

## **Appendix A**

**Capturing the timing of crisis evolution: A machine learning and directional wavelet coherence approach to isolating event-specific uncertainty using Google searches with an application to COVID-19**

**Table A1: Google search keywords**

<b>Panel A: 2020</b>		
<b>coronavirus</b>	<b>coronavirus update</b>	<b>coronavirus symptom</b>
coronavirus update	live coronavirus update	symptoms of coronavirus
coronavirus cases	india coronavirus	the coronavirus symptoms
coronavirus news	coronavirus update india	the symptoms of coronavirus
coronavirus uk	coronavirus india update	corona symptoms
coronavirus india	uk coronavirus	covid symptoms
coronavirus symptoms	coronavirus update uk	symptoms for coronavirus
thank you coronavirus helpers	uk coronavirus update	corona virus
coronavirus tips	coronavirus news	corona virus symptoms
coronavirus france	coronavirus news update	what are coronavirus symptoms
coronavirus map	corona update	what are symptoms of coronavirus
coronavirus us	world update coronavirus	what are the coronavirus symptoms
coronavirus usa	coronavirus update today	covid 19 symptoms
world coronavirus	coronavirus update cases	what is coronavirus symptoms
coronavirus live	coronavirus cases	what is coronavirus
coronavirus italia	update on coronavirus	what are symptoms of the coronavirus
coronavirus worldometer	update of coronavirus	what are the symptoms of the coronavirus
corona virus	latest update coronavirus	symptoms of corona
coronavirus deaths	coronavirus update in india	flu symptoms
coronavirus españa	coronavirus in india	symptoms of covid
coronavirus china	coronavirus update usa	coronavirus symptoms 2020
coronavirus in india	coronavirus usa	coronavirus first symptoms
coronavirus brasil	coronavirus usa update	coronavirus uk
coronavirus latest	covid update	coronavirus symptoms uk
sintomas coronavirus	coronavirus new update	fever symptoms
italy coronavirus	coronavirus vaccine update	fever
<b>Panel B: 2021</b>		
<b>COVID vaccine</b>	<b>COVID</b>	
covid vaccine near me	vaccine covid	
covid 19 vaccine	Vaccine	
covid 19	covid 19	
covid vaccine registration	test covid	
covid registration	covid cases	
vaccine registration	covid testing	
pfizer vaccine	covid symptoms	
pfizer covid vaccine	covid uk	
pfizer	covid news	
cvs vaccine covid	vaccination covid	
cvs	vacuna covid	
cvs vaccine	covid india	
covid vaccine side effects	covid update	
vaccine side effects	long covid	
walgreens covid vaccine	covid testing near me	
walgreens	ontario covid	
walgreens vaccine	vacina covid	
covid vaccine appointment	covid vaccine near me	
book covid vaccine	covid France	
vaccination	sintomas covid	
covid vaccines	covid cases today	
moderna vaccine	covid 19 vaccine	
moderna covid vaccine	covid us	
moderna	covid-19	
covid-19	vaccine covid	

**Notes:** Keywords in **bold** are first-level search terms as reflected by Google's Year in Search feature in 2020 (Panel A) and 2021 (Panel B). Second-level search keywords are the top 25 keywords associated with each first-level search term for each year. Data is obtained for each keyword on a daily frequency over the COVID-19 period, defined as 1 December 2019 to 31 March 2022. For selection purposes, the highest value in each series is scaled to 100 and all other values are scaled relative to this value. Series enter the search set in first differences.

**Table A2: Final iteration results of elastic net regularisation**

Term	$\Delta VIX_t$ : 7 iterations		
	$\lambda_{min}$	$\lambda_{1SE}$	$\lambda_{2SE}$
$\alpha_v$	0.0152	0.0153	0.0154
$\Delta coronavirus\_france_t$	0.2101	0.1484	0.1119
$\Delta coronavirus\_news_t$	0.1420	0.1234	0.1026
$\Delta coronavirus\_symptoms\_uk_t$	0.0545	0.0432	0.0312
$\Delta coronavirus\_uk_t$	0.1023	0.0752	0.0576
$\Delta coronavirus\_us_t$	0.0395	0.0357	0.0248
$\Delta coronavirus\_usa_t$	0.1012	0.0612	0.0357
$\Delta uk\_coronavirus_t$	0.0745	0.0619	0.0484
<i>d.f.</i>	7	7	7
L1	0.7393	0.5643	0.4276
$R^2$	0.3161	0.2776	0.2314

**Notes:** This table reports the results of the final iteration of the elastic net-based selection and identification procedure. The procedure is repeated until only Google search terms for which coefficients are non-zero for the  $\lambda_{min}$ ,  $\lambda_{1SE}$  and  $\lambda_{2SE}$  penalties remain. *d.f.* is the number of measures with non-zero coefficients and L1 norm is the sparsity inducing penalty. Five folds ( $k = 5$ ) are used for  $k$ -fold cross-validation given that our sample comprises 609 observations between 1 December 2019 and 31 March 2022. All series are in first differences.  $R^2$  is the coefficient of determination for COVID-19 measures with non-zero coefficients.

**Table A3: Correlations between  $\Delta VIX_t$  and individual search terms**

Term	Ordinary ( $\rho_O$ )	Spearman ( $\rho_S$ )
$\Delta coronavirus\_france_t$	0.5120***	0.1246***
$\Delta coronavirus\_news_t$	0.5007***	0.0724*
$\Delta coronavirus\_symptoms\_uk_t$	0.4528***	0.0748*
$\Delta coronavirus\_uk_t$	0.4893***	0.1332***
$\Delta coronavirus\_us_t$	0.4356***	0.1467***
$\Delta coronavirus\_usa_t$	0.4239***	0.0556
$\Delta uk\_coronavirus_t$	0.4824***	0.1306***

**Notes:** This table reports ordinary and Spearman correlations between  $\Delta VIX_t$  and individual Google search terms identified by the iterative selection procedure. \*\*\*, \*\* and \* indicate statistical significance at the respective 1%, 5% and 10% levels of significance.

**Table A4: Correlations between  $\Delta CV19_t$  and  $\Delta VIX_t$  over different time horizons**

Horizon	$\rho$
2	0.6376***
4	0.1990**
8	0.4343***
16	0.6072***
32	0.8458***
64	0.7192*
128	0.1718

**Notes:** This table reflects ordinary correlations over different horizons estimated for energy coefficients using MODWT. Both series ( $\Delta CV19_t$ ,  $\Delta VIX_t$ ) have been decomposed into frequencies, i.e. investment horizons which are disjoint and correlations for the respective horizons in the frequency domain were calculated. For example, a 2-day horizon of  $\Delta CV19_t$ , which is an aggregation of 1 to 2 days, is correlated with the 2-day horizon (aggregation of 1 to 2 days) of  $\Delta VIX_t$ . Given that for each time horizon we have multiple wavelet decompositions, the most probable outcomes are chosen on the basis of adjusted  $p$ -values. As a result, we obtain correlations calculated over investment horizons and not specific to certain observations. \*\*\*, \*\* and \* indicate statistical significance at the respective 1%, 5% and 10% levels of significance.

**Table A5: Regression results and stability tests**

Panel A: Regression of alternative keyword-based indices onto $\Delta VIX_t$			
Index	$\alpha$	$\beta_{\Delta UN_t}$	$\bar{R}^2$ ( $\bar{R}_w^2$ )
$\Delta CV19_t$	0.0150	0.5565***	0.3086 (0.4326)
$\Delta IDEMV_t$	0.0158	0.0016	0.0000 (0.0004)
$\Delta EMV_t$	0.0040	0.0112	0.0000 (0.0016)
$\Delta TEU_t$	0.1205	0.2328***	0.0526 (0.0093)
$\Delta TMU_t$	0.2067	0.3491**	0.1204 (0.1116)
Panel B: Regression of alternative keyword-based indices onto $\Delta CV19_t$			
Index	$\alpha$	$\beta_{\Delta CV19_t}$	$\bar{R}^2$ ( $\bar{R}_w^2$ )
$\Delta IDEMV_t$	0.0980	0.0173	0.0000 (0.0001)
$\Delta EMV_t$	0.0145	0.0083	0.0000 (0.0001)
$\Delta TEU_t$	0.0091	0.1579***	0.0233 (0.0243)
$\Delta TMU_t$	0.0148	0.2079***	0.0416 (0.1822)

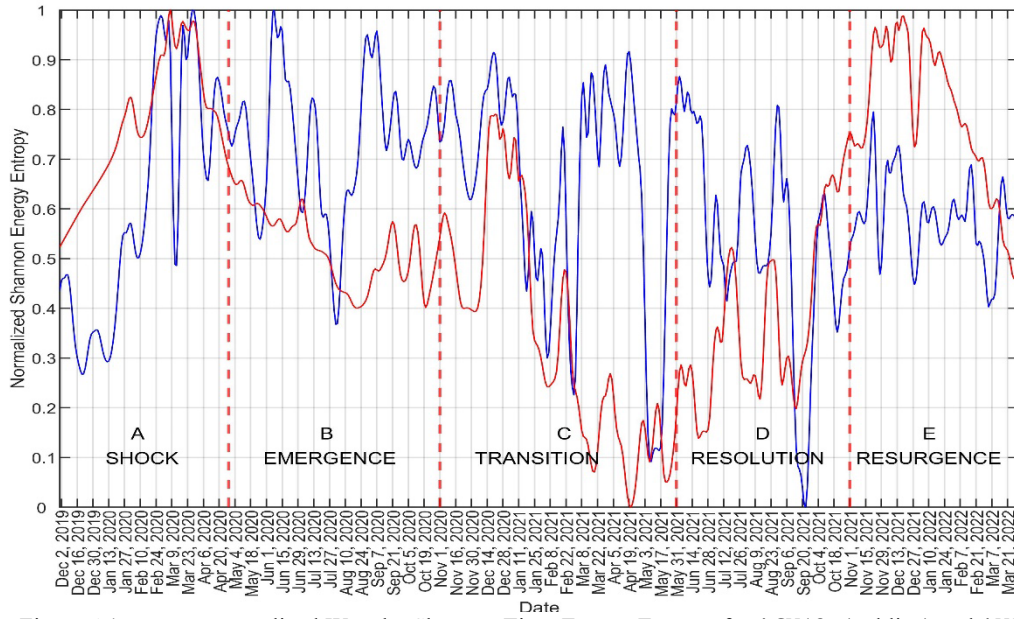
**Notes:** Panel A reports the results of least squares regressions of  $\Delta VIX_t$  and  $\Delta CV19_t$  onto the newspaper-based Infectious Disease Equity Market Volatility Tracker ( $\Delta IDEMV_t$ ), the newspaper-based US Equity Market Uncertainty Index ( $\Delta EMV_t$ ), and the (all English) Twitter-based Economic ( $\Delta TEU_t$ ) and Market Uncertainty ( $\Delta TMU_t$ ) indices over the period 1 January 2019 to 31 March 2022.  $\beta_{\Delta UN_t}$  is the *standardised coefficient* for each index which can be interpreted similarly to correlation and is indicative of the strength of the relationship between  $\Delta VIX_t$  and each index. Panel B reports the results of least squares regressions of each index onto  $\Delta CV19_t$ .  $\beta_{\Delta CV19_t}$  is the *standardised coefficient* for  $\Delta CV19_t$ .  $\bar{R}^2$  is the adjusted coefficient of determination measuring explanatory power.  $\bar{R}_w^2$  in brackets ( ) is the adjusted coefficient of determination proposed by Renaud and Victoria-Feser (2010) that is robust to outliers and departures from normality in the dependant variables obtained using robust least squares (MM-estimation). Least squares regressions are estimated with Newey-West heteroscedasticity and serial correlation consistent (HAC) standard errors. \*\*\*, \*\* and \* indicate statistical significance at the respective 1%, 5% and 10% levels of significance.

**Table A6: Regressions of  $\Delta CV19_t$  and  $\Delta VIX_t$  onto overall measures of responses**

Policy response/measure	Panel A: $\Delta CV19_t$			Panel B: $\Delta VIX_t$		
	0 lags	3 lags	Combined	0 lags	3 lags	Combined
Government response	0.0672	0.0467	0.1406	0.0324	0.0150	0.0552
Stringency of response	0.0703	0.0345	0.1234	0.0361	0.0282	0.0668
Health and containment	0.0689	0.0324	0.1226	0.0305	0.0204	0.0566
Economic support	0.0006	0.0563	0.0565	0.0018	0.0160	0.0174

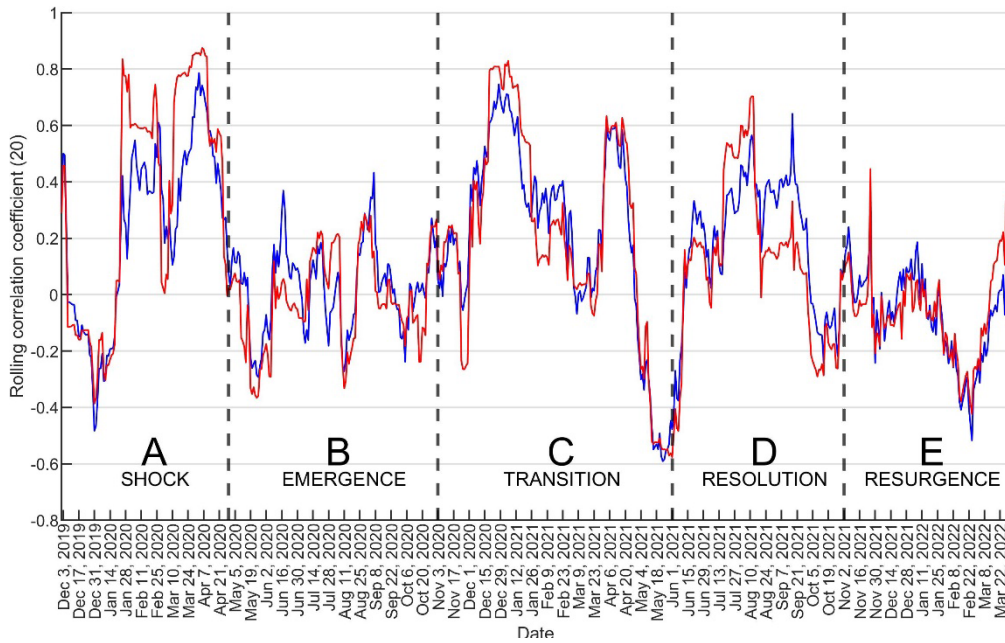
**Notes:** This table reports the adjusted coefficient of determination,  $\bar{R}^2$ , for regressions of  $\Delta CV19_t$  and  $\Delta VIX_t$  onto categorised measures of government responses over the period 1 January 2020 to 31 March 2022. Regressions are estimated with each measure entering the specification contemporaneously (0 lags), with three lags (3 lags) and combining both contemporaneous terms and three lagged terms (Combined).

**Figure A1:  $\Delta CV19_t$  and  $\Delta VIX_t$  normalised entropies**



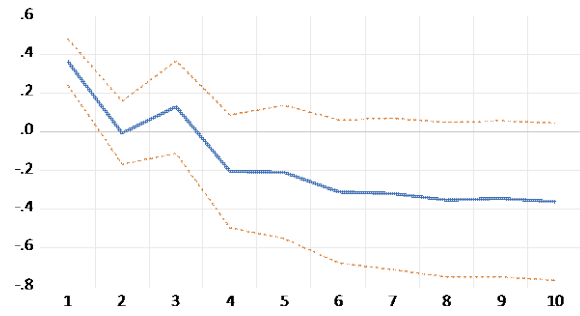
**Notes:** Figure A1 presents normalized Wavelet Shannon Time-Energy Entropy for  $\Delta CV19_t$  (red line) and  $\Delta VIX_t$  (blue line). Dates are stated on the horizontal axis whereas the vertical axis reflects normalised energy entropy levels. Vertical dashed lines delineate phases. If  $\Delta CV19_t$  and  $\Delta VIX_t$  entropies increase (decrease) simultaneously, then COVID-19 related uncertainty contributes positively to overall uncertainty. If  $\Delta CV19_t$  entropy increases (decreases) and  $\Delta VIX_t$  entropy decreases (increases) simultaneously, COVID-19 related uncertainty contributes less to  $\Delta VIX_t$ .

**Figure A2: Rolling correlations for  $\Delta CV19_t$  and  $\Delta VIX_t$**

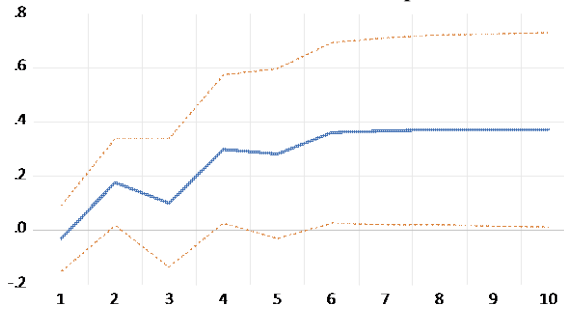


**Notes:** Figure A2 reports 20-day rolling ordinary ( $\rho_o$ , red) and Spearman ( $\rho_s$ , blue) correlations for  $\Delta CV19_t$  and  $\Delta VIX_t$ . Rolling correlations are estimated starting 1 October 2019 and reported for the sample period, 1 December 2019 to 31 March 2022.

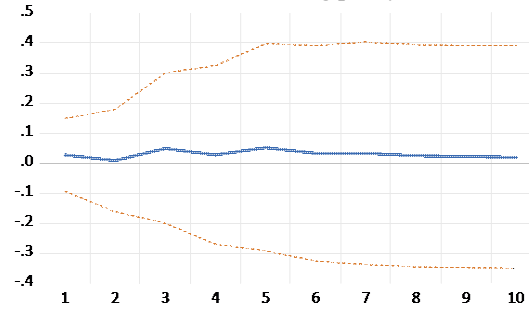
**Figure A3: Cumulative impulse response functions for  $\Delta CV19_t$**



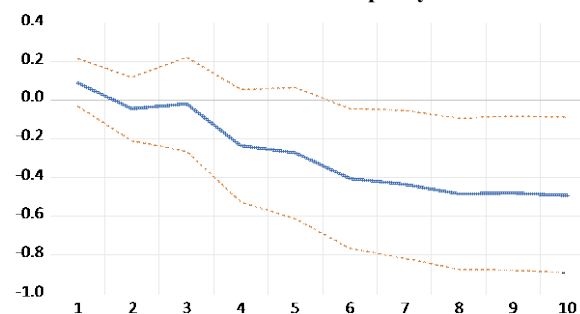
**Panel A: Government response**



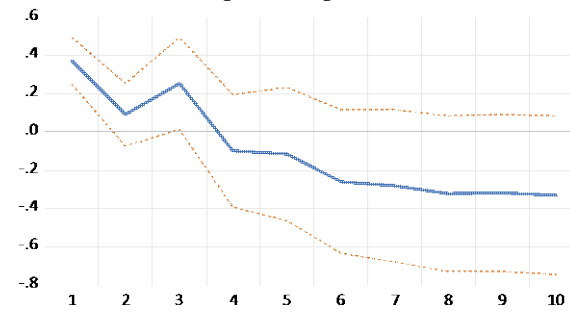
**Panel D: Testing policy**



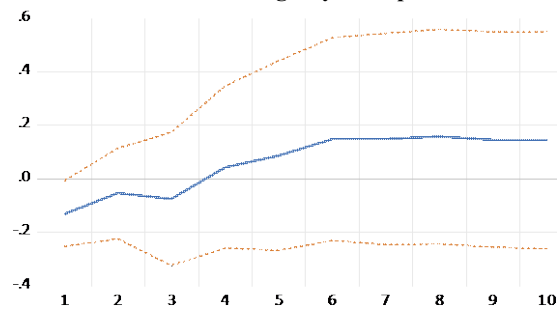
**Panel G: Vaccination policy**



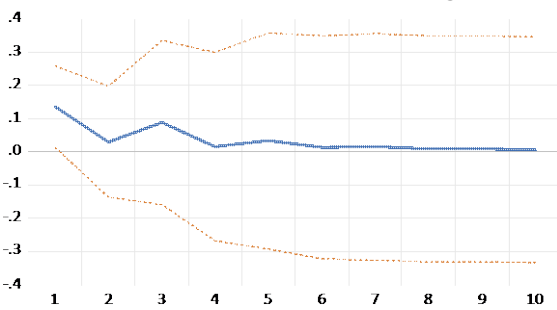
**Panel J: Workplace closing**



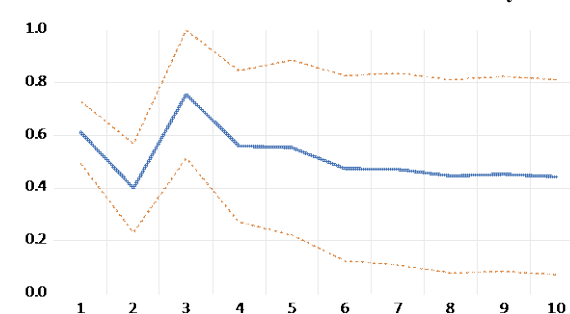
**Panel B: Stringency of response**



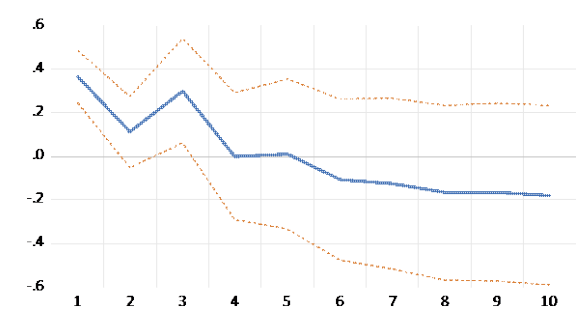
**Panel E: Contact tracing**



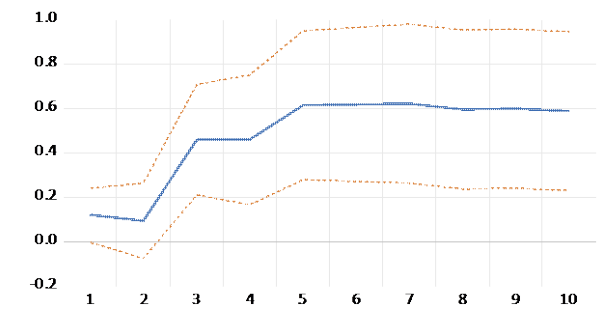
**Panel H: Protection of the elderly**



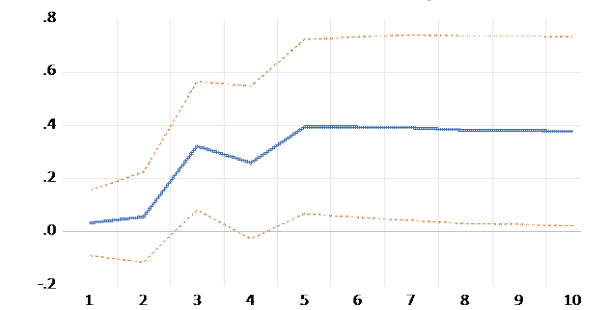
**Panel K: Public event cancellations**



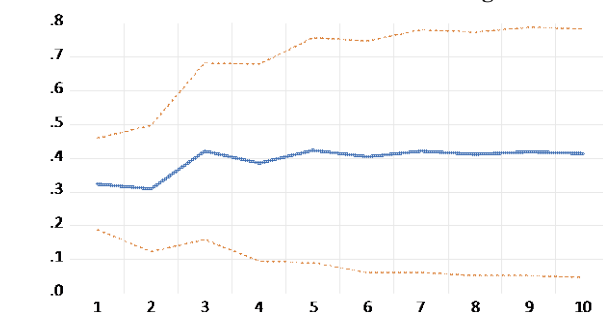
**Panel C: Health & containment**



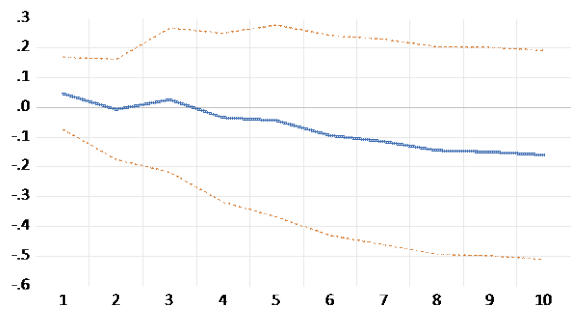
**Panel F: Facial coverage**



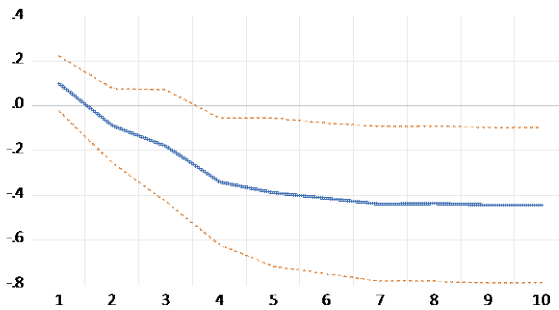
**Panel I: Schools closing**



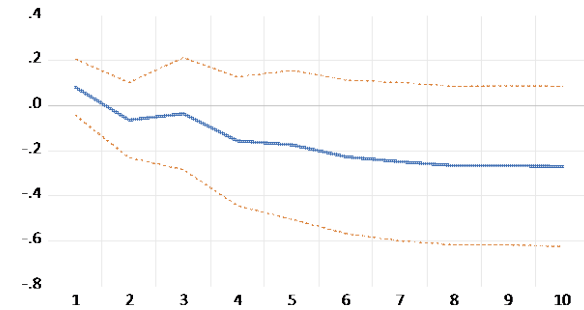
**Panel L: Restrictions on gatherings**



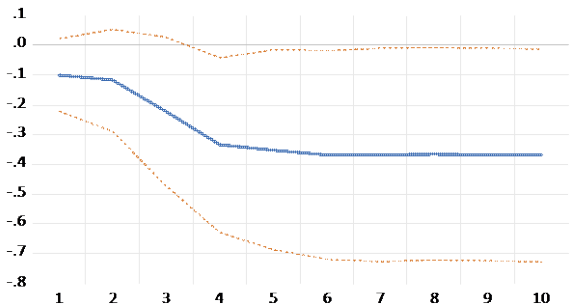
**Panel M: Public transport closures**



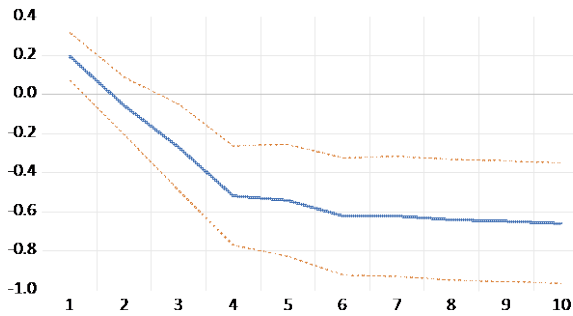
**Panel N: Stay at home requirements**



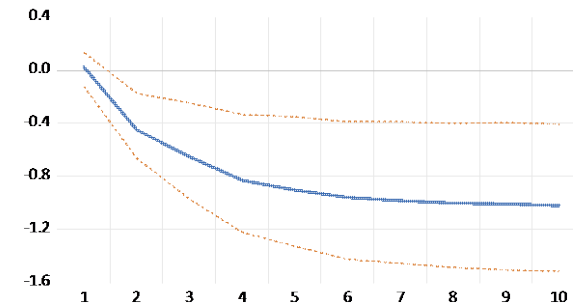
**Panel O: Movement restrictions**



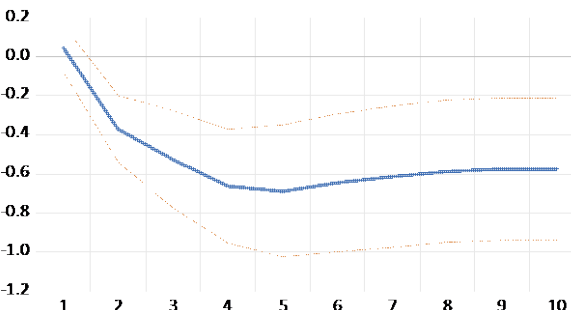
**Panel P: International travel restrictions**



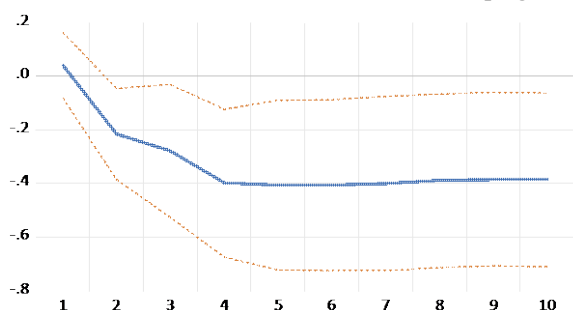
**Panel Q: Public information campaigns**



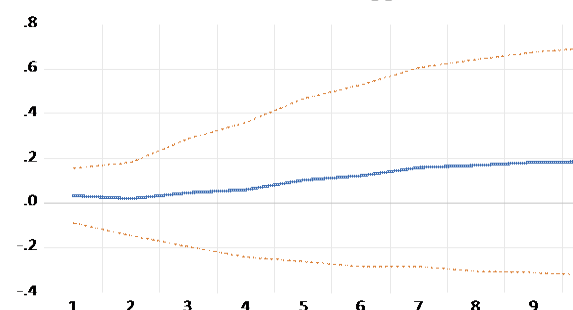
**Panel R: Economic support**



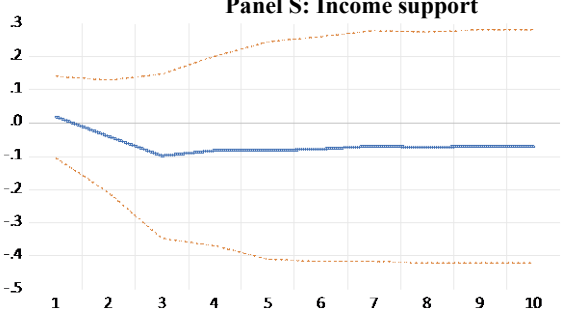
**Panel S: Income support**



**Panel T: Debt relief**



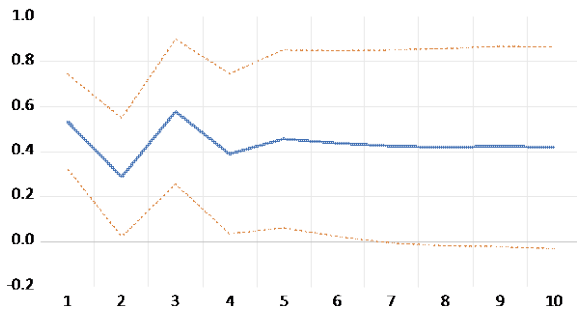
**Panel U: Cases**



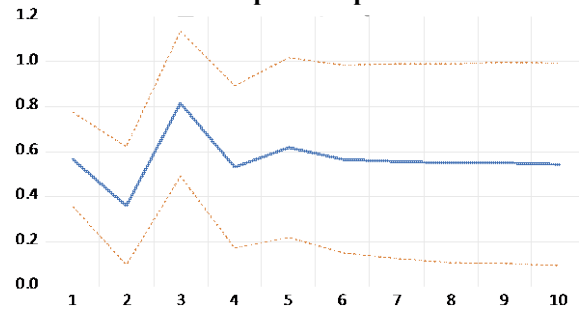
**Panel V: Deaths**

*Notes:* This figure reports the cumulative response of  $\Delta CV19_t$  to value-weighted indices reflecting interventions and measures of the spread of COVID-19 as reported in the Oxford COVID-19 Government Response Tracker (OxCGRT) between 1 January 2020 and 31 March 2022. Generalised cumulative impulse responses are reported with 10% confidence bands.

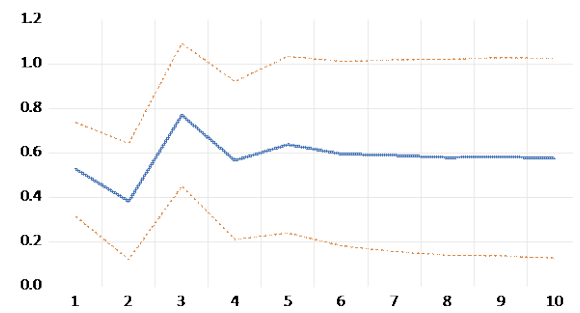
Figure A4: Cumulative impulse response functions for  $\Delta VIX_t$



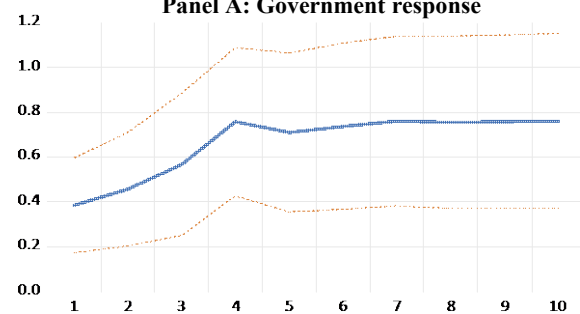
Panel A: Government response



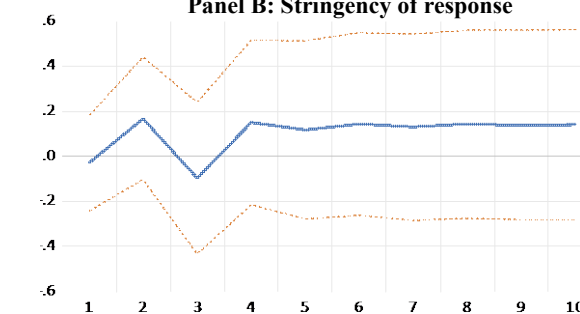
Panel B: Stringency of response



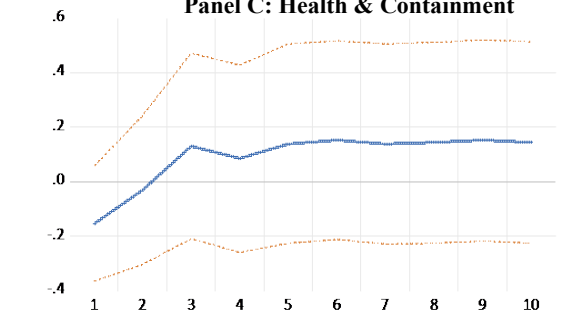
Panel C: Health & Containment



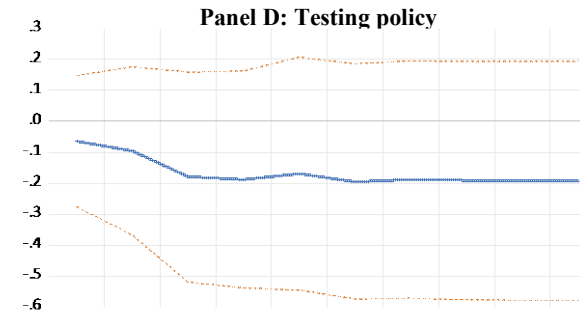
Panel D: Testing policy



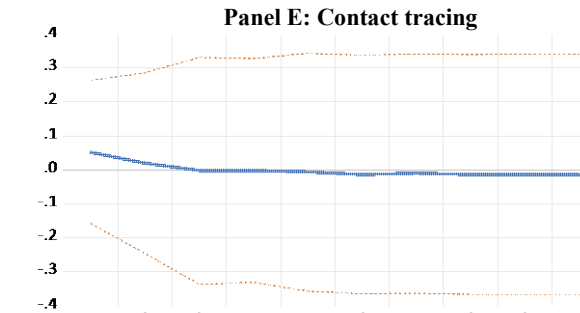
Panel E: Contact tracing



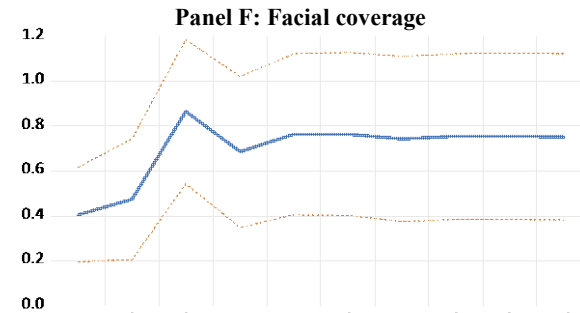
Panel F: Facial coverage



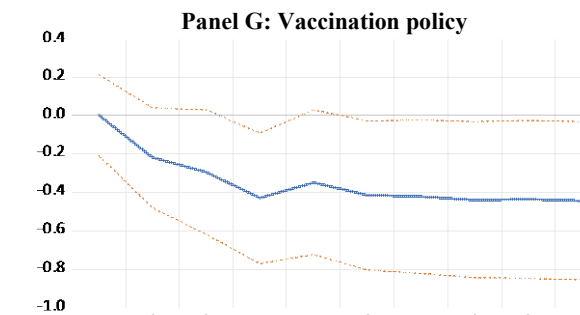
Panel G: Vaccination policy



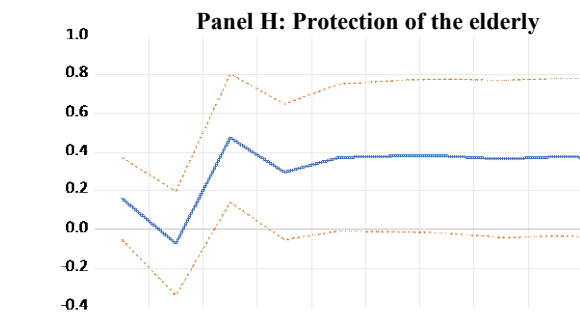
Panel H: Protection of the elderly



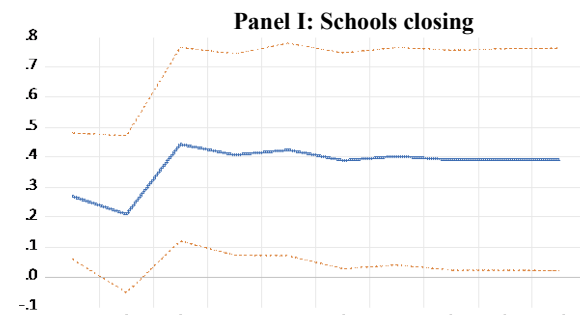
Panel I: Schools closing



Panel J: Workplace closing

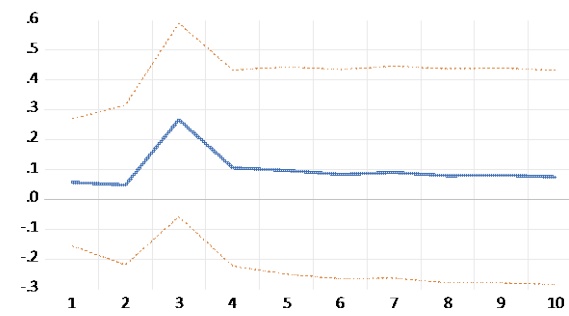


Panel K: Public event calculation

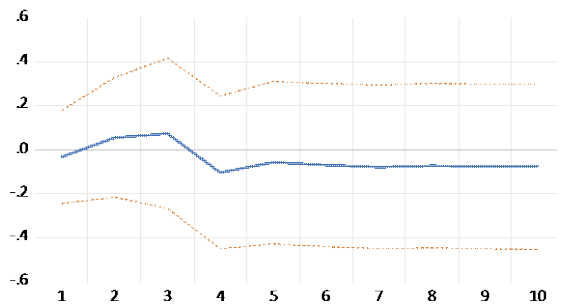


Panel L: Restrictions on gatherings

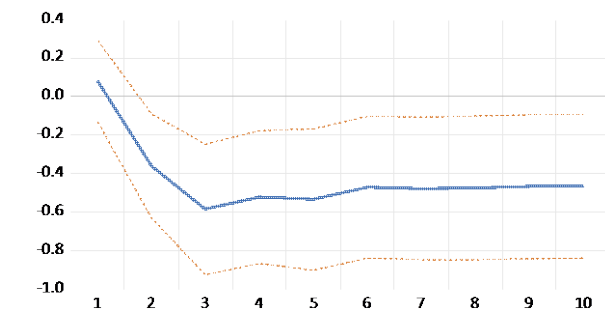




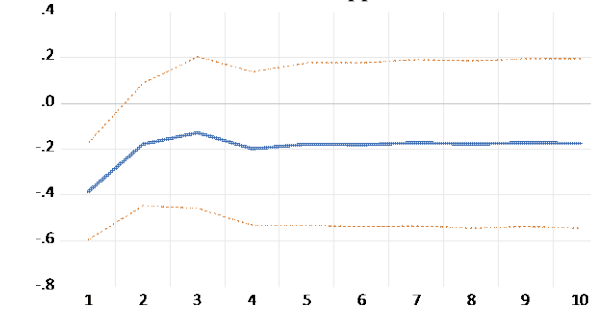
Panel M: Public transport closures



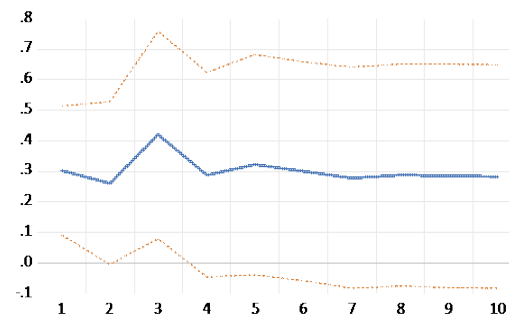
Panel P: International travel restrictions



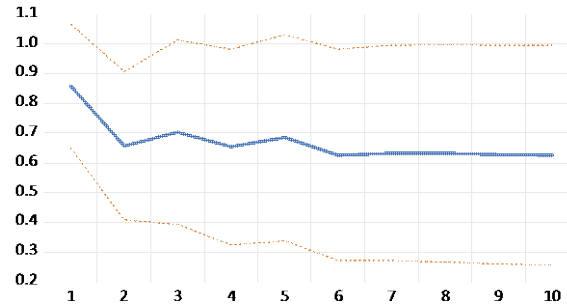
Panel S: Income support



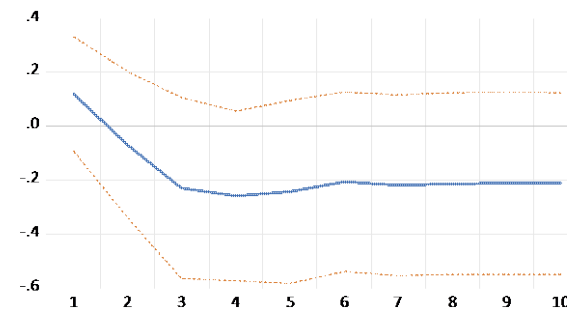
Panel V: Deaths



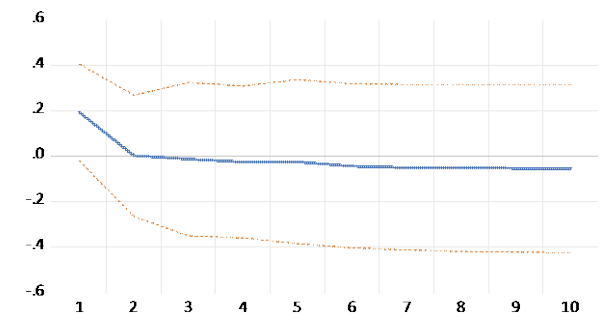
Panel N: Stay at home requirements



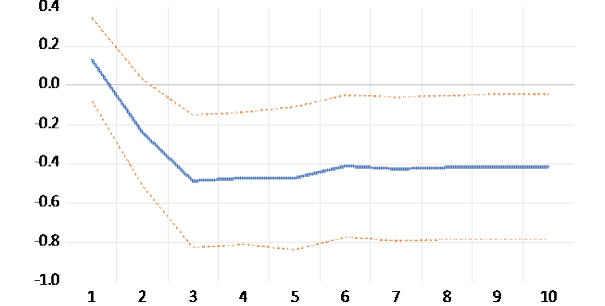
Panel Q: Public information campaigns



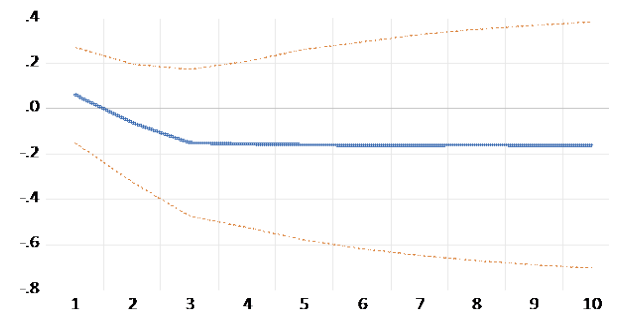
Panel T: Debt relief



Panel O: Movement restrictions



Panel R: Economic support



Panel U: Cases

*Notes:* This figure reports the cumulative response of  $\Delta VIX_t$  to value-weighted indices reflecting interventions and measures of the spread of COVID-19 as reported in the Oxford COVID-19 Government Response Tracker (OxCGRT) between 1 January 2020 and 31 March 2022. Generalised cumulative impulse responses are reported with 10% confidence bands.