Causal Impact of Masks, Policies, Behavior on Early Covid-19 Pandemic in the U.S.

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Issues

- What is the impact of various policies adopted by the US states on the spread of COVID-19?
- Closure of non-essential businesses?
- Mandatory face mask policy?
- How do people adjust their behavior to policies and new information on higher transmission risks?

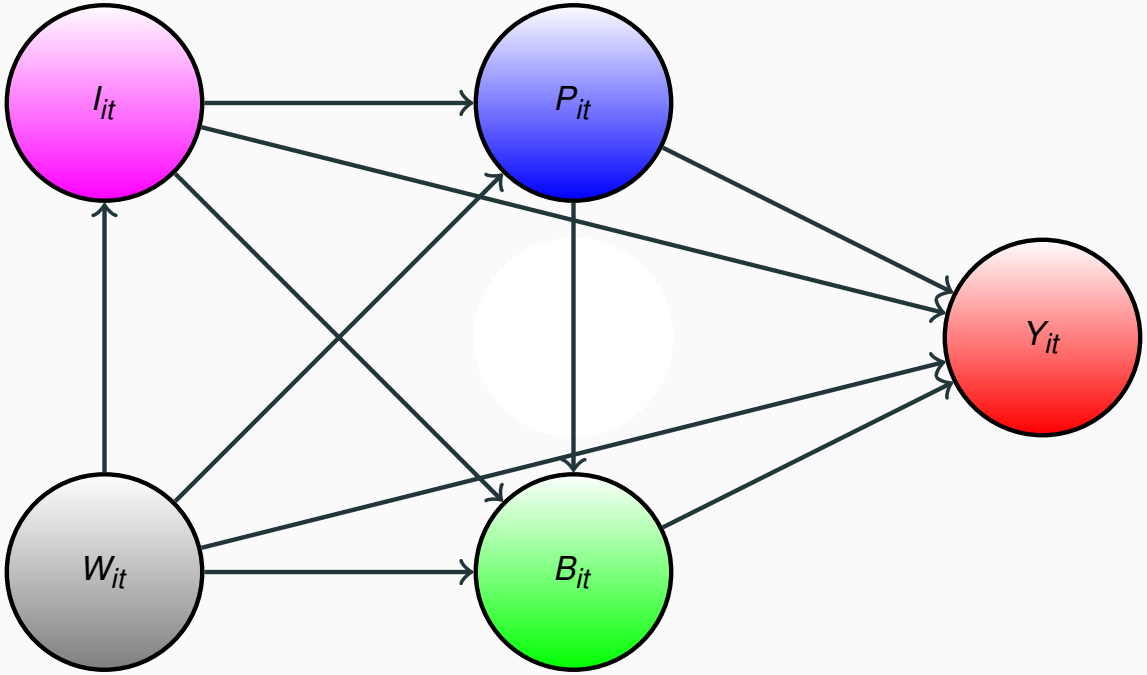
Literature

- The impact of non pharmaceutical interventions on Covid-19 cases: Hsiang et al. (2020), Courtemanche et al. (2020), Avery et al. (2020) for review.
- The impact of social distancing policies on behavior in the US is mixed: Abouk and Heydari (2020), Maloney and Taskin (2020), Gupta et al. (2020), Andersen (2020)
- Pei et al. (2020) provides simulation of implementing all policies 1-2 weeks earlier.
- Model simulations by epidemiologists (e.g., Ferguson et al., 2020). Substantial uncertainty in parameters (Avery et al., 2020; Stock, 2020)
- Fernández-Villaverde and Jones (2020) estimate a SIRD model that captures feedback from daily deaths to future behavior and infections.
- No existing experimental evidence for face mask. Our work is complementary to the medical observational evidence for face mask discussed in Greenhalgh et al. (2020), Howard et al. (2020), and Zhang et al. (2020).

Contributions of this paper

1. The causal framework on how the Covid-19 spread is dynamically determined by policies and human behavior.
    - Direct vs. indirect effect of policies.
    - People voluntarily adjust their behavior in response to new information on reported cases/deaths.
    - Dynamic feedback.
2. Regression analysis on how the growth rates of Covid-19 cases/deaths are determined by policies and behavior using the US state-level data.
3. Counterfactual experiments
    - What if no closure of non-essential businesses?
    - What if mandatory face mask policy had been adopted everywhere on April 1st?

Causal Model



- Y_{it}: the growth rate of cases/deaths
- P_{it}: the lagged policies (e.g., mandatory face mask policy)
- B_{it}: the lagged behavior variables (Google mobility measures)
- I_{it}: information on transmission risks (past cases and deaths)
- W_{it}: confounders (state-level characteristics, month dummies)

Structural Equation Model (SEM) and Orthogonality Restrictions

$$Y_{it} = \alpha' B_{it} + \pi' P_{it} + \mu' I_{it} + \delta_Y' W_{it} + \varepsilon_{it}^y, \quad \varepsilon_{it}^y \perp B_{it}, P_{it}, I_{it}, W_{it} \qquad \text{(BPI}\rightarrow\text{Y)}$$

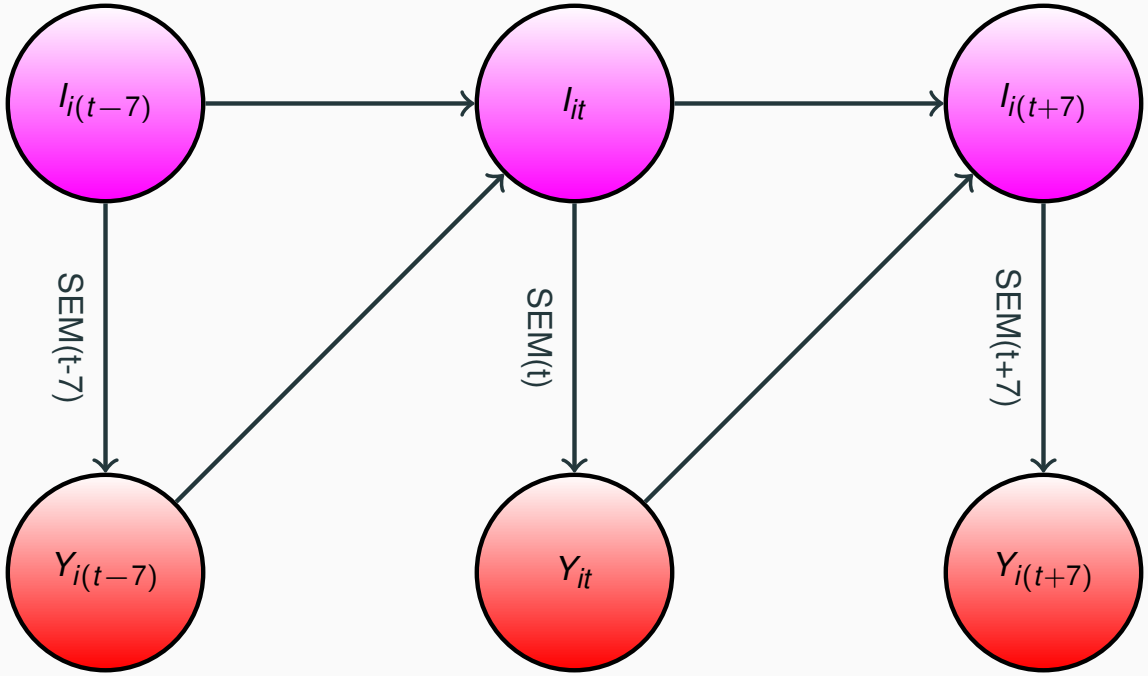
$$B_{it} = \beta' P_{it} + \gamma' I_{it} + \delta_B' W_{it} + \varepsilon_{it}^b, \qquad \varepsilon_{it}^b \perp P_{it}, I_{it}, W_{it} \qquad \text{(PI}\rightarrow\text{B)}$$

and

$$Y_{it} = (\alpha'\beta' + \pi')P_{it} + (\alpha'\gamma' + \mu')I_{it} + \bar{\delta}' W_{it} + \bar{\varepsilon}_{it}, \quad \bar{\varepsilon}_{it} \perp P_{it}, I_{it}, W_{it}. \qquad \text{(PI}\rightarrow\text{Y)}$$

- $\alpha'\beta'$ is the direct effect of policies.
- π' is the indirect effect of policies through behavior.

Dynamic feedback



$$I_{it} = \left(Y_{i,t-\ell}, \sum_{m=1}^{t/\ell} Y_{i,t-\ell m} \right)' = (\text{lagged case growth}, \text{lagged cases})$$

SIR Model and Empirical Specification

SIR Model with confirmed cases $\dot{C}(t)$ and testing $\tau(t)$:

$$\dot{S}(t) = -\frac{S(t)}{N}\beta(t)\mathcal{I}(t), \qquad \dot{\mathcal{I}}(t) = \frac{S(t)}{N}\beta(t)\mathcal{I}(t) - \gamma\mathcal{I}(t),$$
$$\dot{R}(t) = (1-\kappa)\gamma\mathcal{I}(t), \qquad \dot{D}(t) = \kappa\gamma\mathcal{I}(t), \qquad \dot{C}(t) = \tau(t)\mathcal{I}(t).$$

Differentiating $\dot{C}(t) = \tau(t)\mathcal{I}(t)$,

$$\frac{\ddot{C}(t)}{\dot{C}(t)} = \frac{S(t)}{N}\beta(t) - \gamma + \frac{\dot{\tau}(t)}{\tau(t)}.$$

Discrete-time analogue with $\frac{S(t)}{N}\beta(t) \approx X_{it}'\theta + \epsilon_{it}$:

$$Y_{it} := \Delta \log \Delta C_{it} = X_{it}'\theta + \epsilon_{it} - \gamma + \delta_T \Delta \log(T)_{it}.$$

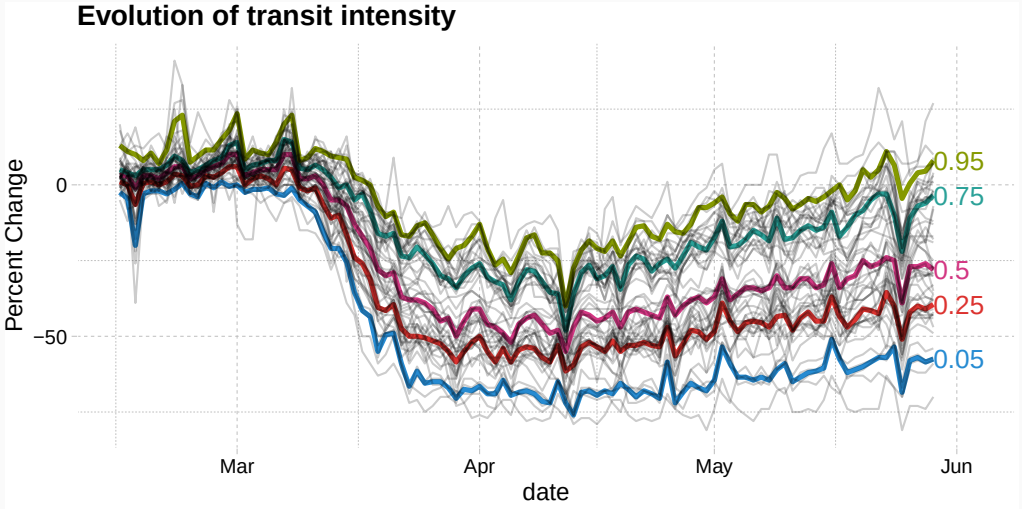
Data

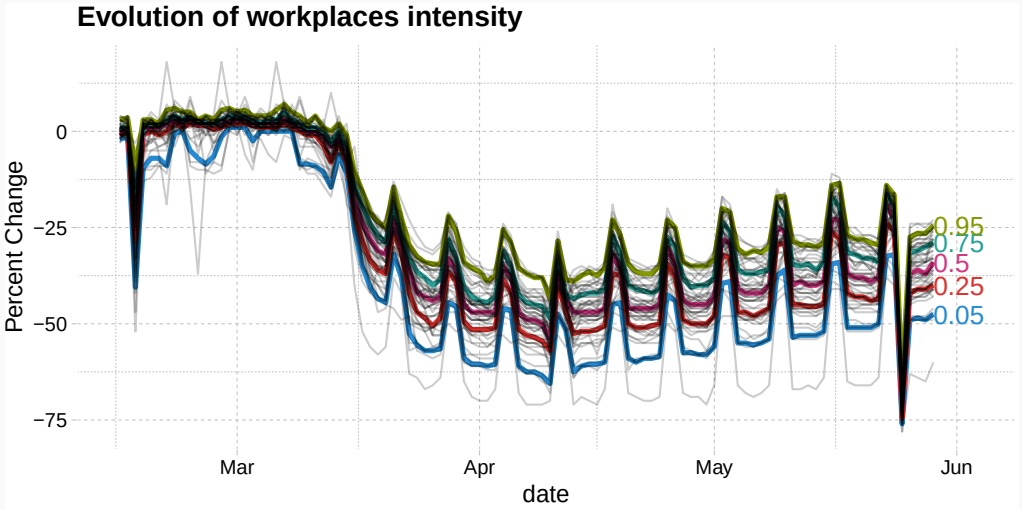
- Daily cases and deaths: NYT, JHU, Covid Tracking Project.
- The number of tests: Covid Tracking Project
- US state policies: Raifman et al. (2020).
- Behavior variables: “Transit stations,” “Workplaces,” “Grocery & pharmacy," and “Retail & recreation” from Google Mobility Reports.

We use 7 days moving averages of all variables because of

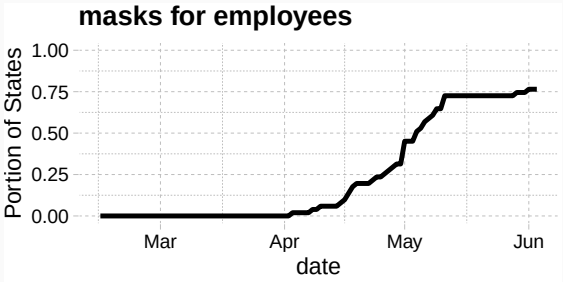
- idiosyncratic reporting delays,
- seasonality associated with the days of the week.

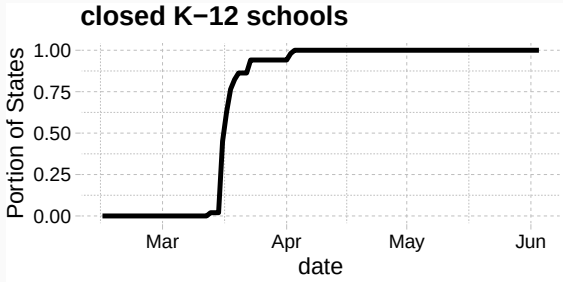
The Evolution of “Transit stations” and “Workplaces”

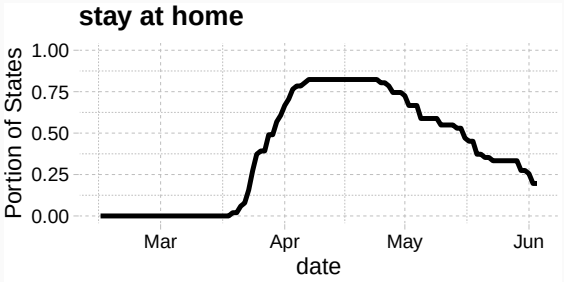


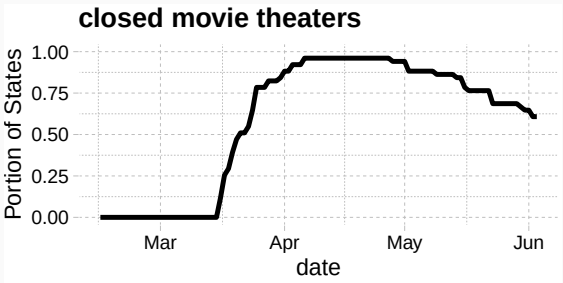


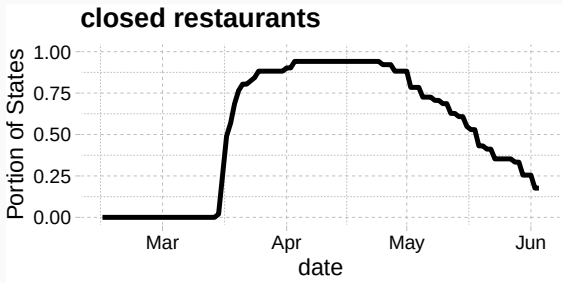
Portion of states with each policy

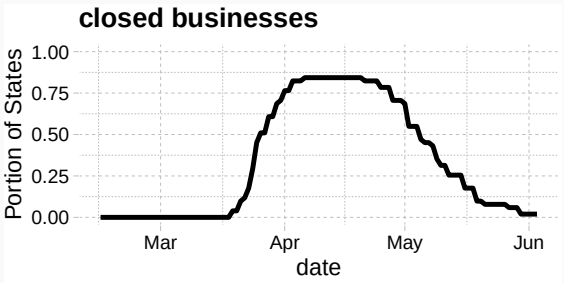












Correlations between policies and behavior variables

	workplaces	retail	grocery	transit	masks for employees	closed K-12 schools	stay at home	closed movie theaters	closed restaurants	closed businesses
workplaces	1.00									
retail	0.94	1.00								
grocery	0.75	0.82	1.00							
transit	0.90	0.92	0.83	1.00						
masks for employees	-0.32	-0.19	-0.16	-0.30	1.00					
closed K-12 schools	-0.92	-0.81	-0.58	-0.75	0.46	1.00				
stay at home	-0.70	-0.69	-0.71	-0.72	0.31	0.65	1.00			
closed movie theaters	-0.82	-0.77	-0.65	-0.72	0.40	0.85	0.75	1.00		
closed restaurants	-0.79	-0.83	-0.69	-0.77	0.26	0.77	0.74	0.84	1.00	
closed businesses	-0.66	-0.68	-0.68	-0.66	0.12	0.59	0.77	0.69	0.73	1.00

The Effect of Policies and Information on Behavior

$$B_{it}^{j} = (\beta^{j})' P_{it} + (\gamma^{j})' I_{it} + (\delta_{B}^{j})' W_{it} + \varepsilon_{it}^{bj},$$

- B_{it}^{j}: “Transit,” “Workplaces” “Grocery," and “Retail” from Google Mobility Reports,
- P_{it}: masks for employees, stay at home, closure of schools, closure of movie theaters, closure of non-essential businesses.
- I_{it}: past growth of cases/deaths, the log of past cases/deaths, national-level cases/deaths and their growth.
- W_{it}: state-level characteristics and month dummies.

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