CAUSAL IMPACT OF MASKS, POLICIES, BEHAVIOR ON EARLY COVID-19 PANDEMIC IN THE U.S.

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Abstract.

1. Sensitivity Analysis

In this section, we provide sensitivity analysis by estimating (**??**) with alternative specifications and methods. Figure 1 shows the 90% confidence intervals of coefficients of (A) masks for employees, (B) closed K-12 school, (C) stay-at-home, and (D) the average variable of stay-at-home, closed movie theaters, closed restaurants, and closed non-essential businesses across different specifications and estimation methods as follows:

(1) Baseline specification in Table **??**.
(2) Exclude the state of New York from the sample because it may be viewed as an outlier in the early pandemic period.
(3) Add the percentage of people who wears masks to protect themselves in March and April as confounder for unobserved personal risk-aversion and initial attitude toward mask wearing.[1]
(4) Add the log of Trump's vote share in 2016 presidential election as confounder for unobserved private behavioral response.
(5) Add past behavior variables as information used to set policies. Under this specification, our causal interpretation is valid when policy variables are sufficiently random conditional on past behavior variables.
(6) Include all additional controls in (3)-(5) with the sample that excludes New York as in (2).
(7) Estimated by Double Machine Learning (DML) of Chernozhukov et al. (2018) with Lasso to reduce dimensionality while adding private mask wearing rates and the log of Trump's vote share as additional controls.

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Key words and phrases. Covid-19, causal impact, masks, non-essential business, policies, behavior.

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[1]The survey is conducted online by YouGov and is based on the interviews of 89,347 US adults aged 18 and over between March 26-April 29, 2020. The survey question is "Which, if any, of the following measures have you taken in the past 2 weeks to protect yourself from the Coronavirus (COVID-19)?".

(8) Estimated by DML with Random Forest to reduce dimensionality and capture some nonlinearities while adding private mask wearing rates and the log of Trump's vote share as additional controls.
(9) Add latent state confounders as components of W_{it}, estimated using fixed effects with bias correction.

In Figure 1, "red", "green", "blue", and "purple" indicate the regression models for case growth without national information variables, case growth with national information variables, death growth without national information variables, and death growth with national information variables, respectively. The left panel of "(i) baseline timing" assume that the times from exposure to case confirmation and death reporting are 14 and 21 days, respectively, while they are 9 and 24 days, respectively, in the right panel of "(ii) alternative timing."[2]

Panel (A) of Figure 1 illustrates that the estimated coefficients of mask mandates are negative and significant across different specifications, methods, and timing assumptions, confirming the importance of mask policy on reducing case and death growths.

In Panel (B) of Figure 1, many estimates of closures of K-12 schools suggest that the effect of school closures is large. The visual evidence on growth rates for states with and without school closures in Figure 2 also suggests that there may be a potentially large effect, though the history is very short. This evidence is consistent with the emerging evidence of prevalence of Covid-19 among children (Lee et al., 2020; Szablewski et al., 2020). Davies et al. (2020) find that although children's transmission and susceptibility rates are half that of ages 20-30, children's contact rates are much higher. This type of evidence, as well as, evidence that children carry viral loads similar to older people (Jones et al. (2020)), led Germany to make the early decision of closing schools.

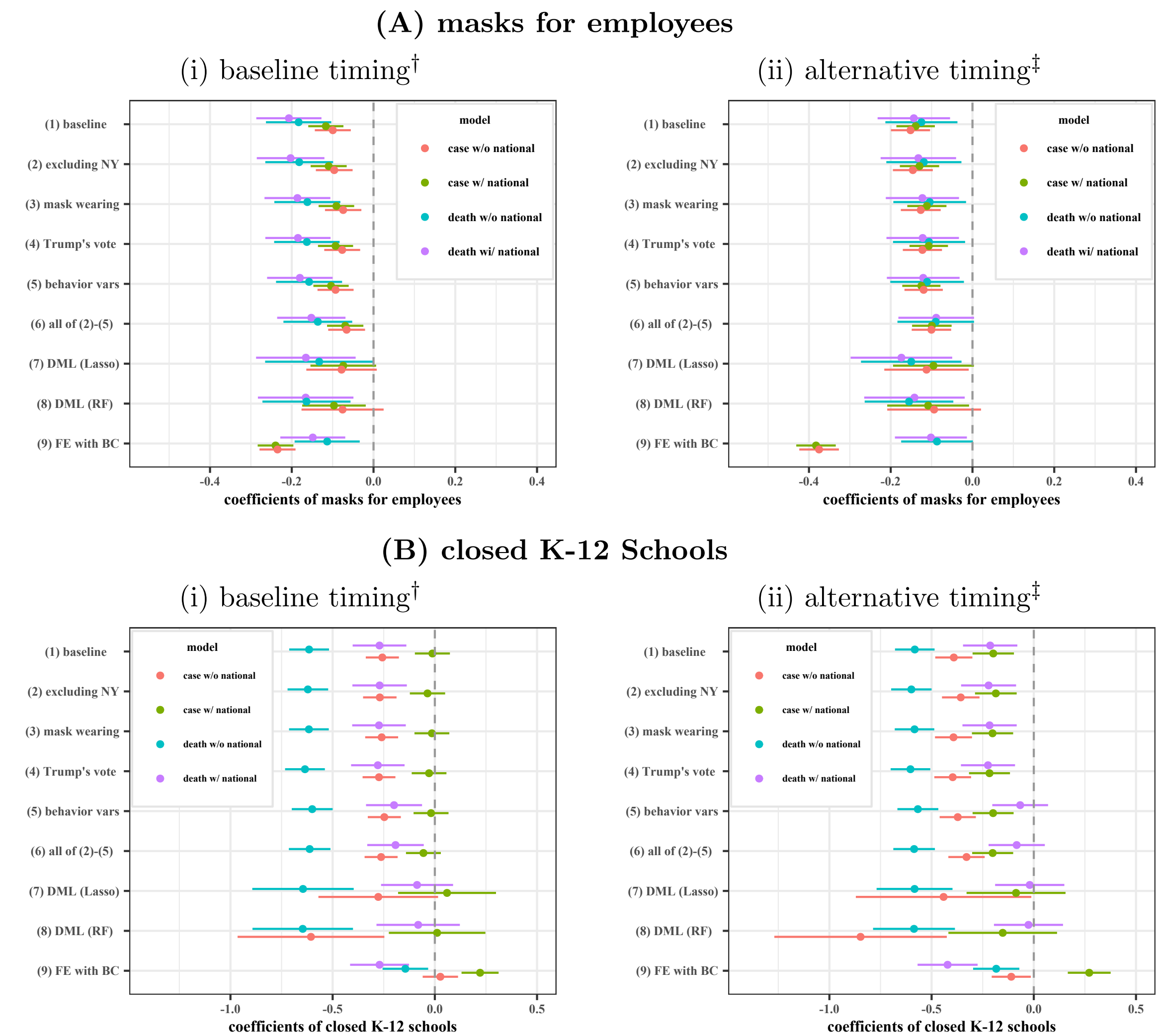
Our estimates of school closures substantially vary across specifications, however, and the estimated effects of school closures on case growth are not significant once national cases are controlled for. In the US state-level data, there is little variation across states in the timing of school closures. Consequently, its estimate is particularly sensitive to an inclusion of some aggregate variables such as national cases. Given this sensitivity, there still exists a lot of uncertainty as to the magnitude of the effect of school closures. Any analyses of re-opening plans need to be aware of this uncertainty. An important research question is how to resolve this uncertainty using additional data sources.

Panel (C) of Figure 1 indicates that the estimated coefficients of stay-at-home order are generally negative and often significant except for fixed effects estimator with bias correction. The sensitivity under fixed effects estimator may be due to high correlations between stay-at-home order and closures of movie theaters, restaurants, and non-essential

[2]This alternative timing assumption is motivated by the lower bound estimate of median times from exposure to case confirmation or death reporting in Table 2 of `https://www.cdc.gov/coronavirus/2019-ncov/hcp/planning-scenarios.html`, which are based on data received by CDC through June 29, 2020. We thank Jessica Metclaf for recommending us to do a sensitivity analysis on the timing assumption while suggesting this reference to us.

businesses (see Table **??**). As shown in Panel (D), the estimated coefficient of the average of stay-at-home order and closures of movie theaters, restaurants, and non-essential businesses are negative and often significant even under fixed effect specification; similar to school closure estimates, however, its estimate is sensitive to controlling for national cases and deaths because the timing of implementing these policies is similar across states.

Figure 1. Estimated Coefficients for Policy Variables: Sensitivity Analysis



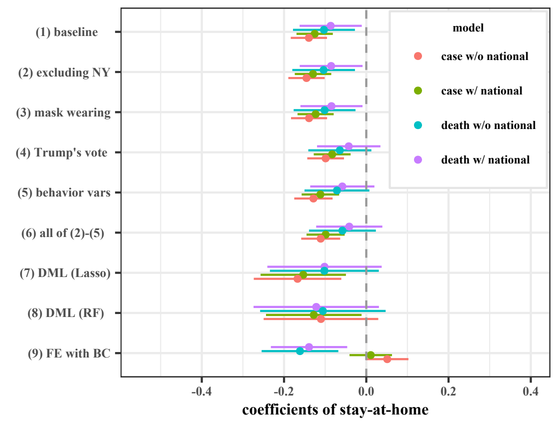
†The times from exposure to case confirmation and death reporting are assumed to be 14 and 21 days, respectively. ‡The times from exposure to case confirmation and death reporting are assumed to be 9 and 24 days, respectively.

1.1. **Fixed Effects Regressions (in Appendix).** Table 2 in the appendix reports the regression result when we include state fixed effects and month dummies. Column (1)

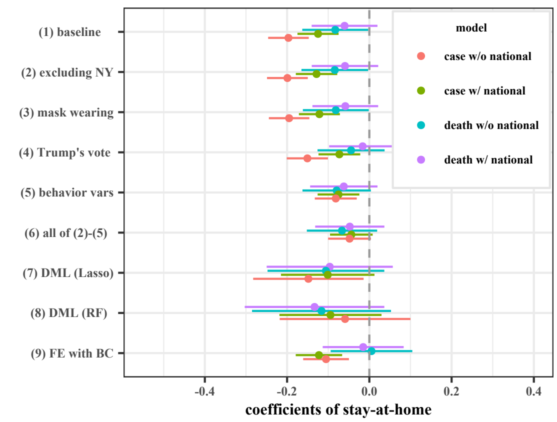
FIGURE 1. Estimated Coefficients for Policy Variables: Sensitivity Analysis (cont.)

(C) stay-at-home orders

(i) baseline timing†

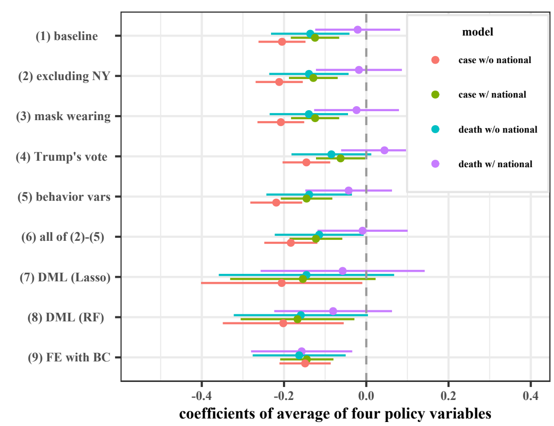


(ii) alternative timing‡

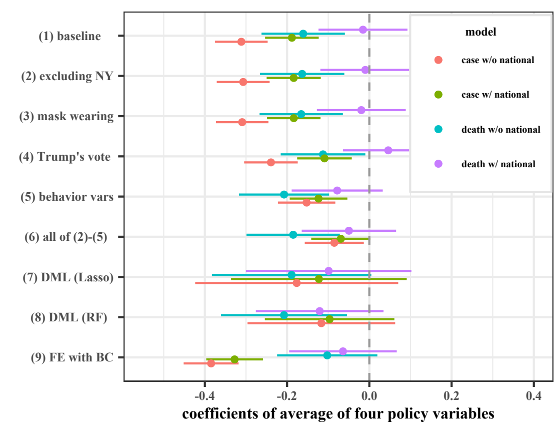


(D) Average of stay-at-home, closed movie theaters, closed restaurants, and closed businesses

(i) baseline timing†



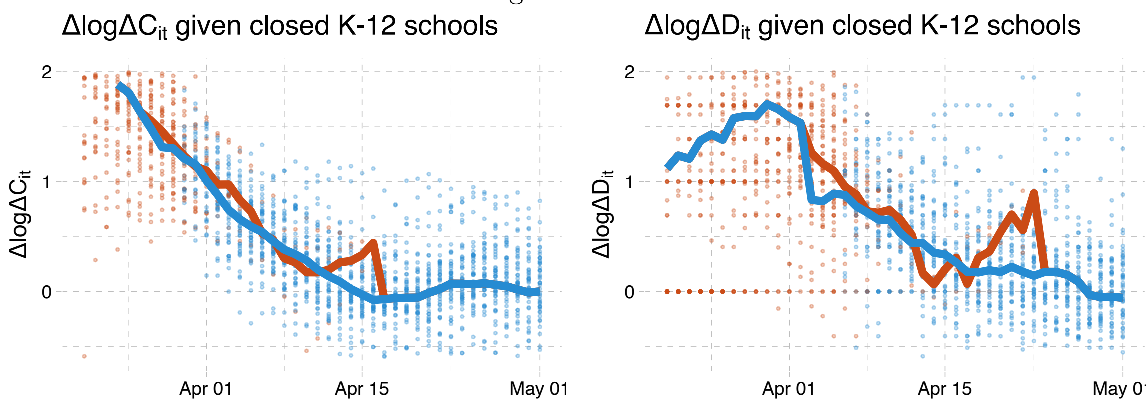
(ii) alternative timing‡



†The times from exposure to case confirmation and death reporting are assumed to be 14 and 21 days, respectively. ‡The times from exposure to case confirmation and death reporting are assumed to be 9 and 24 days, respectively.

reports our baseline estimation when we include state fixed effects while column (2) report the estimate when we apply the bias correction to the fixed effects estimator. Columns (3) and (4) are similar to columns (1) and (2) except that we replace four policy variables (stay-at-home, closure of movie theaters, closure of restaurants, and closure of non-essential businesses) with their average values. Again, the estimated coefficients of mask mandates are significantly negative across different specifications, confirming the importance of mask policy on reducing case and death growths. On the other hand, the estimated coefficients

FIGURE 2. Case and death growth conditional on school closures



In these figures, red points are the case or death growth rate in states without each policy 14 (or 21 for deaths) days earlier. Blue points are states with each policy 14 (or 21 for deaths) days earlier. The red line is the average across states without each policy. The blue line is the average across states with each policy.

of stay-at-home order as well as closures of movie theaters, restaurants, and non-essential businesses under fixed effects specification are substantially different from the estimates under random effects specification. This is likely due to muti-colinearity problem as implied by high correlations among these four policy variables as shown in Table **??**. When we replace these four policy variables with their average variable in columns (3) and (4), the estimated effect of the sum of four policy variables under fixed effects specification is similar to that under random effects specification in column (1) of Table 1.

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Table 1. Sensitivity Check for the Total Effect of Policies on Case and Death Growth ($PI \to Y$)

	Dependent variable: $\Delta \log \Delta C_{it}$					
	(1)	(2)	(3)	(4)	(5)	(6)
lag(masks for employees, 9)	-0.152^{**}	-0.146^{**}	-0.127^{***}	-0.122^{**}	-0.119^{**}	-0.100^{**}
	(0.061)	(0.063)	(0.047)	(0.051)	(0.055)	(0.050)
lag(closed K-12 schools, 9)	-0.391^{***}	-0.357^{***}	-0.393^{***}	-0.397^{***}	-0.372^{***}	-0.329^{***}
	(0.136)	(0.137)	(0.132)	(0.126)	(0.127)	(0.110)
lag(stay at home, 9)	-0.197^{***}	-0.199^{***}	-0.195^{***}	-0.151^{**}	-0.082	-0.048
	(0.069)	(0.071)	(0.067)	(0.063)	(0.061)	(0.064)
lag(closed movie theaters, 9)	-0.006	-0.007	-0.014	-0.015	-0.015	-0.019
	(0.071)	(0.072)	(0.075)	(0.071)	(0.068)	(0.068)
lag(closed restaurants, 9)	-0.068	-0.066	-0.062	-0.027	-0.068	-0.029
	(0.057)	(0.058)	(0.056)	(0.057)	(0.048)	(0.051)
lag(closed businesses, 9)	-0.031	-0.027	-0.031	-0.042	0.009	0.004
	(0.057)	(0.058)	(0.055)	(0.053)	(0.052)	(0.053)
lag(workplaces, 23)					0.137	0.042
					(0.563)	(0.555)
lag(retail, 23)					-0.065	0.114
					(0.465)	(0.484)
lag(grocery, 23)					-0.711^{***}	-0.738^{***}
					(0.269)	(0.246)
lag(transit, 23)					1.253^{***}	1.123^{***}
					(0.395)	(0.386)
lag($\Delta \log \Delta C_{it}$, 9)	0.008	0.011	0.006	0.009	-0.059^{*}	-0.050
	(0.027)	(0.028)	(0.027)	(0.027)	(0.031)	(0.031)
lag($\log \Delta C_{it}$, 9)	-0.200^{***}	-0.207^{***}	-0.200^{***}	-0.209^{***}	-0.179^{***}	-0.199^{***}
	(0.036)	(0.038)	(0.033)	(0.032)	(0.032)	(0.030)
$\Delta \log T_{it}$	0.154^{***}	0.138^{***}	0.156^{***}	0.158^{***}	0.135^{***}	0.121^{***}
	(0.042)	(0.040)	(0.042)	(0.042)	(0.039)	(0.037)
mask_percent			-0.699			-0.096
			(0.752)			(0.643)
log(Trump voting shares)				0.418^{**}		0.393^{***}
				(0.186)		(0.140)
state variables	Yes	Yes	Yes	Yes	Yes	Yes
Month × state variables	Yes	Yes	Yes	Yes	Yes	Yes
$\sum_j$ Policy$_j$	-0.846^{***}	-0.802^{***}	-0.822^{***}	-0.753^{***}	-0.648^{***}	-0.522^{***}
	(0.239)	(0.243)	(0.213)	(0.201)	(0.192)	(0.174)
Observations	3,869	3,790	3,869	3,869	3,869	3,790
R^2	0.778	0.776	0.780	0.782	0.791	0.792
Adjusted R^2	0.776	0.774	0.778	0.780	0.789	0.790

Note: *p<0.1; **p<0.05; ***p<0.01

	Dependent variable: $\Delta \log \Delta D_{it}$					
	(1)	(2)	(3)	(4)	(5)	(6)
lag(masks for employees, 24)	-0.125^{**}	-0.119^{**}	-0.105^{*}	-0.106^{*}	-0.111^{*}	-0.090
	(0.052)	(0.056)	(0.062)	(0.061)	(0.061)	(0.070)
lag(closed K-12 schools, 24)	-0.582^{***}	-0.599^{***}	-0.584^{***}	-0.603^{***}	-0.567^{***}	-0.586^{***}
	(0.109)	(0.111)	(0.106)	(0.101)	(0.115)	(0.106)
lag(stay at home, 24)	-0.083	-0.084	-0.082	-0.044	-0.079	-0.067
	(0.075)	(0.076)	(0.076)	(0.078)	(0.074)	(0.077)
lag(closed movie theaters, 24)	0.028	0.030	0.024	0.007	-0.003	-0.011
	(0.095)	(0.096)	(0.099)	(0.097)	(0.099)	(0.101)
lag(closed restaurants, 24)	-0.039	-0.036	-0.038	-0.005	-0.030	-0.005
	(0.054)	(0.055)	(0.058)	(0.061)	(0.050)	(0.054)
lag(closed businesses, 24)	-0.057	-0.062	-0.059	-0.058	-0.084	-0.090
	(0.066)	(0.067)	(0.067)	(0.063)	(0.066)	(0.063)
lag(workplaces, 38)					0.932	1.222^{*}
					(0.683)	(0.651)
lag(retail, 38)					-1.186^{**}	-1.213^{**}
					(0.543)	(0.534)
lag(grocery, 38)					0.125	-0.113
					(0.447)	(0.367)
lag(transit, 38)					0.197	-0.074
					(0.284)	(0.291)
lag($\Delta \log \Delta D_{it}$, 24)	0.028	0.029	0.027	0.027	0.027	0.033
	(0.027)	(0.028)	(0.027)	(0.027)	(0.031)	(0.032)
lag($\log \Delta D_{it}$, 24)	-0.078^{***}	-0.071^{***}	-0.076^{***}	-0.080^{***}	-0.080^{***}	-0.075^{***}
	(0.023)	(0.024)	(0.022)	(0.020)	(0.026)	(0.024)
mask_percent			-0.620			-0.468
			(0.382)			(0.338)
log(Trump voting shares)				0.324^{*}		0.271
				(0.188)		(0.211)
state variables	Yes	Yes	Yes	Yes	Yes	Yes
Month × state variables	Yes	Yes	Yes	Yes	Yes	Yes
$\sum_j$ Policy$_j$	-0.858^{***}	-0.870^{***}	-0.843^{***}	-0.810^{***}	-0.875^{***}	-0.848^{***}
	(0.129)	(0.132)	(0.125)	(0.132)	(0.136)	(0.142)
Observations	3,136	3,072	3,136	3,136	3,136	3,072
R^2	0.410	0.400	0.412	0.414	0.414	0.409
Adjusted R^2	0.404	0.394	0.405	0.408	0.407	0.401

Note: *p<0.1; **p<0.05; ***p<0.01

Dependent variable is the weekly growth rate of confirmed cases (in the left panel) or deaths (in the right panel) as defined in equation (**??**). Columns (2) and (6) exclude the observations of the state of New York. The covariates include lagged policy variables, which are constructed as 7 day moving averages between t to $t-7$ of corresponding daily measures. The row "$\sum_j$ Policies$_j$" reports the sum of six policy coefficients. Standard errors are clustered at the state level.

Table 2. Fixed Effects Specification for the Total Effect of Policies on Case and Death Growth ($PI \rightarrow Y$)

	Dependent variable:			
	$\Delta \log \Delta C_{it}$			
	(1)	(2)	(3)	(4)
lag(masks for employees, 9)	-0.213^{***}	-0.375^{***}	-0.221^{***}	-0.362^{***}
	(0.064)	(0.064)	(0.064)	(0.064)
lag(closed K-12 schools, 9)	-0.020	-0.110	-0.015	-0.084
	(0.119)	(0.119)	(0.117)	(0.117)
lag(stay at home, 9)	-0.134	-0.105		
	(0.087)	(0.087)		
lag(closed movie theaters, 9)	-0.082	-0.038		
	(0.087)	(0.087)		
lag(closed restaurants, 9)	-0.085	-0.089		
	(0.075)	(0.075)		
lag(closed businesses, 9)	-0.060	-0.124		
	(0.068)	(0.068)		
lag(ave of four policy vars, 9)			-0.366^{***}	-0.385^{***}
			(0.110)	(0.110)
lag($\Delta \log \Delta C_{it}$, 9)	-0.009	-0.013	-0.009	-0.012
	(0.025)	(0.025)	(0.025)	(0.025)
lag($\log \Delta C_{it}$, 9)	-0.284^{***}	-0.227^{***}	-0.284^{***}	-0.228^{***}
	(0.029)	(0.029)	(0.029)	(0.029)
$\Delta \log T_{it}$	0.150^{***}	0.169^{***}	0.151^{***}	0.168^{***}
	(0.036)	(0.036)	(0.036)	(0.036)
Observations	3,869	3,869	3,869	3,869
R^2	0.806	0.806	0.806	0.806
Adjusted R^2	0.803	0.803	0.803	0.803
Note:	*p<0.1; **p<0.05; ***p<0.01			

	Dependent variable:			
	$\Delta \log \Delta D_{it}$			
	(1)	(2)	(3)	(4)
lag(masks for employees, 24)	-0.133^{**}	-0.087^{**}	-0.134^{**}	-0.114^{**}
	(0.055)	(0.055)	(0.056)	(0.056)
lag(closed K-12 schools, 24)	-0.545^{***}	-0.184^{***}	-0.508^{***}	-0.323^{***}
	(0.139)	(0.139)	(0.121)	(0.121)
lag(stay at home, 24)	-0.025	0.005		
	(0.095)	(0.095)		
lag(closed movie theaters, 24)	0.021	-0.276		
	(0.119)	(0.119)		
lag(closed restaurants, 24)	-0.036	-0.084		
	(0.111)	(0.111)		
lag(closed businesses, 24)	-0.120	0.200		
	(0.089)	(0.089)		
lag(ave of four policy vars, 24)			-0.184^{*}	-0.102^{*}
			(0.094)	(0.094)
lag($\Delta \log \Delta D_{it}$, 24)	0.014	-0.009	0.016	-0.007
	(0.026)	(0.026)	(0.026)	(0.026)
lag($\log \Delta D_{it}$, 24)	-0.081^{***}	-0.137^{***}	-0.084^{***}	-0.141^{***}
	(0.021)	(0.021)	(0.019)	(0.019)
Observations	3,136	3,136	3,136	3,136
R^2	0.427	0.427	0.426	0.426
Adjusted R^2	0.416	0.416	0.415	0.415
Note:	*p<0.1; **p<0.05; ***p<0.01			

Dependent variable is the weekly growth rate of confirmed cases (in the left panel) or deaths (in the right panel) as defined in equation (**??**). The covariates include lagged policy variables, which are constructed as 7 day moving averages between t to $t-7$ of corresponding daily measures. The row "$\sum_j$ Policies$_j$" reports the sum of six policy coefficients. Standard errors are clustered at the state level.

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