 2. Measure (Minimize) death 3. Measure (Minimize) probability of hitting a hospital boundary condition <hr/> |
| Soc-Eco | <ol style="list-style-type: none"> 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 $SWF = \alpha_1 U_1 + \alpha_2 U_2 + \alpha_3 U_3 \dots$

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 $\alpha_i = \left(\frac{\partial U}{\partial m}\right)^{-1}$