Appendix B

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 B1: Search terms used to construct $\Delta ENPU_t$

brent oil
coal price
coal price today
coal prices 2021
coal prices india
coal prices today
gas prices today
heating oil
international coal prices
natural gas futures
natural gas stock
oil natural gas prices
oil prices news
oil stock price
us coal prices
us oil prices
what is natural gas

Notes: This table presents keywords that comprise the energy price uncertainty index, $\Delta ENPU_t$. The keyword search set related to VIX spans the period 1 June 2021 to 31 January 2023. A total of 95 keywords were considered in the search terms set. Keywords were permitted to enter the search set contemporaneously and with up to one lead and three lags to account for intertemporal structures. The full list of keywords and model results are available upon request from the authors.

Table B2: Regression results and stability tests

Panel A: Regression results		
α	$\beta_{\Delta EPNU_t}$	$\bar{R}^2$
-0.0026	1.1585***	0.2699
Panel B: Quandt-Andrews breakpoint test		
Maximum LR F-statistic	Exponential LR F-statistic	Average LR F-statistic
2.9599	0.9644	0.7354
Panel C: Bai-Perron test of m+1 versus m sequentially determined breaks		
Break test	F-statistic	Scaled F-statistic
0 vs. 1	3.4478	6.8956

Notes: In Panel A, least squares with Newey-West heteroscedasticity, is used. Panel B reports the results of the Quandt–Andrews break point test for one or more unknown structural break points. Panel C reports the results of the Bai-Perron test with heterogeneous error distributions across breaks with 5% trimming and a 10% level of significance. *** indicates statistical significance at the 1% level of significance.

Table B3: Results for specifications without breaks

Index	$\Delta ENPU_t$	ΔVIX_t
Panel A: Conditional mean		
α_W	0.0004***	0.0005***
$\beta_{W,\Delta UN}$	-0.0020***	-0.0035***
$\beta_{I,1}$	0.0051***	0.0046***
$\beta_{I,2}$	0.0062***	0.0057***
$\beta_{I,3}$	-	-
$\beta_{I,4}$	0.0037***	0.0037***
r_{t-13}		-0.0194
Panel B: Conditional variance		
Model	GARCH(1,1)	GARCH(1,1)
ω_W	8E-07*	5.89E-07*
α_1	0.1231***	0.1197***
β_1	0.8281***	0.8443***
$\varphi_{W,\Delta UN}$	0.0734**	0.0698***
Panel C: Diagnostics		
$\bar{R}^2$	0.7923 (0.1604)	0.7858 (0.5270)
$Q(1)$	0.0221	0.0747
$Q(10)$	7.5045	8.6005
ARCH(1)	0.8961	1.4270
ARCH(10)	1.2080	1.2880
Log-likelihood	4413.746	4450.495

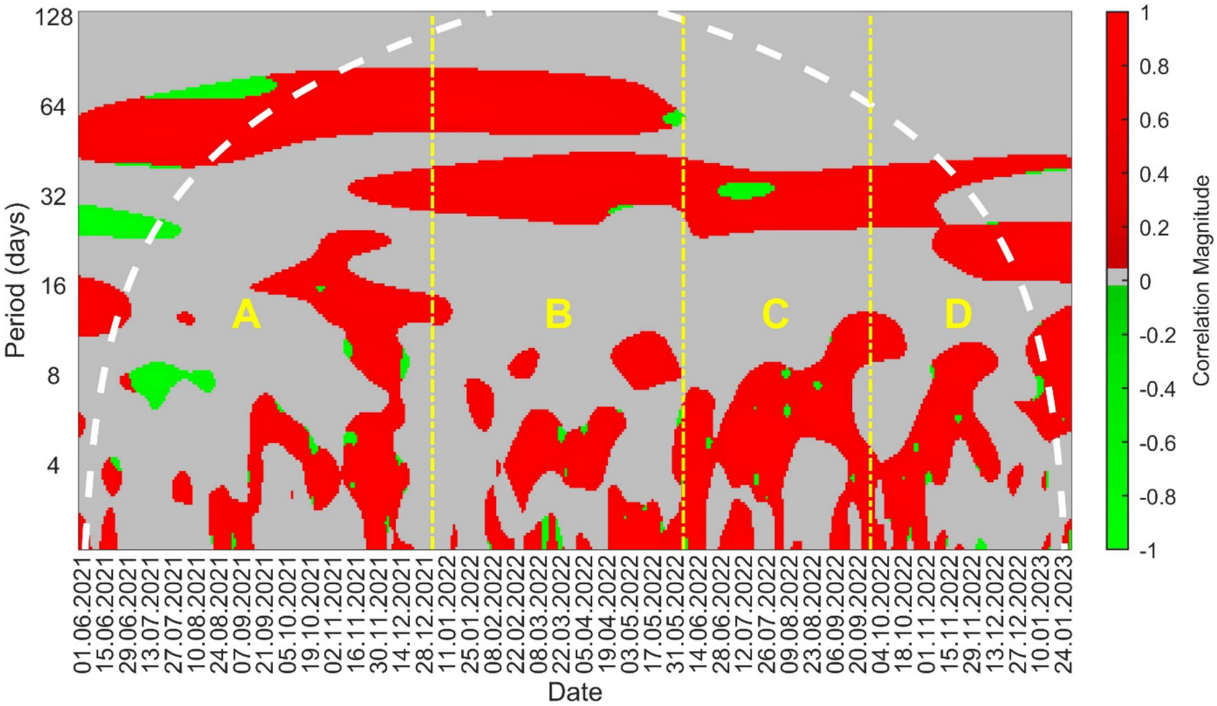
Notes: This table reports the results of the impact of both uncertainty measures, $\Delta\widehat{EPNU}_t$ and ΔVIX_t, on the returns and variance of the MSCI ACWI. Coefficients on each uncertainty measure in the conditional variance equation are scaled by 100 000. Panel A reports estimation results for the conditional mean, which also includes proxy factors derived from industry returns using factor analysis and adjusted for the impact of each uncertainty measure. Panel B reports the results for the conditional variance. Panel C reports model diagnostics, with $Q(1)$ and $Q(10)$ representing Ljung-Box tests statistics for joint serial correlation at the 1st and 10th orders respectively. ARCH(1) and ARCH(10) are test statistics for the ARCH LM test for heteroscedasticity. The equations above are first estimated using maximum likelihood estimation. If residuals are non-normal, they are re-estimated using quasi-maximum likelihood estimation with Huber-White standard errors and covariance. The $\bar{R}^2$ value in brackets ( ) reports the 'true' explanatory power for $\Delta\widehat{EPNU}_t$ and ΔVIX_t obtained by regressing returns onto these uncertainty proxies over the crisis period using least squares while excluding proxy factors and lags adjusting for serial correlation. Each model is estimated over the period 1 January 2019 to 31 January 2023. This extended estimation sample is used to account for dependence structures in the residuals, with the global energy crisis period defined as 1 June 2021 to 31 January 2023. ***, ** and * indicate statistical significance at 1%, 5% and 10% levels of significance, respectively.

Table B4: Causality tests

Hypothesis	1 lag	3 lags	5 lags
Panel A: Energy prices			
ΔTTF_t does not cause $\Delta\widehat{EPNU}_t$	0.8338	6.3369***	5.2975***
$\Delta NG1_t$ does not cause $\Delta\widehat{EPNU}_t$	2.3884	0.7752	0.9261
$\Delta FN1_t$ does not cause $\Delta\widehat{EPNU}_t$	0.1209	6.7479***	4.8427***
ΔWTI_t does not cause $\Delta\widehat{EPNU}_t$	5.5063***	5.2188***	4.8292***
$\Delta BRENT_t$ does not cause $\Delta\widehat{EPNU}_t$	7.4466***	6.0625***	4.4513***
$\Delta OAQ1_t$ does not cause $\Delta\widehat{EPNU}_t$	6.8370***	5.6391***	4.9570***
$\Delta HDE1_t$ does not cause $\Delta\widehat{EPNU}_t$	6.9517**	6.2599***	10.3454***
$\Delta XW1_t$ does not cause $\Delta\widehat{EPNU}_t$	7.1440***	7.3067***	10.2170***
$\Delta XO1_t$ does not cause $\Delta\widehat{EPNU}_t$	13.7529***	9.6644***	11.6727***
Panel B: Energy price volatility			
ΔTTF_t^2 does not cause $\Delta\widehat{EPNU}_t$	13.6062***	8.4448***	8.8971***
$\Delta NG1_t^2$ does not cause $\Delta\widehat{EPNU}_t$	1.9903	0.5076	0.7113
$\Delta FN1_t^2$ does not cause $\Delta\widehat{EPNU}_t$	0.4824	0.5957	0.9403
ΔWTI_t^2 does not cause $\Delta\widehat{EPNU}_t$	0.9148	2.2718*	2.2159*
$\Delta BRENT_t^2$ does not cause $\Delta\widehat{EPNU}_t$	0.4534	3.6000**	3.6068***
$\Delta OAQ1_t^2$ does not cause $\Delta\widehat{EPNU}_t$	0.9234	1.7713	2.3356**
$\Delta HDE1_t^2$ does not cause $\Delta\widehat{EPNU}_t$	14.8635***	13.9740***	10.0526***
$\Delta XW1_t^2$ does not cause $\Delta\widehat{EPNU}_t$	7.1372***	19.7370***	13.9468***
$\Delta XO1_t^2$ does not cause $\Delta\widehat{EPNU}_t$	11.2718***	14.9757***	12.1035***

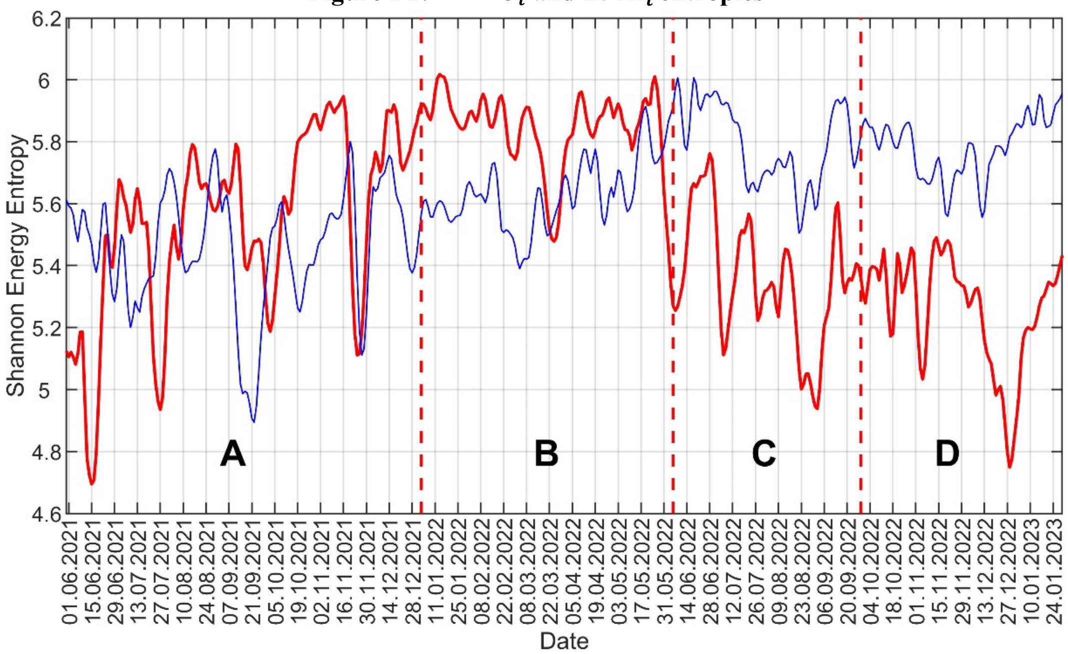
Notes: The Granger causality test is conducted at one, three and five lags with causality assumed to run from energy prices and energy price volatility to energy price uncertainty, $\Delta\widehat{EPNU}_t$. Panels A and B report the results of the Granger causality test for energy prices and energy price volatility respectively. As the energy crisis has a global character and energy markets are fragmented, we consider a number of benchmarks. For natural gas, we use Dutch TTF (Europe) (TTF_t), Henry Hub (US) ($NG1_t$) and the National Balancing Point (NBP) futures prices ($FN1_t$) (Zhang et al., 2023). For coal, Newcastle (Australia) ($XW1_t$), Richard's Bay (South Africa) ($XO1_t$) and API2 Rotterdam (Netherlands) futures prices ($HDE1_t$) are used. West Texas Intermediate (WTI_t), Brent crude ($\Delta BRENT_t$) and Dubai Mercantile Exchange (DME) Oman Crude Oil futures prices ($OAQ1_t$) are used as oil price benchmarks. ***, ** and * indicate statistical significance at the respective 1%, 5% and 10% levels of significance.

Figure B1: Spectrogram for $\Delta ENPU_t$ and ΔVIX_t



Notes: Figure B1 presents a spectrogram for $\Delta ENPU_t$ and ΔVIX_t in three dimensions: time on the horizontal axis, frequency domain on the vertical axis expressed in the number of days and wavelet coherence values (contour map). Regions in red (green) reflect a positive (negative) association. Coloured regions report associations for $\Delta \widehat{EPNU}_t$ and ΔVIX_t at the 10% significance level. The white dashed line indicates the 5% significance level for edge effects occurring in associated data. A greater number of days indicates a longer investment horizon and more persistent associations. However, associations occurring over shorter horizons are more impactful. Periods of between 1 and 4 days are defined as the short run, periods of 5 to 32 days are defined as the medium run and periods greater than 33 days are designated as the long run. The energy crisis is defined as starting on 1 June 2021.

Figure B2: $\Delta \widehat{EPNU}_t$ and ΔVIX_t entropies



Notes: Figure B2 presents Wavelet Shannon Time-Energy Entropy for $\Delta \widehat{EPNU}_t$ (red line) and ΔVIX_t (blue line). Dates are stated on the horizontal axis whereas the vertical axis reflects energy entropy levels. Vertical dashed lines delineate phases. If $\Delta \widehat{EPNU}_t$ and ΔVIX_t entropies increase (decrease) simultaneously, then energy price uncertainty contributes positively to overall uncertainty. If $\Delta ENPU_t$ entropy increases (decreases) and ΔVIX_t entropy decreases (increases) simultaneously, energy price uncertainty contributes less to ΔVIX_t .