PENN WHARTON
UNIVERSITY of PENNSYLVANIA

Budget Model

Epidemiological and Economic Effects of Lockdown

Alexander Arnon, John Ricco, and Kent Smetters

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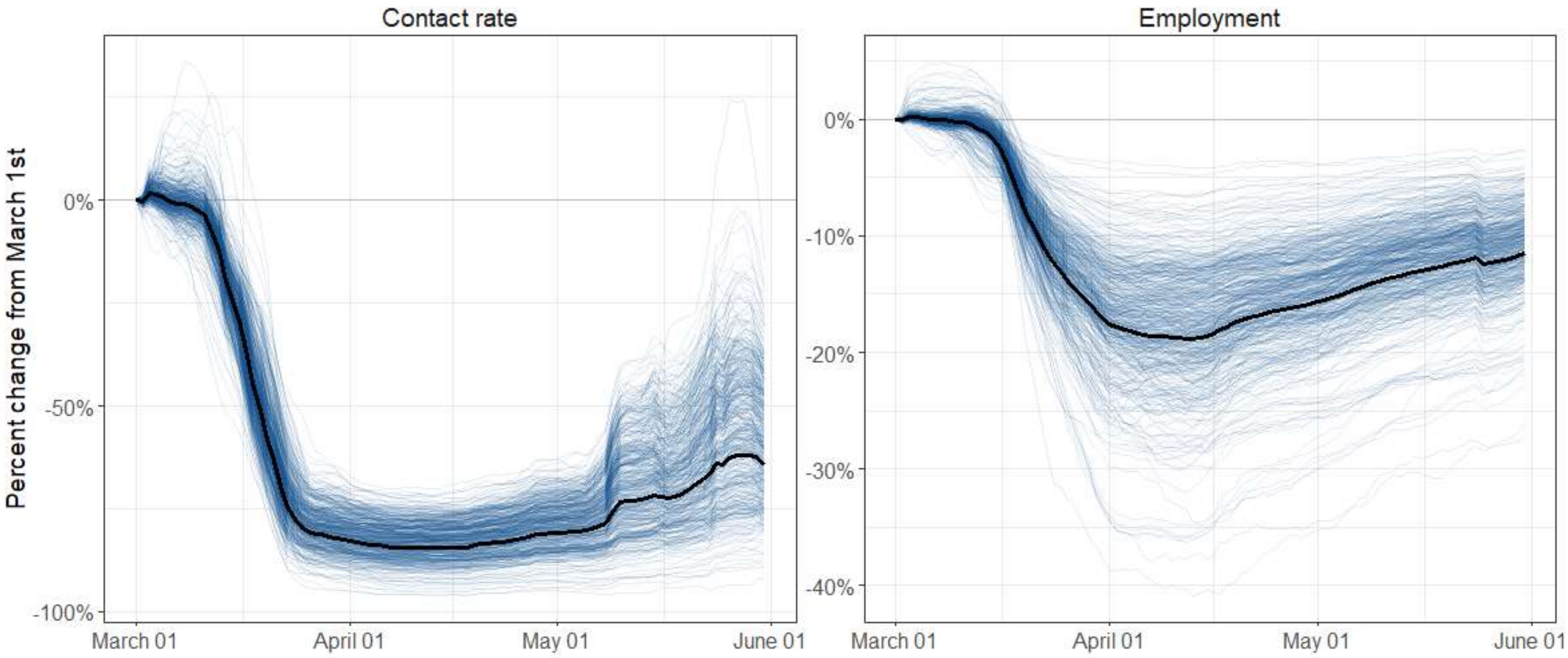
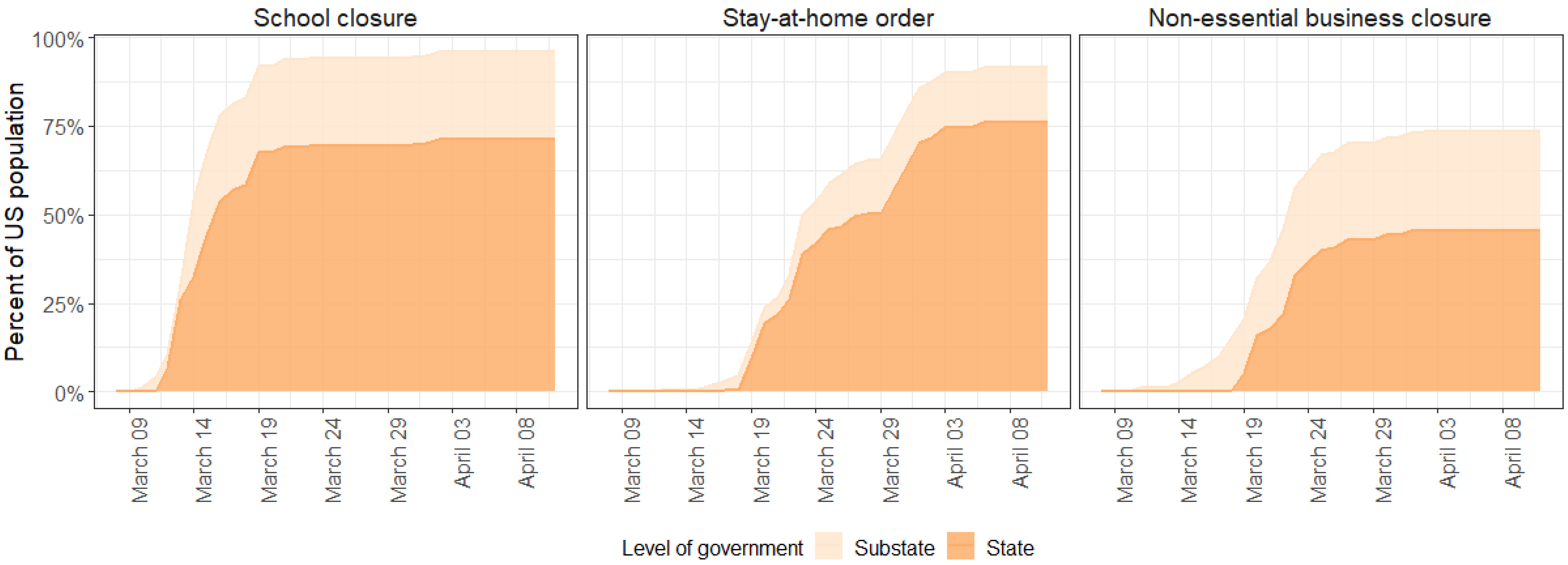
Background – Shutting down



Background – Non-pharmaceutical interventions (NPIs)



Summary

Mostly voluntary action, not government mandates. NPIs explain:

- 7% of the fall in the contact rate,
- 15% of the fall in employment.

NPIs reduced confirmed COVID-19 deaths through May 31st by more than 33,000 – or 29% – and reduced employment by almost 3 million – or 1.7%.

Issuing stay-at-home orders and closing schools earlier – without ordering businesses to close – could have saved more lives and one million jobs.

Methods

Infectious disease model (SEIR) augmented with behavioral responses, simultaneous determination of epidemiological and economic outcomes.

New high-frequency measures of contact rates and employment at the county level, aggregating information from many proxies via principal components.

Difference-in-differences framework to estimate behavioral parameters, integrated directly into the model.

Augmented SEIR model

Disease transmission depends on contacts (physical proximity) between infectious and susceptible persons and the likelihood of infection per contact:

$$transmission\,rate = \ contact\,rate \times infection\,rate$$

Conventional model: contact rate is externally given.

Augmented model: contact rate responds to severity of local epidemic and to NPIs. Employment depends on the same factors.

Augmented SEIR model

Three components of behavior determine contact rate and employment:

1. Response to local infection risk

2. Response to state and local NPIs

3. Precautionary response, by demographic/economic/political characteristics

Note: Precautionary response may include more than just pure “precaution” (e.g. effects of CDC guidance, national trends in non-modeled NPIs).

Data – COVID-19

Estimate true infections by estimating the "confirmation rate":

1. Confirmation rate = confirmed cases / (deaths / IFR)
2. Regress output from step 1) on the positivity rate and a time trend
3. Fit values from step 2) and use to scale confirmed cases

Estimate historical reproduction number using method from Cori et. al. (2013):

- Requires daily infection data and an assumption about the distribution of the virus's *serial interval* (days between successive cases)
- Iterate over hundreds of combinations of serial interval parameters, choosing the set that best matches observed epidemic curve

Data – Contact rate and employment

Daily, county-level proxies from:

- mobile device location data
- business and financial services software
- payroll service providers
- web search activity

Sources: PlaceIQ, SafeGraph, Google Mobility, Unacast, Homebase, Opportunity Insights (Paychex, Intuit, Earnin, Kronos), Google Trends

Contact rate and employment indexes

Challenges:

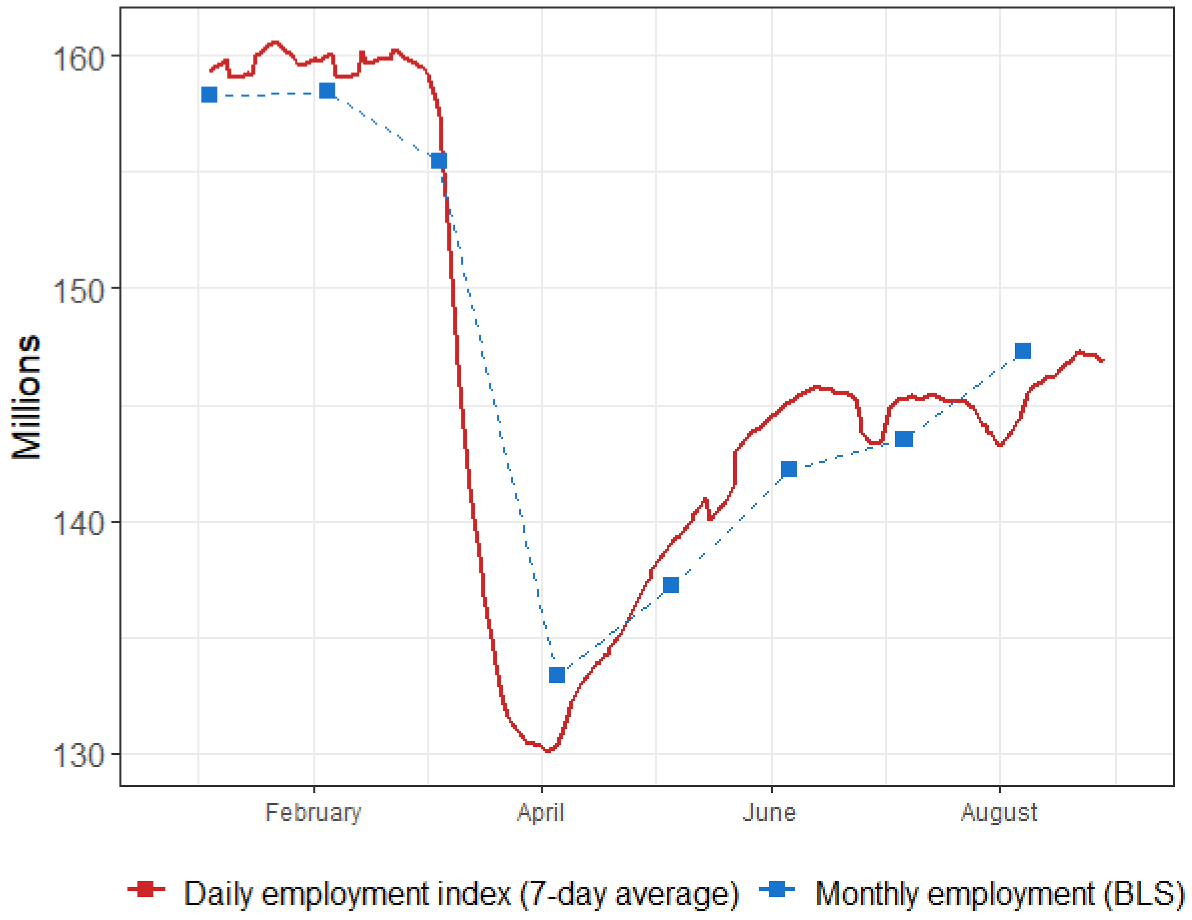
- Many imperfect proxies for an unmeasured target.
- Daily data for small geographic units → lots of noise.
- Relationship between proxies and target varies by county.

Solution: principal components

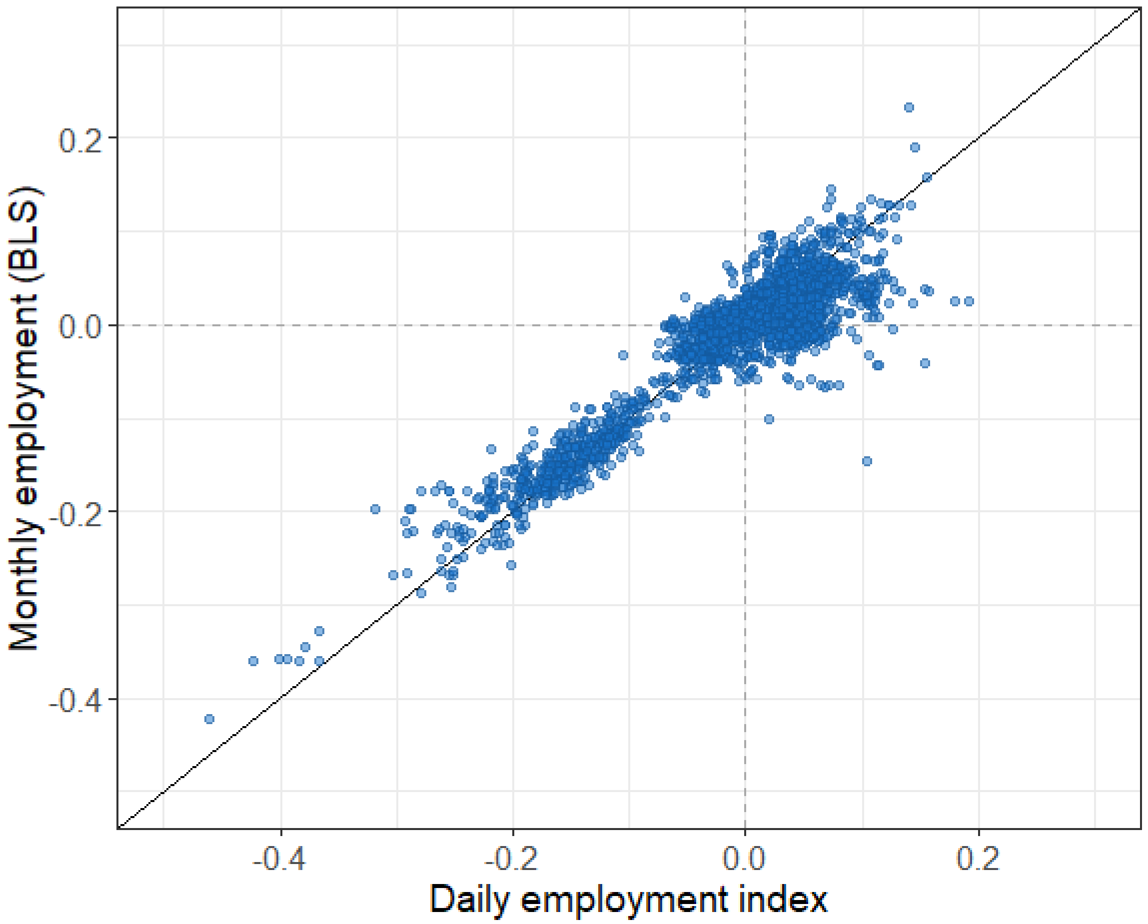
- Extract a latent signal that explains common variation across all proxies.
- Removes idiosyncratic variation and noise.
- Weights on each proxy are county-specific.

Daily employment index vs. BLS monthly employment

Employment level

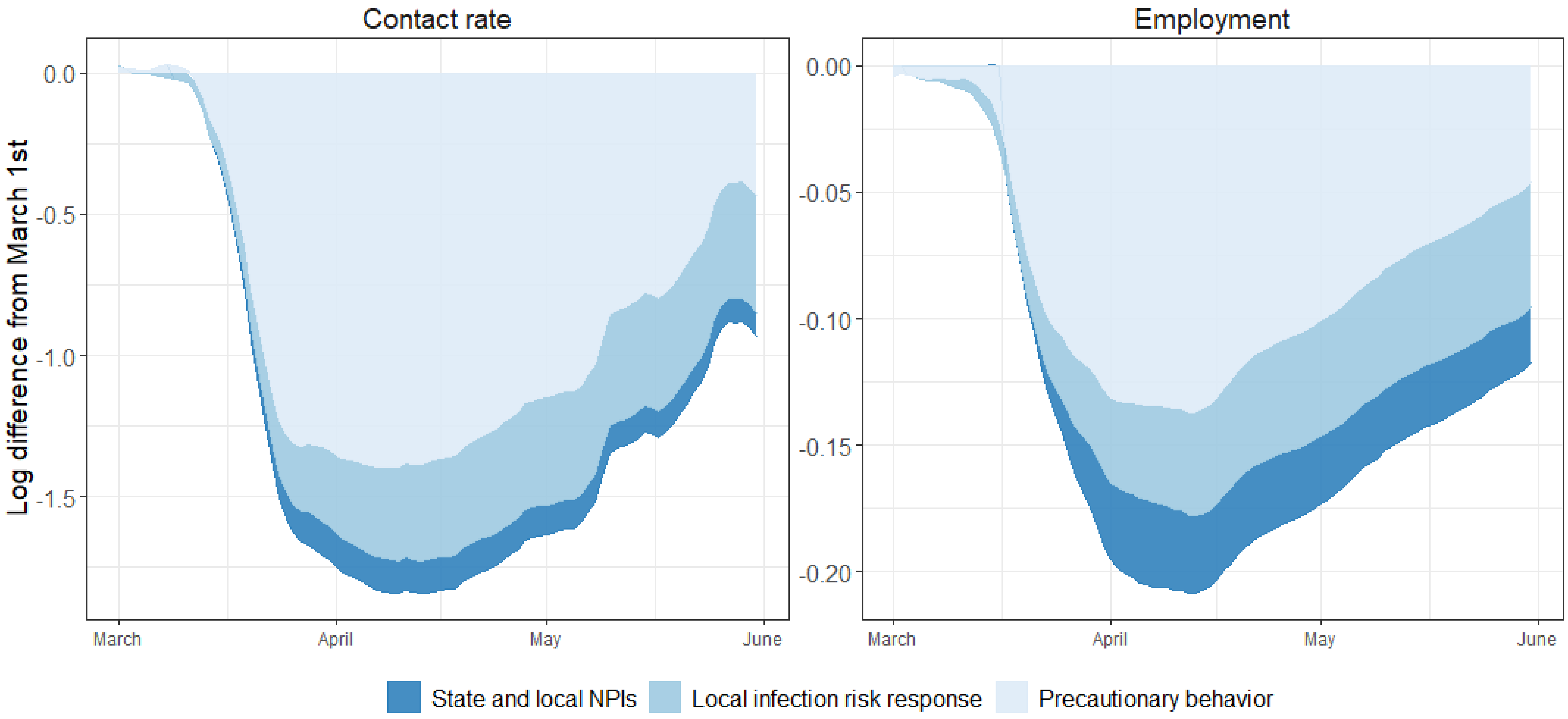


Monthly log change in county employment

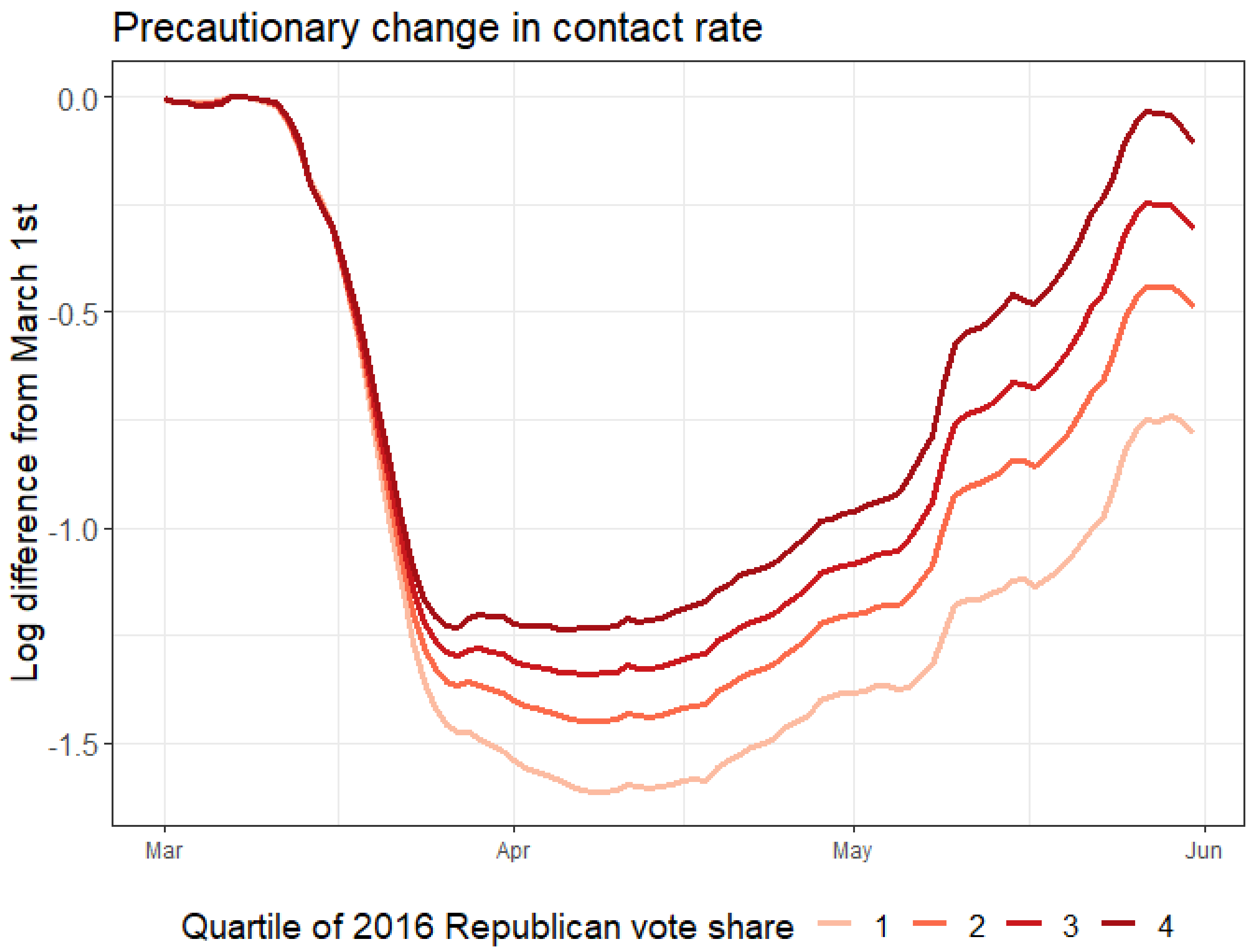


Declines in contacts and employment were mostly voluntary action, not government mandates.

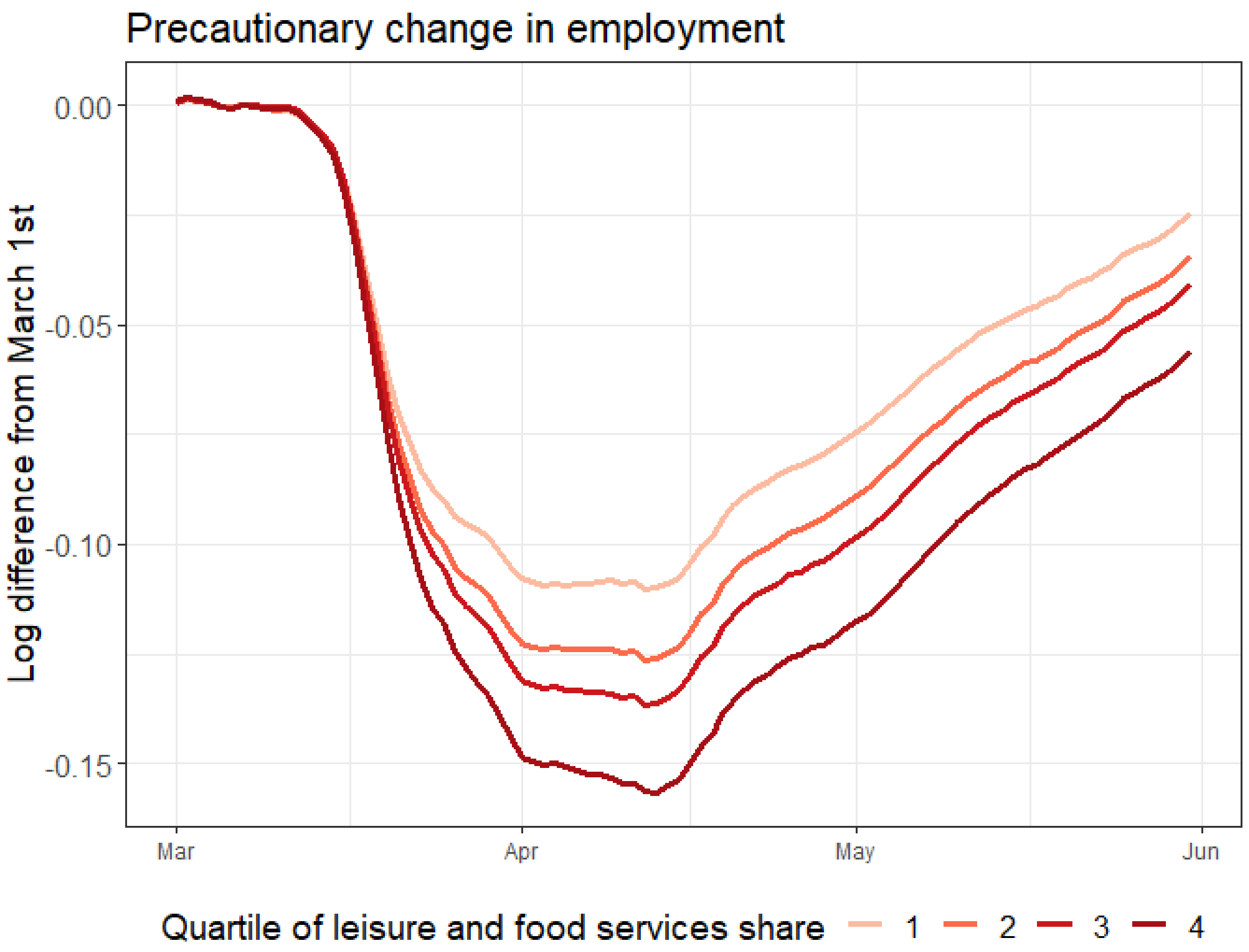
Decomposition of response to COVID-19



Precautionary contact rate response and political preference

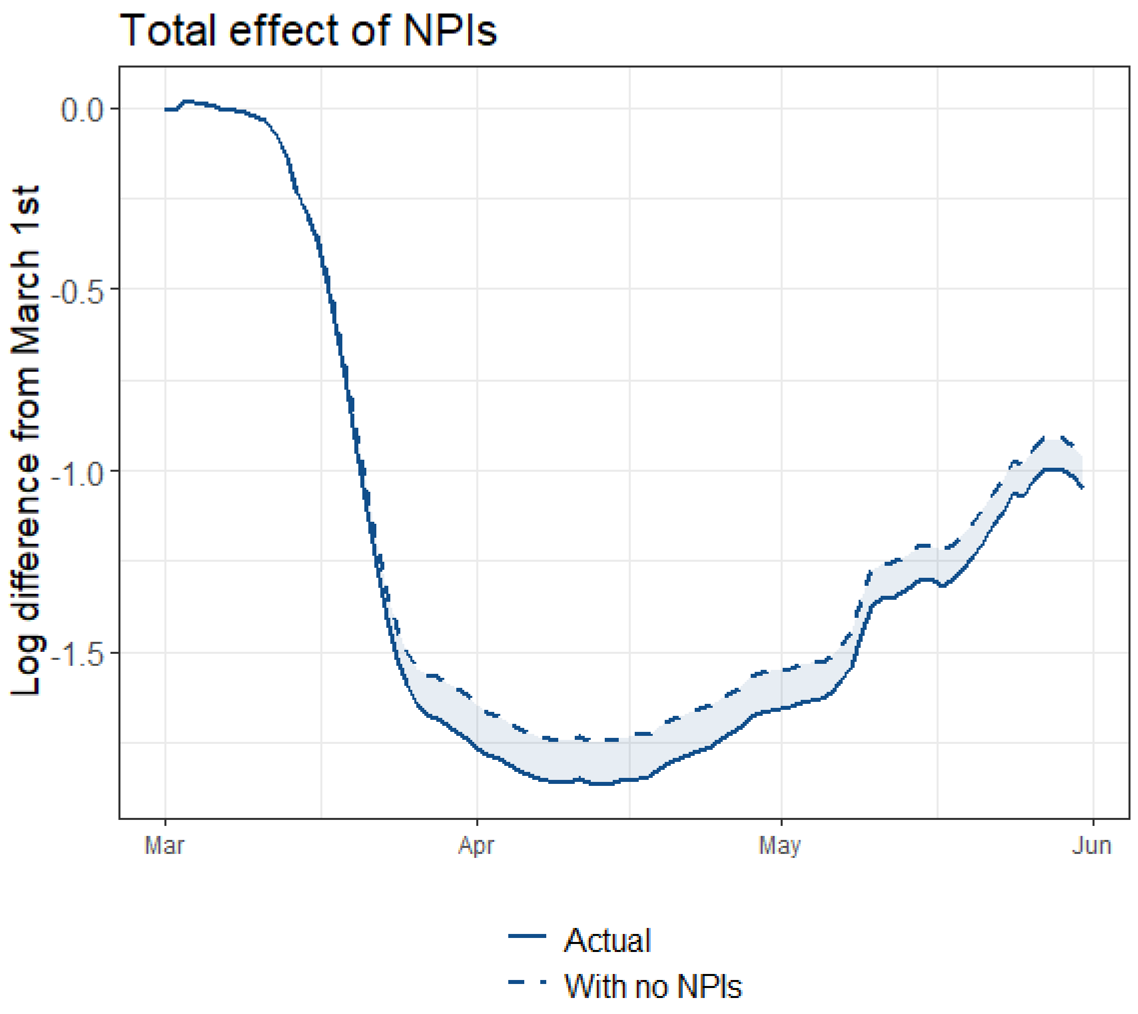


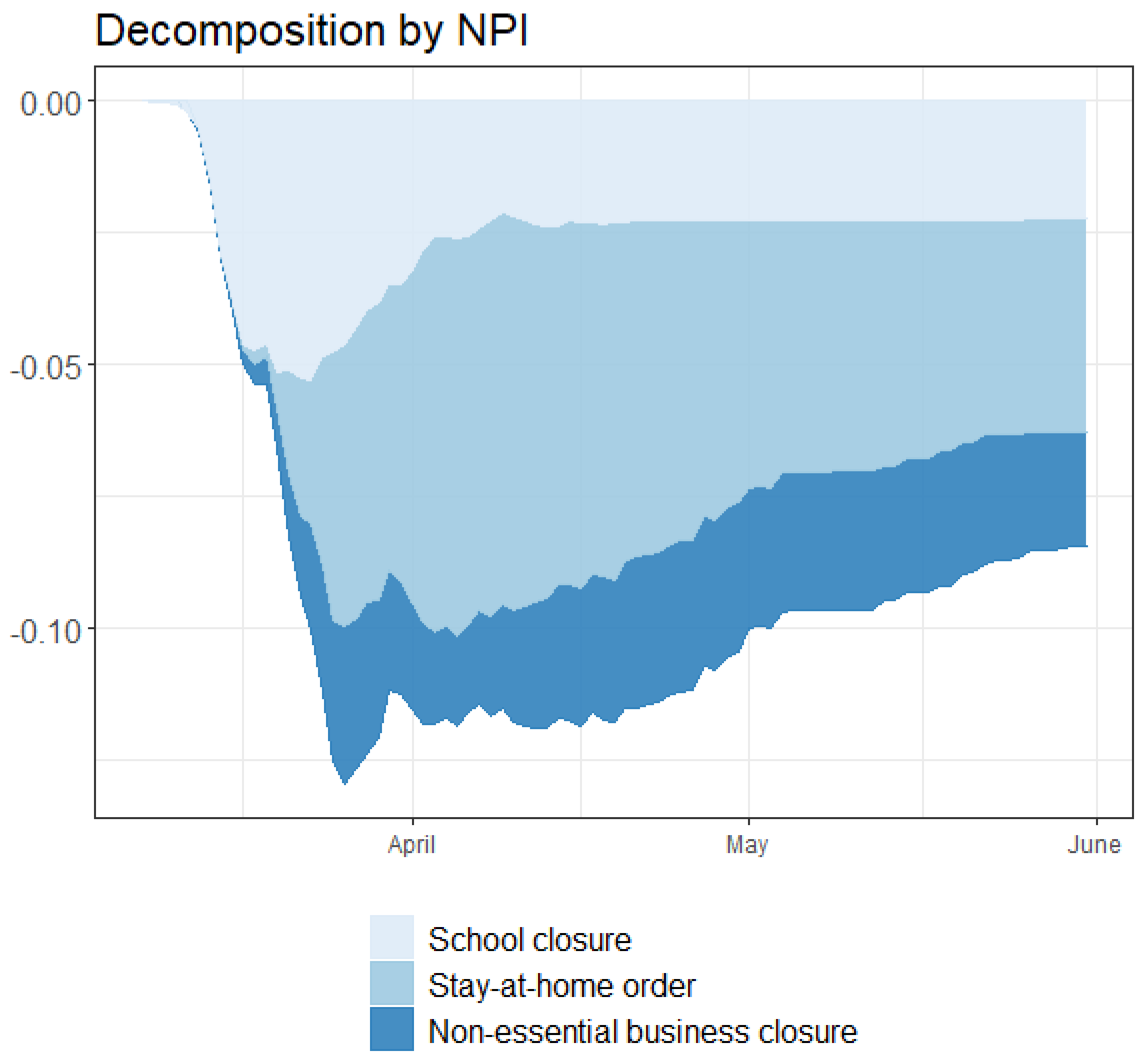
Precautionary employment response and industry



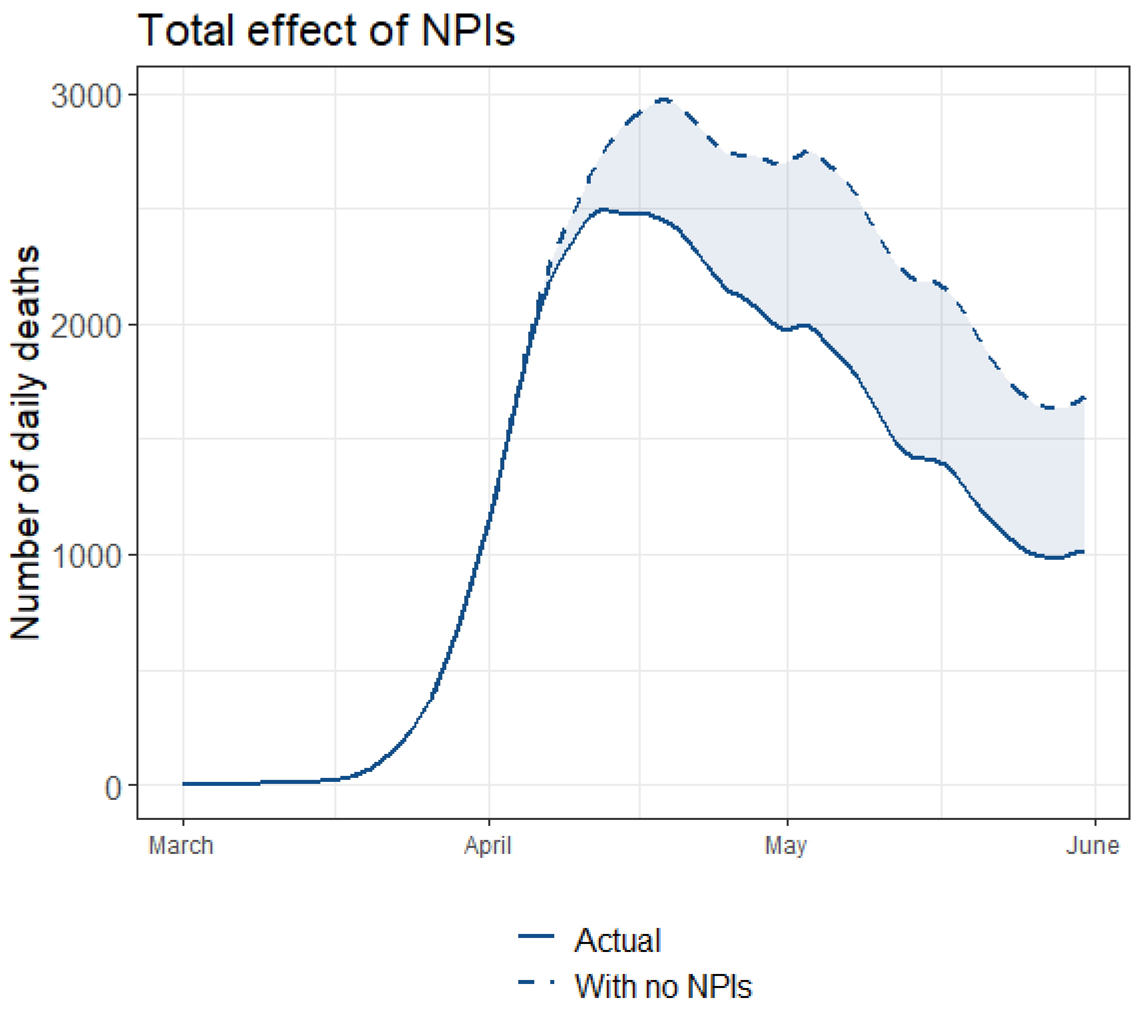
NPIs reduced confirmed COVID-19 deaths by more than 500 per day and reduced employment by almost 3 million.

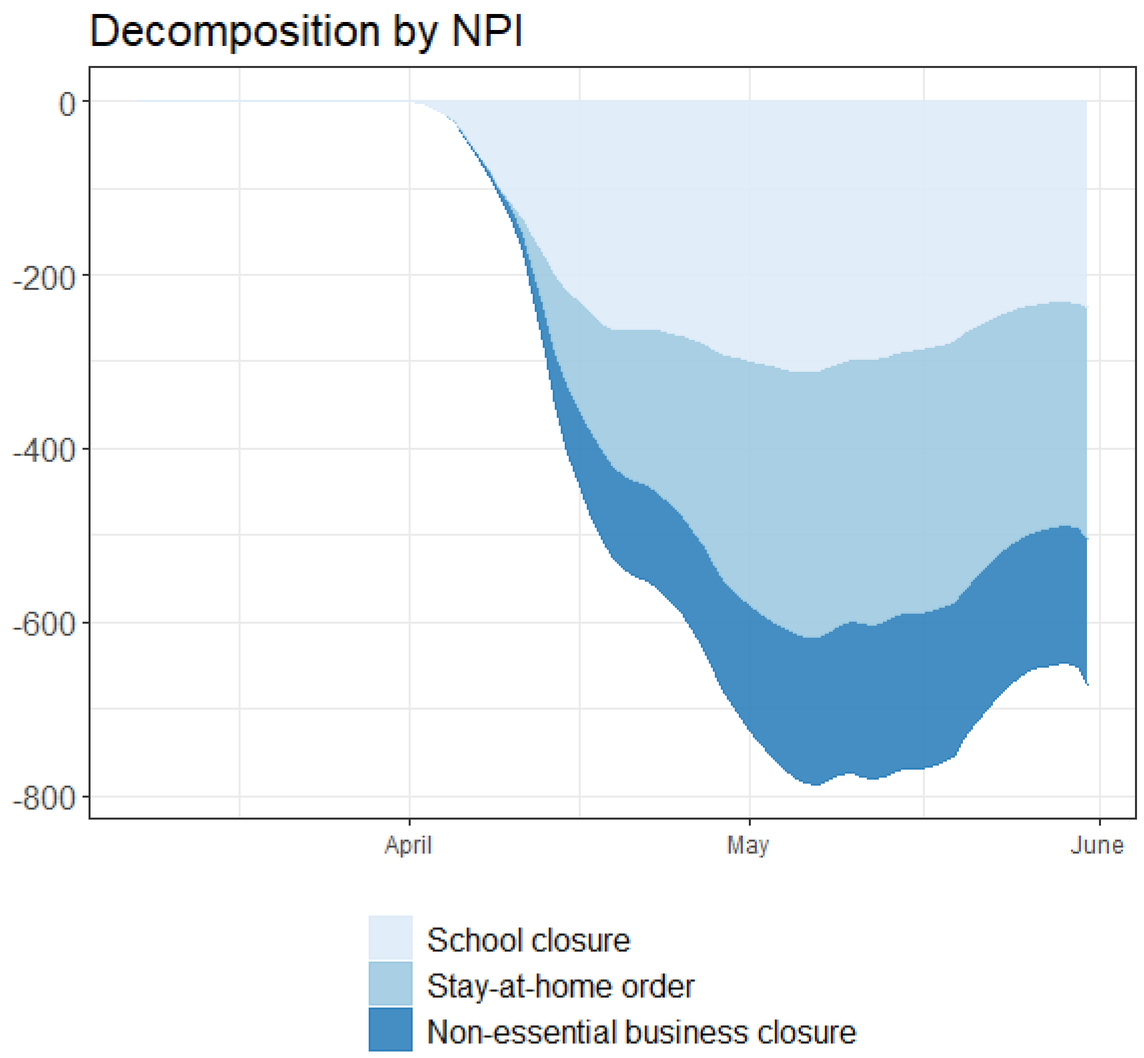
Impact of NPIs – Contact rate



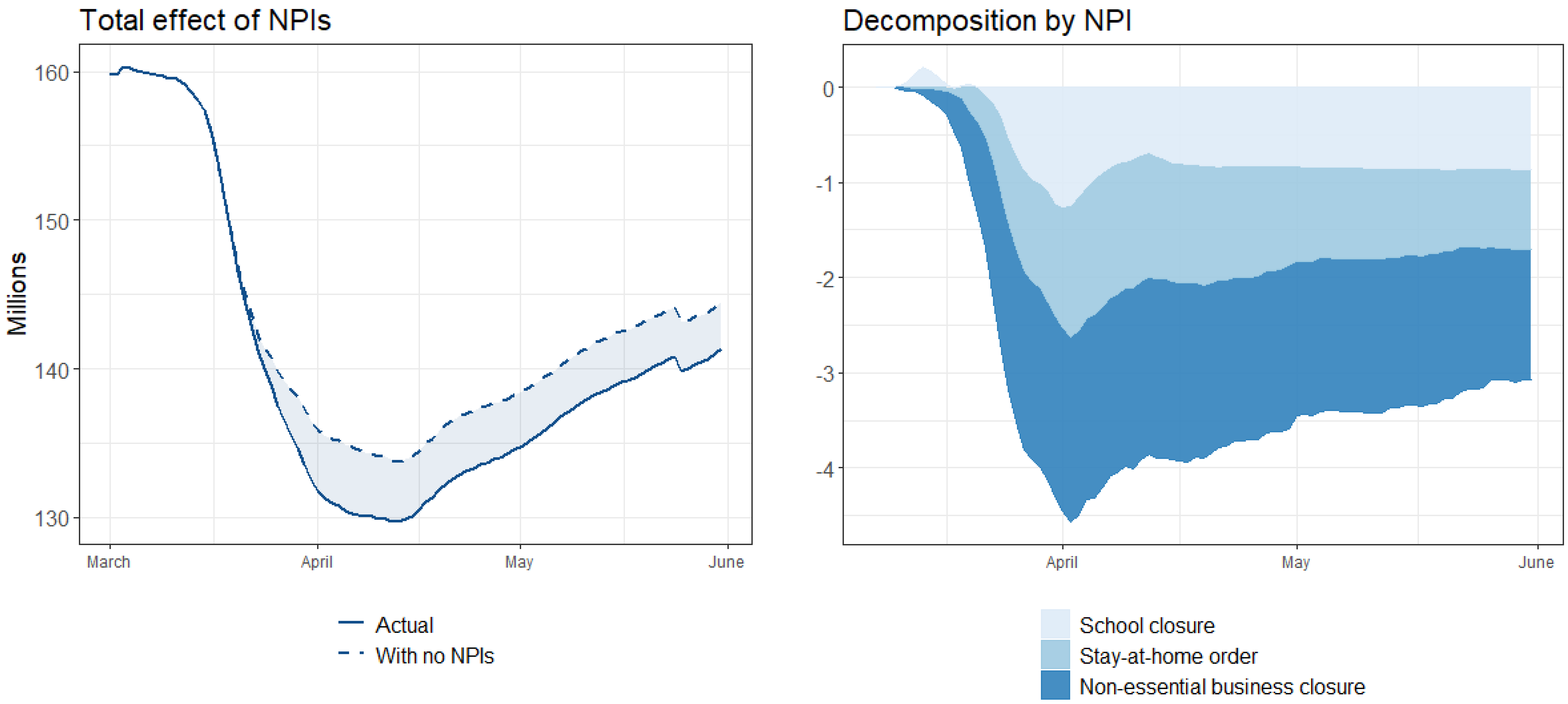


Impact of NPIs – Daily COVID-19 deaths



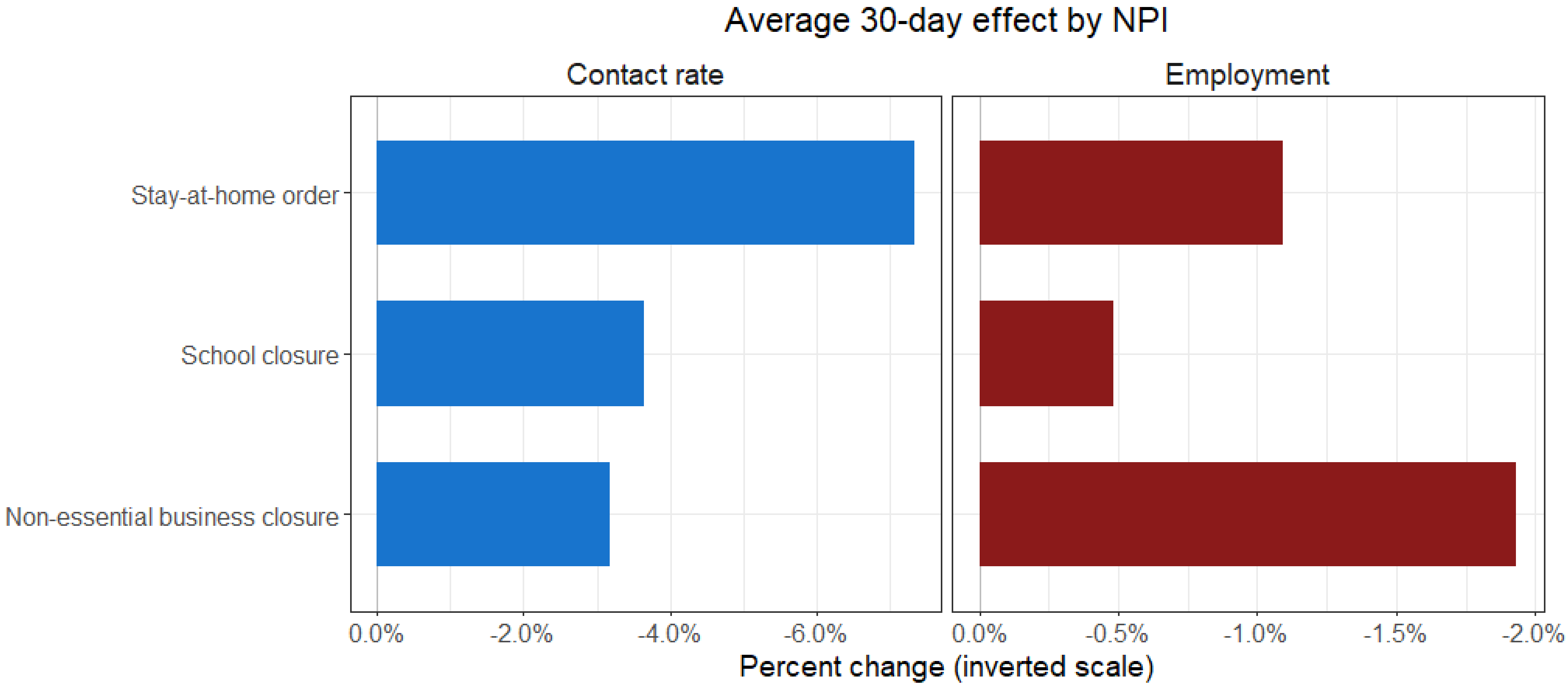


Impact of NPIs – Employment



Issuing stay-at-home orders and closing schools earlier – without ordering businesses to close – could have saved more lives and a million jobs or more.

Relative NPI efficiency



Policy counterfactuals

	Cumulative COVID-19 deaths through May 31st		Average difference in employment from March 1st	
	Deaths	Difference from actual	Millions	Difference from actual
Actual	114,423		-20.5	
No NPIs	147,661	33,238	-17.8	2.67
National response on March 13th				
Stay-at-home order	120,314	5,891	-18.9	1.62
Stay-at-home order and school closure	110,037	-4,386	-19.5	1.01
Stay-at-home order, school closure, and non-essential business closure	102,293	-12,130	-21.6	-1.08
Local response to confirmed cases				
Stay-at-home order	120,385	5,962	-18.8	1.76
Stay-at-home order and school closure	112,798	-1,625	-19.3	1.21
Stay-at-home order, school closure, and non-essential business closure	107,102	-7,321	-21.1	-0.62

Appendix

SEIR model

$$\frac{dS_{it}}{dt} = -\beta_{it}(\alpha A_{it} + \ I_{it})\frac{S_{it}}{N_i}$$

$$\frac{dE_{it}}{dt} = \beta_{it}(\alpha A_{it} + \ I_{it})\frac{S_{it}}{N_{it}} - \sigma E_{it}$$

$$\frac{dA_{it}}{dt} = (1-\psi)\sigma E_{it} - \gamma^A A_{it}$$

$$\frac{dI_{it}}{dt} = \psi\sigma E_{it} - \gamma^I I_{it}$$

$$\frac{dR_{it}}{dt} = \gamma^I I_{it}\left(1 - \frac{\mu_{i(t-1/\gamma^I)}}{\psi}\right) + \gamma^A A_{it}$$

$$\frac{dT_{it}}{dt} = \gamma^I I_{it}\left(\frac{\mu_{i(t-1/\gamma^I)}}{\psi}\right)$$

$$\frac{dD_{it}}{dt} = \frac{\mu_{i(t+\tau_F+1/\gamma^I)}}{\psi}\left(\frac{I_{it}}{\tau_F - (\gamma^I)^{-1}}\right)$$

i = state (simulations) or county (estimation)

t = date

N_i = total population

S_{it} = susceptible

I_{it} = infected, symptomatic

A_{it} = infected, asymptomatic

E_{it} = exposed

R_{it} = recovered

T_{it} = terminal

D_{it} = deceased

SEIR model – exogenous parameters

Parameter	Definition	Value	Source
$\boldsymbol{\alpha}$	ratio of asymptomatic to symptomatic transmission rates	1	Lee and others (2020), Tan and others (2020)
$\boldsymbol{\sigma}$	$1/\tau_E$, where τ_E is the noninfectious latent period in days	1/2	Peng and others (2020)
$\boldsymbol{\psi}$	symptomatic share of new infections	0.84	He and others (2020)
$\boldsymbol{\gamma^A}$	$1/\tau_A$, where τ_A is the infectious period for asymptomatic cases in days	1/7	Peng and others (2020)
$\boldsymbol{\gamma^I}$	$1/\tau$, where τ_I is the infectious period for symptomatic cases in days	1/7	Peng and others (2020)
$\boldsymbol{\tau_S}$	duration from infectiousness onset to symptom onset	3	Lauer and others (2020), Peng and others (2020)
$\boldsymbol{\tau_F}$	duration from symptom onset to death for severe cases in days	19	Zhou and others (2020)
$\boldsymbol{\tau_P}$	duration from symptom onset to positive test result for confirmed cases	7	Assumed
$\boldsymbol{\mu_t}$	infection fatality ratio	0.008-0.0025	Gu (2020)

Canonical SEIR model – exogenous $\mathcal{R}_{it}$

$$\mathcal{R}_{it} = \frac{\beta_{it}}{\gamma_i}$$

$$\beta_{it} = \kappa_{it}\zeta_{it}$$

κ_{it} and ζ_{it} are exogenous

$\mathcal{R}_{it}$ = reproduction number

β_{it} = transmission rate

γ_i = duration of infectiousness

κ_{it} = contact rate

ζ_{it} = infection rate

Augmented SEIR model – endogenous $\mathcal{R}_{it}$, NPIs, employment

$$\mathcal{R}_{it} = \frac{\beta_{it}}{\gamma_i}$$

$$\beta_{it} = \kappa_{it}\zeta_{it}$$

$$\kappa_{it} = \exp\left(\Omega_{it}^{\kappa} \cdot \Phi_{it}^{\kappa} \cdot (C_{it})^{\rho^{\kappa}}\right)$$

ζ_{it} is exogenous

$$W_{it} = \exp\left(\Omega_{it}^{W} \cdot \Phi_{it}^{W} \cdot (C_{it})^{\rho^{W}}\right)$$

$\mathcal{R}_{it}$ = reproduction number

β_{it} = transmission rate

γ_i = duration of infectiousness

κ_{it} = contact rate

ζ_{it} = infection rate

Ω_{it} = precautionary behavior

Φ_{it} = behavioral response to NPIs

C_{it} = confirmed COVID-19 cases

ρ = infection risk response elasticity

W_{it} = employment (number of workers)

Behavioral parameter estimation

Ideally, we would estimate behavioral parameters from historical $\mathcal{R}_{it}$:

$$\ln \mathcal{R}_{it} = \underbrace{\boldsymbol{\omega}_t X_i}_{\Omega_{it}} + \underbrace{\boldsymbol{\phi} P_{it}}_{\Phi_{it}} + \rho c_{it} + \ln \zeta_{it} - \ln \gamma_i$$

X_i = county demographics, labor force characteristics, 2016 Republican vote share

$\boldsymbol{\omega}_t$= precautionary response parameters

P_{it} = state and local NPI event study indicators

$\boldsymbol{\phi}$ = NPI response parameters

Not feasible to estimate directly because $\mathcal{R}_{it}$ is only measurable once the epidemic is already underway $\rightarrow$ lose sample coverage of initial response in many counties.

Parameter estimation

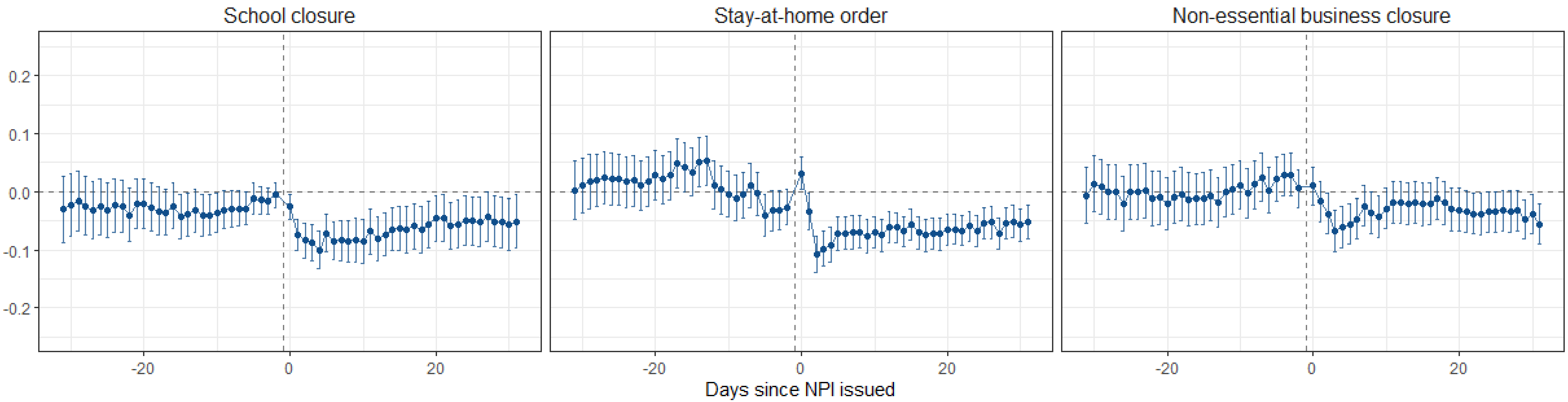
We estimate parameters using the contact rate κ_{it} instead of $\mathcal{R}_{it}$:

$$\ln \kappa_{it} = \underbrace{\boldsymbol{\omega}_t^{\kappa} X_i}_{\Omega_{it}^{\kappa}} + \underbrace{\boldsymbol{\phi}^{\kappa} P_{it}}_{\Phi_{it}^{\kappa}} + \rho^{\kappa} c_{it}$$

Same specification for employment:

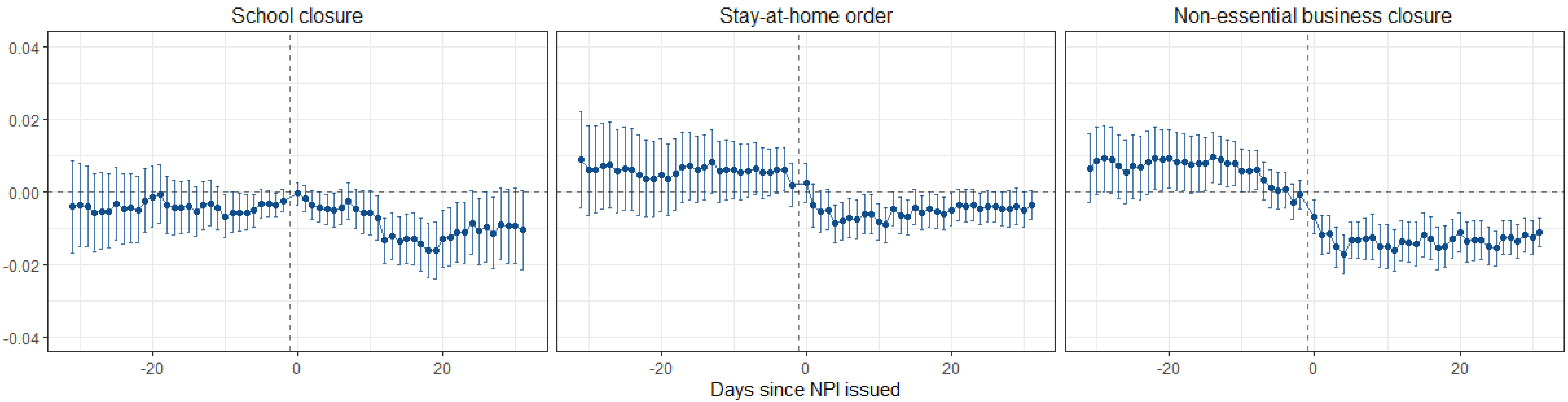
$$\ln W_{it} = \underbrace{\boldsymbol{\omega}_t^{W} X_i}_{\Omega_{it}^{W}} + \underbrace{\boldsymbol{\phi}^{W} P_{it}}_{\Phi_{it}^{W}} + \rho^{W} c_{it}$$

NPI event study treatment effects – Contact rate



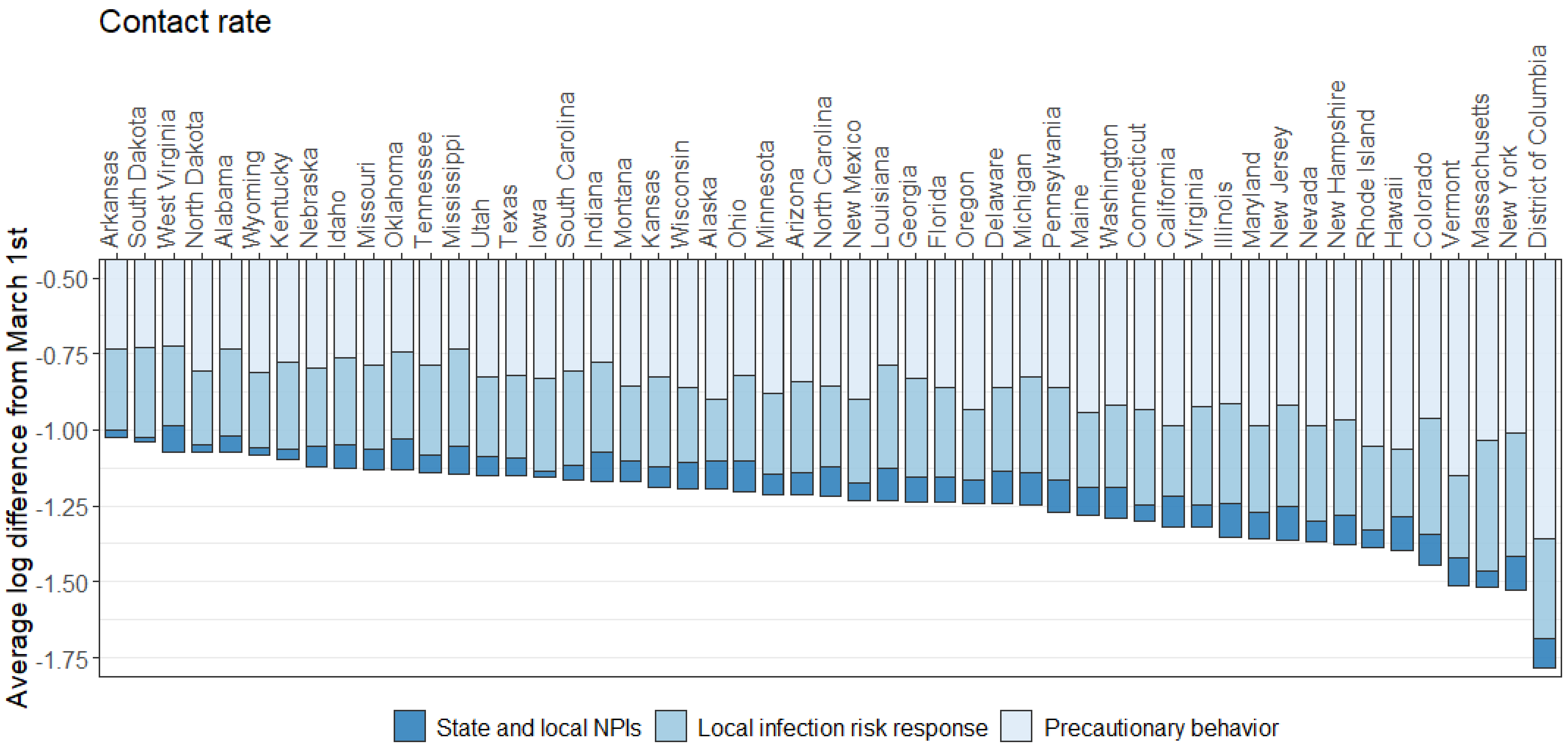
$$\ln \kappa_{it} = \boldsymbol{\omega}_t^{\kappa} X_i + \boldsymbol{\phi}^{\kappa} P_{it} + \rho^{\kappa} c_{it}$$

NPI event study treatment effects – Employment



$$\ln W_{it} = \boldsymbol{\omega}_t^W X_i + \boldsymbol{\phi}^W P_{it} + \rho^W c_{it}$$

Decomposition of response to COVID-19 by state



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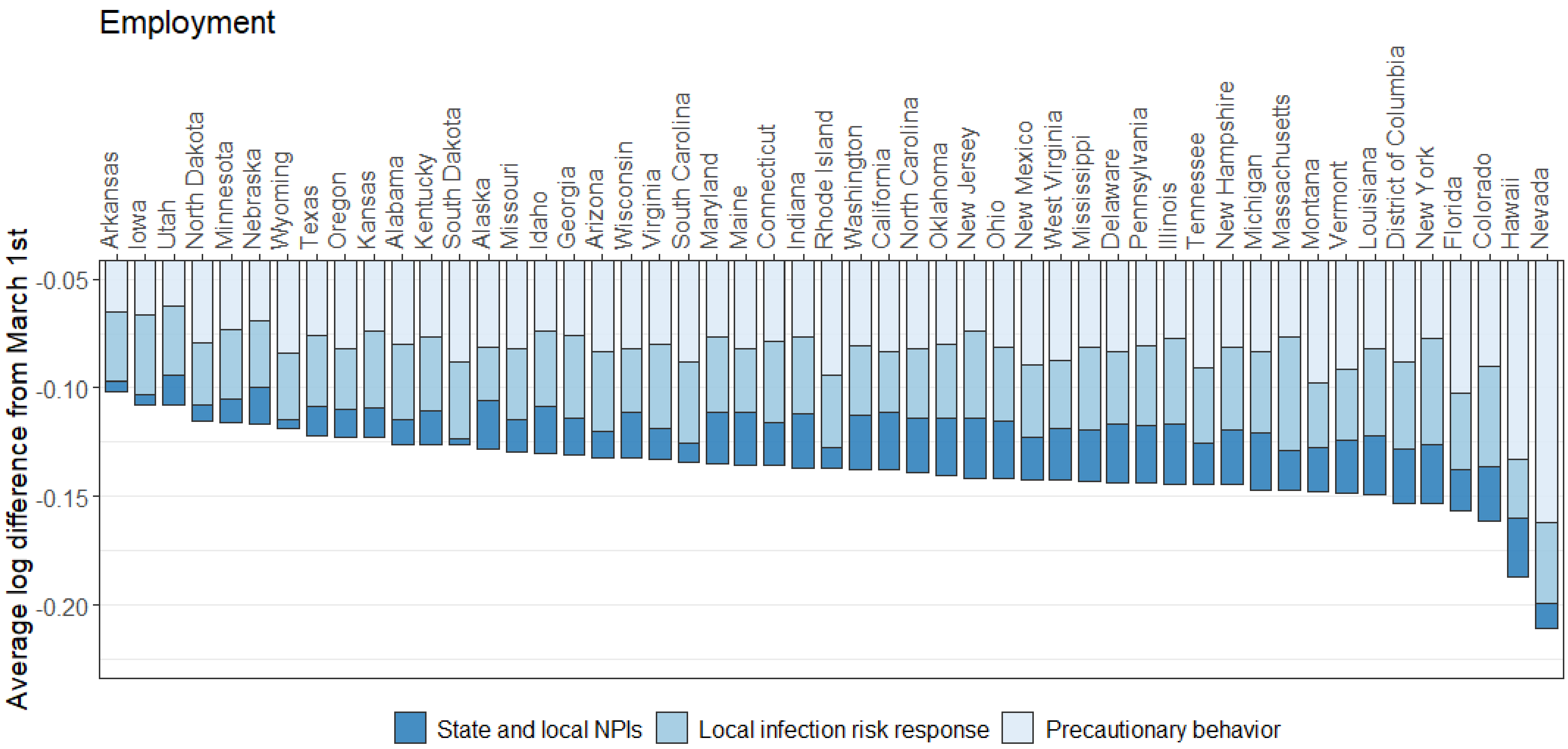

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