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Geopolitical shocks and commodity market dynamics: New evidence from the Russia-Ukraine conflict

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ABSTRACT

We investigate the event-based geopolitical shocks from the Russian invasion of Ukraine on agricultural and energy commodities using daily event-based structural vector autoregression (SVAR). We find that the geopolitical shock affects the markets of wheat (2%), corn (1%), and European natural gas (7.5%). However, substantial heterogeneity is observed among the agricultural and energy markets. Geopolitical risk stemming from the Russia-Ukraine conflict affects the European natural gas market more strongly than the US and Asian markets. The regional segment of natural gas markets could explain this. Finally, our analysis explores how geopolitical news affects the dynamics of stock, currency, and bond markets.

1. Introduction

Global supply chains have recently faced significant disruptions. In early 2020, the world grappled with the repercussions of the COVID-19 pandemic which reshaped global trade and commodity flows. However, before the world was able to stabilize fully, another major geopolitical event shook the world – the Russian invasion of Ukraine in February 2022. The consequences of the invasion were not contained regionally but rapidly created a significant disruption of the global economy.

The geopolitical ramifications of the invasion were immediate and far-reaching. Many nations responded by imposing economic sanctions on Russia to exert economic pressure and to signal their opposition to the invasion. A direct consequence of these sanctions was observed in the energy markets. Europe, closely tied to Russian natural gas, witnessed a sharp increase in energy prices, adding another layer of complexity to the already stressed global economic situation post-COVID. Yet, the conflict's impact extended beyond the energy sector, affecting other financial and commodity markets.

Ukraine has consistently been a pivotal part of the global agricultural supply chain. In 2021, Ukraine was responsible for 46% of sunflower oil exports, 12% of corn exports, and 9% of wheat exports (World Economic Forum, 2022). The conflict has significantly hampered Ukraine's export capacity, as evidenced by the rapid price increases and high volatility in these key commodities, shown in Fig. 1.

Recent academic literature has started to quantify the financial and economic consequences of the Russia-Ukraine war (RUW). Studies have estimated its impact on green financial assets (Q. Zhang et al., 2023a), equity markets (Lo et al., 2022; Qureshi et al.,

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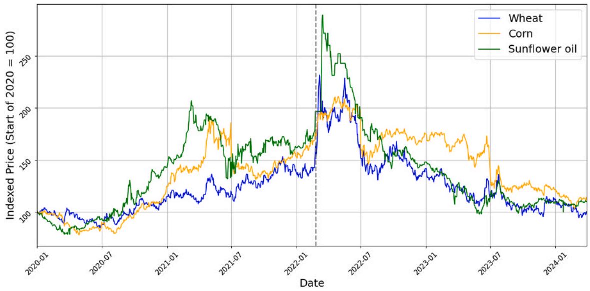

Fig. 1. Price development of wheat, corn, and sunflower oil. The gray vertical line indicates the start of the Russian invasion of Ukraine on 2022-02-24.

2022; Sun et al., 2022; Obi et al., 2023), precious metals (Shahzad et al., 2023) and on various financial markets (e.g., Z. Umar et al., 2022b; Tong, 2024). Goyal and Steinbach (2023) found that agricultural prices rose by 16% nine weeks after the invasion and that the Black Sea Grain Initiative, brokered in July 2022, failed to alleviate uncertainty in agricultural markets. Additionally, Beckmann and Czudaj (2017) demonstrate that heightened economic policy uncertainty, similar to what might be experienced during the conflict, can significantly influence exchange rates. Drastic exchange rate changes will then impact commodity trade and the necessity for hedging activities.

Although the current literature provides a diverse perspective on the war's initial impact, there is still room for improvement. First, many studies rely on a short sample period spanning approximately one year or less and thus only capture the conflict's early effects. Second, comprehensive studies focusing on agricultural markets remain scarce. Even though Ukraine is a significant exporter of several agricultural commodities, it is essential to broaden the scope of research to include a wider array of agricultural products for a more thorough analysis.

Table 1 presents a comprehensive overview of recent literature on geopolitical risk. Overall, the consensus across these studies indicates that geopolitical risks adversely affect various asset classes and macroeconomic variables. For instance, research has shown that energy commodities tend to experience increases in both price and volatility (e.g., Wang et al., 2022; Fang and Shao, 2022), while energy firms have been found to outperform other equities (Lo et al., 2022). Nerlinger and Utz (2022) further note that renewable energy firms benefit more than traditional ones. In addition, recent studies reveal a negative impact of geopolitical risks on agricultural markets (e.g., Balsalobre-Lorente et al., 2023; Bossman et al., 2023) and emphasize its potential to increase spillovers across commodities (e.g., Fang and Shao, 2022; Gong and Xu, 2022; Salachas et al., 2024). Fan et al. (2023) also demonstrate how geopolitical tensions can influence international prices through trade channels, illustrating that localized events can exert a far-reaching global impact. Similarly, Aiyar et al. (2024) find that geopolitical alignment positively influences foreign direct investment (FDI) flows, further highlighting a broader trend of economic fragmentation as geopolitical tensions rise.

Outside of the geopolitical context, an extensive literature has documented interdependence and spillover effects among energy commodities, mainly crude oil, and agricultural commodities (e.g., Nazlioglu et al., 2013; Shahzad et al., 2018; Ji et al., 2018; Dahl et al., 2020; Tiwari et al., 2022). This interdependency suggests that a surge in energy prices due to the war could have spillover effects on agricultural commodities; given that the Russia-Ukraine war can directly affect both energy and agricultural markets, the potential for even more significant disruptions exists, highlighting the importance of a thorough investigation.

Against this background, this study aims to quantify the impact of the Russia-Ukraine war on the prices of agricultural and energy commodities. We also extend our analysis to agricultural companies, creating an equity index with companies particularly exposed to agricultural commodities.[1] To discern their tangible effects, we identify war-related events from February 24, 2022, until March 30, 2024. To achieve this, we use the methodology developed by Rigobon (2003) and subsequently expanded upon by Wright (2012). This approach utilizes a structural vector autoregression (SVAR) and allows us to measure shocks by identifying heteroskedasticity between non-event and event days. This method has recently been used to study the effect of other events on financial markets (e.g., Boer et al., 2023; Miescu and Rossi, 2021).

Our study makes several contributions to the existing literature. While previous research has addressed volatility spillover and price shocks in agricultural markets (e.g., Hamadi et al., 2017; Nazlioglu et al., 2013; Z. Umar et al., 2021; Yang et al., 2003), no study to our knowledge has investigated the effect of Russia-Ukraine war and focused in such a detailed manner on agricultural markets. Additionally, we extend our analysis beyond commodity prices to examine the impact on publicly traded agricultural companies, providing insights into broader sectoral effects. Lastly, we contribute to the current literature by providing more knowledge on the contrasting effects on the European and American natural gas markets, assessing the impact on the European equity market, and examining the war-related effects on specific currencies and bond markets.

Our study primarily relates to Tong (2024), who extensively investigated the economic effects of the Russia-Ukraine conflict across various financial markets using a similar methodological approach. However, our study differs from Tong (2024) in several crucial

[1] The purpose of this specialized equity index is to investigate whether or not these firms respond to the war shock in a similar manner as the broader stock market. The companies we include in this stock market index are not meant to have major business in Ukraine.

Table 1
Literature investigating the effect of geopolitical risk on various markets. "GPR Measure" column identifies each study's method for quantifying geopolitical risk.

Author	Method	GPR Measure	Variables	Result
Baur and Smales (2020)	OLS	GPR Index (Caldara and Iacoviello, 2022)	Stock, bond, and metal markets	Precious metals hedge against GPR
Känzig (2021)	Heteroskedasticity-based VAR	GPR Index (Caldara and Iacoviello, 2022) & OPEC announcements	Oil and macroeconomic variables	OPEC announcement increases GPR index
Fang and Shao (2022)	GJR-GARCH & connectedness	Adjusted GPR Index (Caldara and Iacoviello, 2022)	Agriculture, energy, and metal commodities	Increased volatility on commodity markets
Gong and Xu (2022)	GARCH-Midas	GPR Index (Caldara and Iacoviello, 2022)	Agriculture, energy, metal, and livestock commodities	GPR increases overall connectedness
Lo et al. (2022)	Panel regression	Google Search volume index (RUW related terms)	Stock markets	Negative impact on stock returns
Nerlinger and Utz (2022)	OLS	Subsample, comparison pre- and during RUW	Energy firms	Energy firms outperform other equity post invasion
Saâdaoui et al. (2022)	Multiresolution data analysis	GPR Index (Caldara and Iacoviello, 2022)	Agricultural commodities	One-way causal relationship, GPR affects food
Shahzad et al. (2022)	Partial cross-quantilogram	Oil supply shock	Oil and macroeconomic uncertainties	Negative impact on macroeconomic uncertainty variables
M. Umar et al. (2022a)	OLS	Event study, comparison pre- and post 24 Feb 2022	Energy and metals markets	Renewable energy benefitted, but significant losses in other markets
Z. Umar et al. (2022b)	TVP-VAR	–	RU, EU, and US equities. Oil, natural gas, and wheat	Changed connectedness post invasion
Wang et al. (2022)	TVP-VAR	GPR Index (Caldara and Iacoviello, 2022)	Agricultural, energy, and metal commodities	GPR increases spillovers on commodity markets
Balsalobre-Lorente et al. (2023)	Cross-quantilogram	Sub-sample, comparison pre- and during RUW, and RUW sentiment via Google Trends	Oil and gas	Stronger quantile correlations during war
Bossman et al. (2023)	Quantile-on-Quantile	GPR Index (Caldara and Iacoviello, 2022)	Agricultural and oil commodities	Negative relationship between GPR and agricultural markets
Chishti et al. (2023)	Cross-quantilogram	GPR Index (Caldara and Iacoviello, 2022)	Agricultural, energy, and metal commodities	General loses in different quantiles
Fan et al. (2023)	Panel regression	GPR Index (Caldara and Iacoviello, 2022)	Rare earth metals	GPR increases price and decrease import values
Liadze et al. (2023)	New Keynesian model (NiGEM)	–	GDP, Inflation	RUW estimated to cost 1% of global GDP in 2022
W. Zhang et al. (2023b)	CRP-MIF	–	Crude oil	RUW increased trading volume, speculation, and price fluctuations
Q. Zhang et al. (2023a)	Connectedness	Sub-samples	Green Finance indices	RUW has a mild effect on green finance markets
Biswas et al. (2024)	TVP-VAR	GPR Index (Caldara and Iacoviello, 2022)	Equity, oil, natural gas, and wheat markets	Increased connectedness during heightened GPR
Hartvig et al. (2024)	Energy trade modeling (REK WGGM & 3EME-FTT)	Energy export restrictions	Gas markets, energy supply, and trade	Negative short-term consequences, but accelerated European energy diversification
Jiang and Chen (2024)	Quantile & time-frequency connectedness	Sub-sample, comparison pre- and during RUW	Agriculture, energy, and metal commodities	Increased spillover effects and volatility
Salachas et al. (2024)	Panel VAR	GPR Index (Caldara and Iacoviello, 2022)	Stock market return	Negative impact of geopolitical shocks on stock markets
Tong (2024)	Heteroskedasticity-based VAR & local projection	GPR Index (Caldara and Iacoviello, 2022)	Macroeconomic variables and financial markets	Increase in commodity prices & inflation. Decrease in GDP. Equity fell while bonds were stable. Increases in financial stress.
U et al. (2024)	Connectedness	Subsample, comparison pre- and during RUW	Equity, FX, wheat, gold, oil, natural gas	Increased long-term component of volatility spillover

Note: RUW is an abbreviation for "Russia-Ukraine War". Missing value in "GPR Measure" column indicates that the study did not have a specific measure for geopolitical risk but e.g. examined changes in a time-series.

aspects. Methodologically, we employ a narrative-based approach to identify significant events by analyzing news reports. This allows for the inclusion of specific incidents, such as attacks on ports, that are pivotal to agricultural markets but may not be prominently featured in major news outlets. The narrative-based selection contrasts with the quantitative method in Tong (2024), which relies on the Geopolitical Risk Index (GPR Index) by Caldara and Iacoviello (2022). Our method allows us to specifically select dates that are relevant to our research question, which would not be possible using the GPR Index. The daily GPR index measures the frequency of various words (of geopolitical relevancy) in major US newspapers but does not distinguish or categorize the underlying event. Thus, the GPR Index will include overlapping events and can therefore exhibit high values due to news unrelated to one's research objective.

Most notably, the escalation of the Israel-Palestine conflict has been a large contributor to the GPR Index from October 7, 2023. If we were to base our selection of events on extreme values of the index, we would inevitably include days that spiked the GPR Index due to the Israel-Palestine conflict and generate misleading signals. Hence, our narrative approach is the most appropriate method for capturing the full extent of the Russian-Ukraine war and its effects on agricultural markets. In terms of the data, our study differs from Tong (2024) as we focus on a selected number of energy commodities and agricultural markets instead of financial markets. Thus, we include a more extensive set of agricultural commodities and the self-created stock price index for Western agricultural-related companies. Furthermore, in contrast to Tong (2024), we explore the effects on different natural gas prices, highlighting the heterogeneous impacts that the war has had across various geographical natural gas markets. Finally, unlike Tong (2024), who initiated the study period a year before the invasion (January 2021), our sample begins closer to the onset of the conflict in January 2022 and extends through March 2024, thus providing insights into the longer-term effects of the war.

Our paper is also related, although to a lesser extent, to two other studies that assess the effect of the Russia-Ukraine war on commodities, i.e., Saâdaoui et al. (2022) and Wang et al. (2022). These studies diverge from ours in three notable ways. Firstly, they analyze a narrower selection of agricultural commodities.[2] Secondly, their methodologies differ, focusing on causality testing (Saâdaoui et al., 2022) or connectedness (Wang et al., 2022). Lastly, both conclude their analysis in April 2022, thereby only capturing the very initial period of the Russian invasion.

Our results show heterogeneous responses among agricultural commodities. Wheat, corn, and rapeseed show a notably positive response, whereas sunflower oil exhibits a smaller and less significant negative price movement following shocks. European natural gas markets reacted strongly, with a significant price increase of 7.5%, contrasting with the relative stability observed in other natural gas markets. Our propriety equity index does not exhibit the same negative response seen in general European equity markets.

From this point onward, the paper will be structured as follows. The next section describes the data used to analyze the impact of the war on the selected markets, along with the heteroskedasticity-based SVAR methodology employed. Following that, we present the findings from the SVAR models and provide an evaluation of these results. Finally, our paper concludes with a summarization of our insights, offering a broader perspective on the markets most impacted by the conflict.

2. Data and methodology

2.1. Data and event days

We use daily data from LSEG Workspace from January 3, 2022, to March 30, 2024. Table 2 outlines the selection of commodity and financial variables used in this study. To control for macroeconomic factors, we incorporate the German 10-year yield, the Euronext equity index, the VSTOXX 50, and the USD-EUR exchange rate into our model. All variables are entered into the model as log levels, except for interest rate, which is entered as first-difference due to its clear upward trend. Descriptive statistics for all variables are presented in Table 3.

In constructing our proprietary equity index, we focus on publicly traded firms in North America and Europe, specifically those in the milling, corn, wheat, and sunflower oil sectors. We compiled daily market capitalization data for these firms and assigned weights in the index based on each firm's size. See the appendix for a detailed list of all the firms included in the index.

We identified significant days during the Russian-Ukraine war using the news feature on LSEG Workspace, employing a keyword search syntax ("(Ukraine OR Russia) AND (Agriculture OR Attack OR Port OR War OR Conflict)") to filter news articles. The selection of relevant events was made based on these results, as detailed in Table 4. All events in Table 4 are included in our baseline model. If an event was reported on a day the market was closed, the subsequent trading day is selected. As a robustness check, we also ran our model with a subset of events categorized as "Restricted" and "Attacks". These results can be found in the appendix.

The baseline model consists of 84 dates starting from February 24, 2022, to March 30, 2024. In selecting these dates, we aimed to closely mimic real-time news reporting to analyze price shocks as they occurred, rather than relying on retrospective analysis of confirmations of events. This approach ensures that our model captures the immediate market reactions to geopolitical events. As previously discussed, using a narrative-based selection of events allows us to avoid the potential inaccuracies that could arise from relying on generalized indices such as the GPR Index. With our procedure, each event included in our analysis is directly relevant to the scope of our study.

2.2. Methodology

In this study, we employ the identification through heteroskedasticity method originally developed by Rigobon (2003) and further expanded upon by Wright (2012). We use a structural vector autoregression (SVAR) with five lags, following Boer et al. (2023). The model includes five endogenous variables such that $y = (P_i, STOCK_t, VSTOXX_t, YIELD_t, FX_t)$, where $P_{i,t}$ represents each asset found in Table 2, and four financial variables: the Euronext Index, VSTOXX implied volatility index, German 10-year yield, and USD-Euro exchange rate. In line with Boer et al. (2023) and Miescu and Rossi (2021), we interpret a war shock as an event that causes an increase in market volatility,[3] reflected by a rise in the VSTOXX index. This setup allows us to capture the immediate impact of

[2] As relates to the agricultural market, Saâdaoui et al. (2022) include rice, corn, and wheat, while Wang et al. (2022) include Wheat, Corn, Oats, Sugar, and Soybeans.

[3] Practically, this is implemented by imposing a restriction such that we force the parameter for VSTOXX to be positive.

Table 2
Commodity data.

	Description	Symbol
Wheat future	Chicago Board of Trade Wheat Composite Futures	CWFCS00
Corn future	Chicago Board of Trade Corn Composite Futures	CCFCS00
Soybean future	Chicago Board of Trade Soybean Composite Futures	CSYC.01
Rough rice future	Chicago Board of Trade Rough Rice Composite Futures	CRRCS00
Rapeseed future	MATIF Euro Rapeseed TRC1	PROC.01
Cocoa future	CSCE – Cocoa Continuous Index	NCCCS04
Coffee future	CSCE – Coffee Continuous Index	NKCCS04
Sugar future	CSCE – Sugar #11 Continuous Index	NSBC04
Sunflower oil future	1 Month US futures	SUNFXT1
Crude oil future	NYMEX – Light Crude Oil Continuous	NCLCS00
Natural gas future (US)	NYMEX – Natural Gas Continuous	NNGCS00
Natural gas future (EU)	RFV Natural Gas TTF Netherlands	TRNLTTM
Natural gas future (India)	MCX – Natural Gas TRc1	MNGC.01
Natural gas spot (Japan)	Clean Tanker Middle East Gulf-Japan 75 KT TC1	CFMEJPL
Agricultural Index	S&P 600 Agricultural and Farming Machinery Index	SP6SAG4

Table 3
Descriptive statistics.

	Mean	Std. dev	Skewness	Kurtosis	ADF	PP
Wheat	6.60	0.21	0.59	2.52	0.43	0.44
Corn	6.39	0.19	−0.32	1.87	0.38	0.38
Sunflower oil	7.11	0.27	0.72	2.52	0.38	0.38
Soybean	7.27	0.10	−0.24	2.43	0.47	0.48
Rough rice	7.43	0.06	−0.50	2.69	0.78	0.75
Rapeseed	6.32	0.26	0.65	2.34	0.19	0.21
Cocoa	4.82	0.34	1.72	6.05	1.00	1.00
Coffee	3.45	0.13	−0.38	1.82	0.62	0.64
Sugar	4.98	0.21	0.14	1.45	0.93	0.92
Milling Companies	10.50	0.12	−0.74	2.89	0.51	0.53
S&P GSCI Agricultural	5.20	0.11	−0.05	1.91	0.68	0.60
Crude oil	4.43	0.14	0.77	2.83	0.65	0.68
US Natural gas	1.33	0.51	0.27	1.71	0.31	0.35
EU Natural gas	4.19	0.53	0.68	2.71	0.36	0.33
India Natural gas	5.73	0.49	0.29	1.75	0.41	0.43
Japan Natural gas	5.07	0.27	0.01	4.13	0.74	0.76
VSTOXX 50	3.02	0.29	0.30	2.31	0.47	0.49
Euronext	7.17	0.07	−0.29	2.69	0.82	0.80
German 10-year yield	0.00	0.07	−0.57	4.15	0.00	0.00
Euro/USD	0.07	0.04	−0.80	3.41	0.15	0.16

Notes: Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests are presented with 5 lags, in line with our specification for the VAR-model.

geopolitical shocks on asset prices and market conditions.

The reduced form VAR can be represented as:

$$A(L)Y_t = \mu + \varepsilon_t \tag{1}$$

Where Y_t is the p x 1 vector of variables, and ε_t is the reduced-form errors. Following Wright (2012) the relationship between the reduced-form errors and the structural shock is defined by:

$$\varepsilon_t = \sum_{i=1}^{p} R_i \eta_{i,j} \tag{2}$$

Where η represents the structural shocks from the event and R is the vector of coefficients, the rest of the variables in equations (1) and (2) are assumed to be constant. The core assumption is that the structural shock on event days has the variance, σ_e^2, with a mean of zero, but differs from the variance on non-event days, σ_{ne}^2.[4] Meaning this method requires that $\sigma_e^2 \neq \sigma_{ne}^2$, but that all other shocks to the variables are identically distributed throughout the period.[5] Wright (2012) notes that day-to-day fluctuations in unrelated shocks may

[4] Our sample spanning consists of 585 trading days. In our baseline model, σ_e^2 consists of the 84 event-days specified in Table 4, and the remainder 501 days are a part of the non-event days σ_{ne}^2.

[5] We performed bootstrapped Wald statistic to test $\sigma_e^2 \neq \sigma_{ne}^2$. P-value <5% for all our models and we can therefore proceed with our analysis.

Table 4
Description of selected events days.

Date	Description	Events: Baseline	Restricted	Attacks
2022-02-24	Russian invasion begins	X	X	X
2022-02-25	First attacks on Kyiv	X	X	X
2022-03-01	Siege of Mariupol and attacks on Kharkiv	X	X	X
2022-03-04	Seizure of Zaporizhzhia nuclear power plant	X		X
2022-03-09	Mariupol hospital attack	X		X
2022-03-16	Mariupol theater bombing	X		X
2022-03-23	Mykolaiv port attack	X		X
2022-03-29	Attack on Mykolaiv Regional State Administration building	X	X	X
2022-04-02	Russia retreats from Kyiv	X		X
2022-04-08	Attack on Kramatorsk railway station	X	X	X
2022-05-09	Biden signed the act to lend defensive support to Ukraine	X		
2022-06-27	Attack on Kremenchuk	X	X	X
2022-07-01	Attack on Odesa	X		X
2022-07-22	Black Sea Agreement begins	X		
2022-07-24	Attack on Odesa port	X		X
2022-09-21	Russia extends mobilization and draft	X		
2022-10-08	Crimean bridge attack	X		X
2022-10-10	Attack on Kyiv, blackout in city	X	X	X
2022-10-29	Russia leaves Black Sea Agreement	X		
2022-11-02	Russia re-enters Black Sea Agreement	X		
2022-11-19	Black Sea Agreement extended to 18th of March	X		
2022-12-12	Odesa port attacked	X		X
2023-01-25	Germany ships military equipment	X		
2023-03-18	The Black Sea Agreement extended another 60 days	X		
2023-05-02	Poland, and others, ban Ukrainian grain imports	X		
2023-05-17	The Black Sea Agreement extended another 60 days	X		
2023-05-29	Attack on Odesa port	X		X
2023-07-17	Russia leaves Black Sea Agreement	X	X	
2023-07-18	Attack on Odesa port	X		X
2023-07-19	Attack on Chornomorsk port and Poland extends import ban	X		X
2023-07-20	Attack on Odesa port. Chinese consulate damaged	X		
2023-07-21	Attack on Odesa port. Grain terminals and silos damaged	X		
2023-07-23	Attack on Danube port. 13 000-ton grain destroyed	X		
2023-07-27	Attack on Odesa port	X	X	X
2023-08-02	Attack on Odesa port	X		
2023-08-04	Attack on Novorossiysk port. Russian grain port in the Black Sea	X		
2023-08-14	Attack on Odesa	X		
2023-08-16	Attack on Reni port	X		X
2023-08-23	Attack on Danube port	X		X
2023-08-28	Attack on vegetable oil facility	X		X
2023-09-03	Attack on Odesa port	X		X
2023-09-06	Attack on Danube port	X		X
2023-09-07	Attack on Danube port	X		X
2023-09-13	Attack on Danube port	X		X
2023-09-17	Attack on agricultural facility in Odesa	X		X
2023-09-19	Attack on Lviv	X		X
2023-09-20	Attack on oil refinery in Kremenchuk	X		X
2023-09-21	Large attacks around Ukraine. Energy facilities damaged.	X		X
2023-09-25	Attack on Odesa port	X		X
2023-09-26	Attack on Izmail port	X		X
2023-10-05	Attacks on southern Ukraine. Ports in Odesa and Mykolaiv	X	X	X
2023-10-06	Attack on grain silos and port on Danube	X		X
2023-10-12	Attack on Danube port	X		X
2023-10-18	Attack on Zaporizhzhia	X		X
2023-10-30	Attack on ship repair yard in Odesa	X		X
2023-11-08	Cargo ship attacked when entering Odesa	X		X
2023-11-15	Grain deliveries by trained stopped due to railway damage, headed to Odesa	X		X
2023-11-18	Attacks on energy infrastructure, large outages	X		X
2023-11-21	Attack on Odesa port	X		X
2023-11-26	Attack on Kyiv	X		X
2023-12-07	Attack on Danube port	X		X
2023-12-14	Attacks in Odesa region. Damages to port and grain storage facilities	X	X	X
2023-12-17	Attack on Odesa	X		X
2023-12-29	Large attacks around Ukraine	X		X
2023-12-31	Large attacks on southern regions	X		X
2024-01-01	Attack on Odesa port	X		X
2024-01-02	Large attacks around Ukraine	X	X	X

(*continued on next page*)

Table 4 (*continued*)

Date	Description	Events: Baseline	Restricted	Attacks
2024-01-06	Attacks on Pokrovsk	X		X
2024-01-17	Attack on Odesa port	X		X
2024-01-24	Attack on Odesa port	X		X
2024-02-07	Attack on Kyiv	X		X
2024-02-09	Attack on Kharkiv	X		X
2024-02-15	Large attacks around Ukraine	X	X	X
2024-02-20	Attacks on around northern Ukraine	X		X
2024-02-24	Attack on Odesa port	X		X
2024-03-02	Attack on Odesa port	X	X	X
2024-03-06	Attacks on power infrastructure. Attack on Odesa port	X		X
2024-03-08	Attack in north-eastern Ukraine	X		X
2024-03-13	Attacks around Ukraine	X		X
2024-03-15	Large attack on Odesa	X	X	X
2024-03-17	Attack on Odesa. Damage to port, agricultural companies, and infrastructure	X		X
2024-03-20	Attack on Kharkiv	X		X
2024-03-21	Attacks on Kyiv and Mykolaiv	X		X
2024-03-30	Attack on power facilities, significant damage to power plants	X		X
Total		**84**	**14**	**67**

occur but it will not distort the measurement of our targeted war-shock, assuming they average out between event and non-event days.

This methodology depends on accurately distinguishing between event and non-event days. Misclassification, such as incorrectly identifying significant war-related days as non-events, would include relevant information in the covariance matrix of non-event days. Since our analysis derives shocks from the differences in covariance matrices, misspecifications of events could potentially skew the results.

Similar to Wright (2012), we denote the variance-covariance matrix of reduced-form errors on announcement days as Σ_e, and for non-event days, Σ_{ne}. We can now subtract the variance-covariance matrices, $\Sigma_e - \Sigma_{ne}$ and express them as:

$$\Sigma_e - \Sigma_{ne} = \mathrm{R}_1 R_1' \sigma_e^2 - \mathrm{R}_1 R_1' \sigma_{ne}^2 = \mathrm{R}_1 R_1' (\sigma_e^2 - \sigma_{ne}^2) \tag{3}$$

And following Wright (2012), we can estimate the impact of the war shock, represented by R_1, through solving minimum distance problem:

$$\left[vech(\widehat{\Sigma}_e - \widehat{\Sigma}_{ne}) - vech(\mathrm{R}_1 R_1')\right]' \left[\widehat{V_e} + \widehat{V_{ne}}\right]^{-1} \left[vech(\widehat{\Sigma}_e - \widehat{\Sigma}_{ne}) - vech(\mathrm{R}_1 R_1')\right] \tag{4}$$

Following Boer et al. (2023), we can obtain the first structural shocks by:

$$\varepsilon_{1t} = \frac{\mathrm{R}_1{}' \Sigma_s{}^{-1} \mathrm{u}_t}{\mathrm{R}_1{}' \Sigma_s{}^{-1} \mathrm{R}_1} \tag{5}$$

Where Σ_s is the reduced form covariance matrix over the whole sample.

This methodology is particularly well-suited for research questions that investigate the effects of frequently re-occurring events during the sample period, such as our war events. Other examples of this application are Miescu and Rossi (2021), who investigated the effects of major COVID-19 news and announcements on various financial and economic indicators. Boer et al. (2023) define their events as policy announcements about US trade with China between January 2, 2017 and January 17, 2020 and their effect on equity price, among other variables.

3. Empirical results

The results from our primary model, presented in Fig. 2, show a significant reaction to a war shock. Note that the calculated impulse responses show our sample's average reaction to one war-related event. The wheat market experienced a notable price surge of approximately 2% in future prices in response to the war shock, which contrasts with Tong (2024), who found a slightly negative immediate reaction. This discrepancy could be attributed to differences in event selection between studies. Regarding the financial variables, the results align with our expectations. European stock market volatility shows a significant increase of 3% in response to the identified events. In line with this heightened volatility, European stocks declined while the Euro weakened against the US dollar.

Additionally, the German 10-year yield exhibits a negative response. The observations can be interpreted as the occurrence of the flight-to-safety mechanism. As geopolitical uncertainty increases, global wheat prices increase instantaneously, reflecting the market's concerns over supply disruptions from Ukraine. Notably, the effects remain significant even at longer horizons, with wheat losing significance around day 70.

Fig. 3 aggregates the results for the remainder of the assets. We observe a positive response in corn prices, with an increase of 1%. However, unlike wheat and corn, no significant effect can be found in observing our self-constructed equity index ("Milling companies"), or sunflower oil futures. Sugar, rough rice, and soybean exhibit a positive price shock but are smaller in magnitude and drop

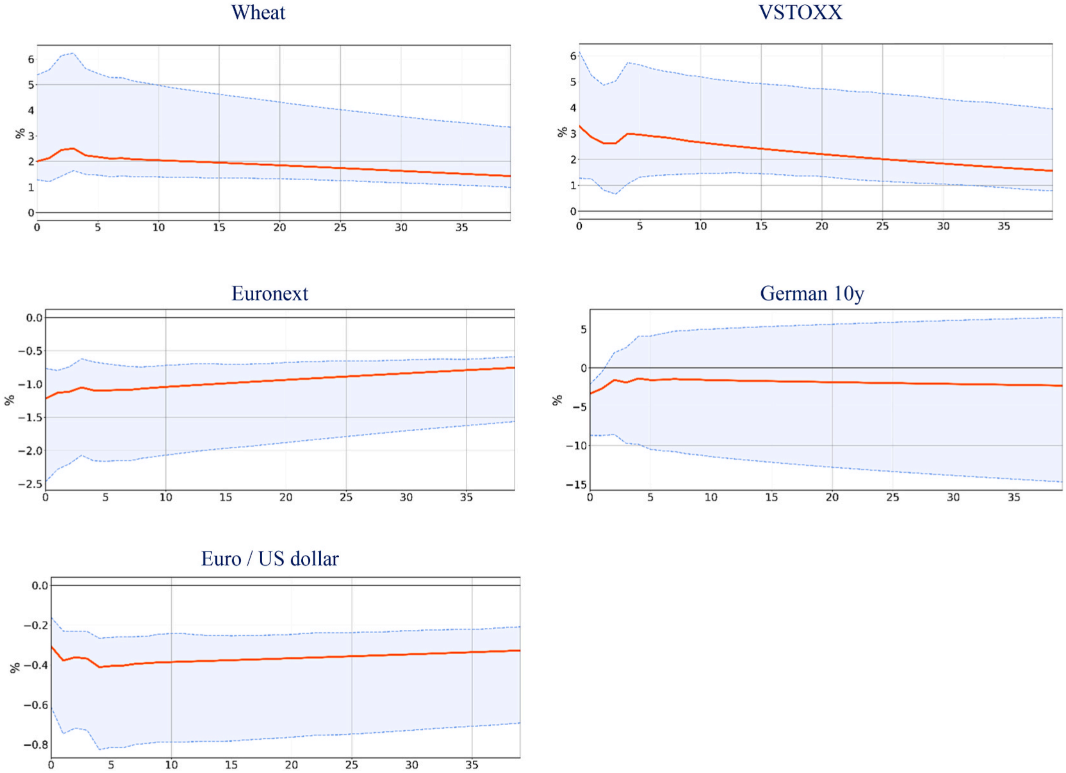

Fig. 2. The effect of heteroskedasticity based war shock on wheat future and financial variables.
Notes: The red line represents the impulse response function. The shaded area is the bootstrapped (n = 1000) confidence interval of 95%. The x-axis is expressed in days. The impulse response for the German 10-year yield is presented as the cumulative sum. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

off quicker than wheat prices. While Russia and Ukraine also export these commodities, their roles are comparatively minor, lessening the observed response. Interestingly, an initial negative reaction of the American S&P Agricultural Index turns positive after around two weeks. This change in reaction suggests that investors may take time to fully assess and price in the conflict's implications on U.S. agricultural equity, reflecting a cautious approach to integrating geopolitical uncertainties into market valuations.

As for the energy sector, we observe a large positive response in European natural gas prices, which increased by 7.5% on the average event day. This effect persists over longer time horizons, indicating sustained market sensitivity to geopolitical tensions. Crude oil prices similarly react positively, albeit smaller by 2% initially. Interestingly, the shock to European natural gas does not appear to spread to US or Indian natural gas as the effect is insignificant. It is noteworthy that, contrary to any other region, Japanese natural gas prices exhibit a slight decrease, suggesting a unique market response possibly due to different supply chain dynamics or energy dependencies.

3.1. Robustness

As robustness checks, we assess the sensitivity of our results to different event selections compared to the baseline model. Table 4 lists the three different event selections. The alternative selections, labeled "Restricted" and "Attacks", are used to test the robustness of our findings, with complete results presented in the appendix (Figures 6 and 7 for "Restricted" events and Figures 8 and 9 for "Attacks" events).

The responses generally are amplified for the "Restricted" events, which consist of a more selected and more major set of 14 dates related to the war, compared to observations from the "Baseline" model relating to the agricultural commodities. Wheat prices show a more robust response of 5%, compared to 2% in "Baseline." Similarly, corn and rapeseed also exhibit a firmer shock. Surprisingly, European natural gas prices actually decreased compared to baseline findings. US and Indian natural gas prices have increased by approximately 2%. This unexpected shift in the response of European, US, and Indian gas markets could be attributed to the previously mentioned potential for misspecification issues. The limited number of events in the "Restricted" selection increases the likelihood that dates with relevant price information are now categorized as "non-events," thus skewing the results. Crude oil prices still increase, albeit smaller. The financial variables (VSTOXX, Euronext, German 10-year yield, and Euro/USD) exhibit similar but stronger responses to "Baseline" events. As the "Restricted" event selection is meant to select events deemed to be the most pronounced dates relating to the war, the results on financial variables are expected to be more significant.

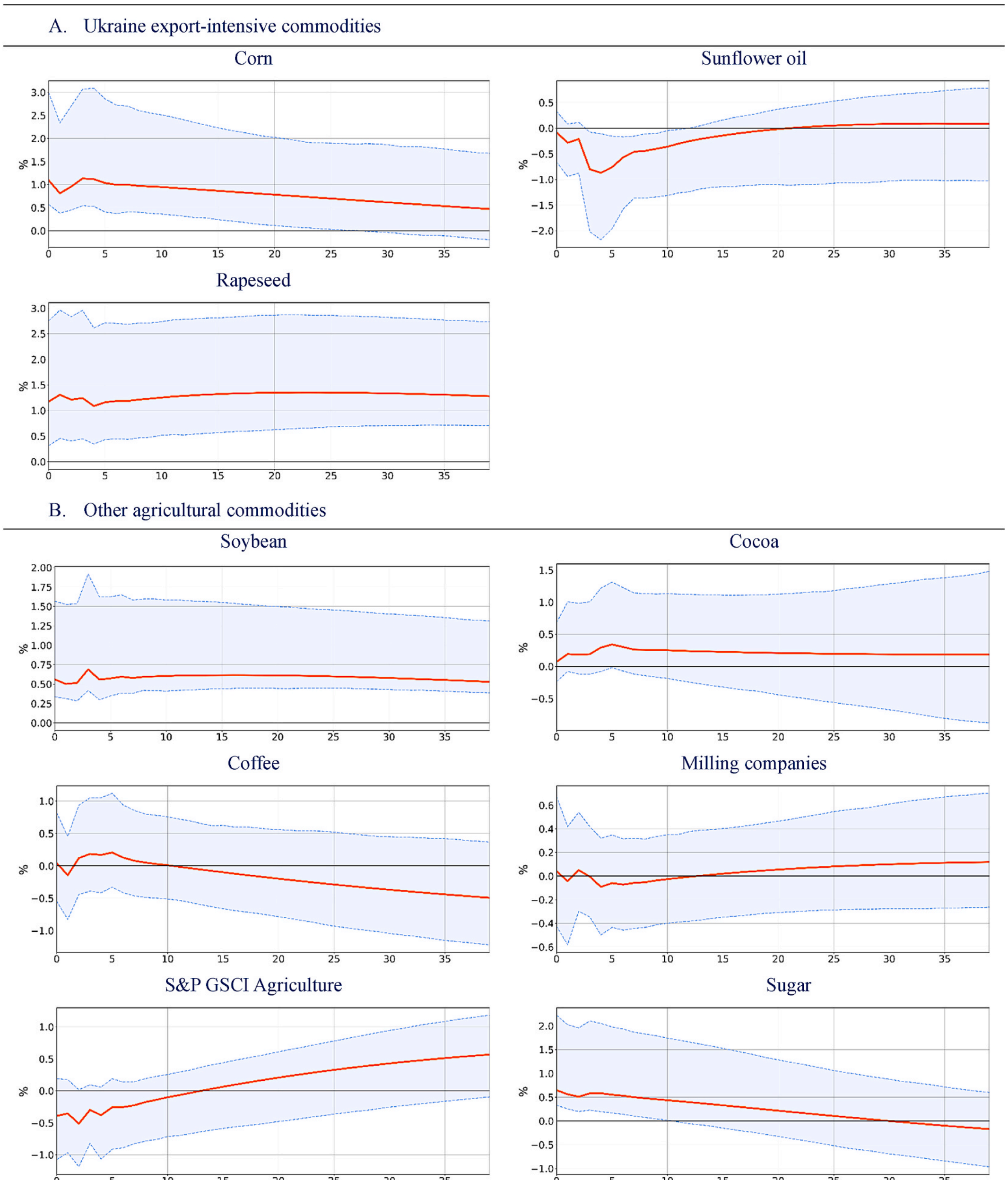

Fig. 3. The effect of heteroskedasticity based war shock on commodities.
Notes. The red line represents the impulse response function. The shaded area represents the bootstrapped (n = 1000) confidence interval of 95%. The x-axis is expressed in days. All variables in this table are run in a model similar to that of Fig. 1 but replacing the wheat series and maintaining the other four financial variables. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

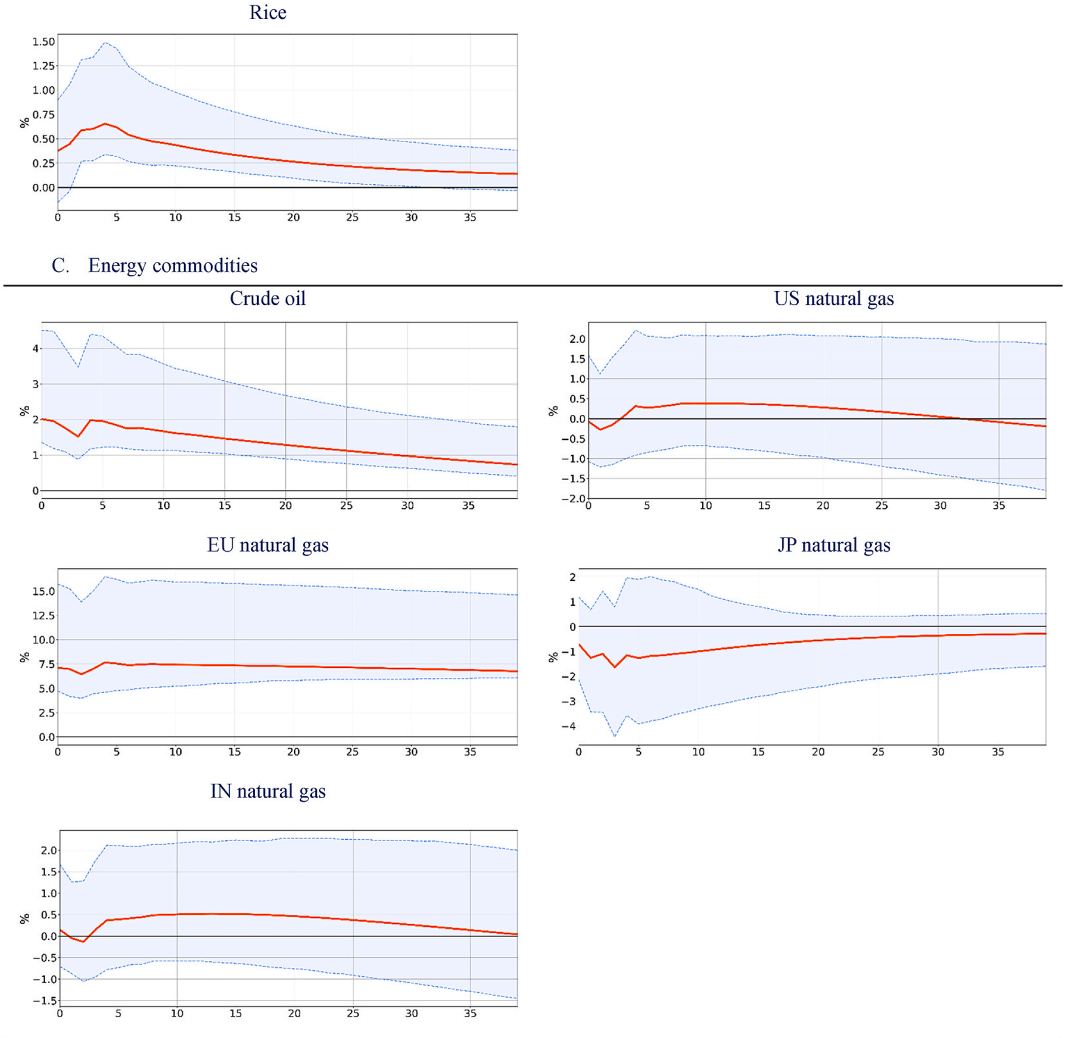

Fig. 3. (*continued*).

Our third event series, labeled as “Attacks”, focuses explicitly on instances where civilian, agricultural, or energy infrastructure was directly targeted, such as attacks on ports and silos. The responses observed are consistent with those from our baseline model, mainly due to the high frequency of overlapping events. However, the magnitude of the responses tends to be slightly smaller than in the baseline. Overall, the robustness checks using different event series largely confirm the reliability of our baseline findings, with some variations.

4. Conclusion

The Russian invasion of Ukraine has caused significant disruption to major parts of the global agricultural supply chain. In this study, we investigate the effects of this heightened geopolitical risk on agricultural and energy commodity markets by identifying heteroskedasticity on defined event days occurring between January 2022 and March 2024. Our findings reveal a direct and significant impact on several markets. The largest positive shocks are in wheat and European natural gas prices in the agricultural and energy sectors. Additionally, our analysis of financial variables contributes to the literature by showcasing increased volatility in the European stock market and a weakening of the Euro against the USD. These financial shocks align with the flight-to-safety mechanism, signifying concerns about the disruptions and risks emanating from the conflict.

Interestingly, while Euronext exhibits a negative price reaction, our self-constructed equity index of milling companies shows an insignificant effect. This suggests that the increased risk from the conflict is subsumed by the positive consequences, such as increased demand and price of their goods, for these firms. We find mixed results for the remainder of agricultural commodities, but shorter and positive responses can be found in commodities of which Russia and Ukraine are exporters. Our paper contributes to previous research by examining how the Russian-Ukraine conflict affected agricultural and financial markets and the broader literature of event-based studies.

Future research could adopt the same methodological approach we have used but apply it to other war-related events to understand their effects on financial markets. The method could be effectively used to understand the consequences of the Israel-Palestine conflict. Another idea would be to delve into the impact of market sentiment in influencing commodity markets within a heightened geopolitical context. Investigating how reactions in market sentiment, driven by news and media coverage, impact price or macroeconomic factors under different geopolitical risk regimes would provide deeper insights into the relevant dynamics. This could be implemented by utilizing natural language processing (NLP) methods to analyze news articles, social media, and financial reports.

CRediT authorship contribution statement

Joshua Aizenman: Writing – original draft, Supervision, Conceptualization. **Robert Lindahl:** Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation. **David Stenvall:** Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis. **Gazi Salah Uddin:** Writing – original draft, Supervision, Project administration, Conceptualization.

Declaration of competing interest

We declare no competing interests that could influence the contents of this study.

Data availability

The authors do not have permission to share data.

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Appendix

Table 5
List of companies included in the milling index. Market capitalizations as of 2024-05-10

Company Name	Market Cap (thousand USD)	Country of Exchange
Archer-Daniels-Midland Co	30 872 695	US
General Mills, Inc	39 665 196	US
Bunge Global SA	14 922 708	US
Grupo Minsa SAB de CV	3 533 073	Mexico
Seaboard	3 239 439	US
Skane mollan AB	683 009	Sweden
Groupe Minoteries SA	97 433	Switzerland
Loulis Food Ingredients SA	48 748	Greece
Landshuter Kunstmuehle CA Meyer's Nachfolger AG	21 600	Germany
Granolio dd	12 872	Croatia
Paulic Meunerie SA	8752	France
Zito Karaorman AD Kicevo	6874	Macedonia
Flour Mills C Sarantopoulos SA	4598	Greece
Mitsides PCL	1885	Cyprus
MPI Mlin dd Ustikolina	368	Bosnia and Herzegovina

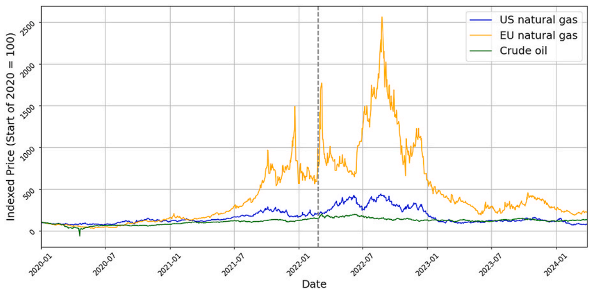

Fig. 5. Price development of US and EU natural gas. The gray vertical line indicates the start of the Russian invasion of Ukraine on 2022-02-24.

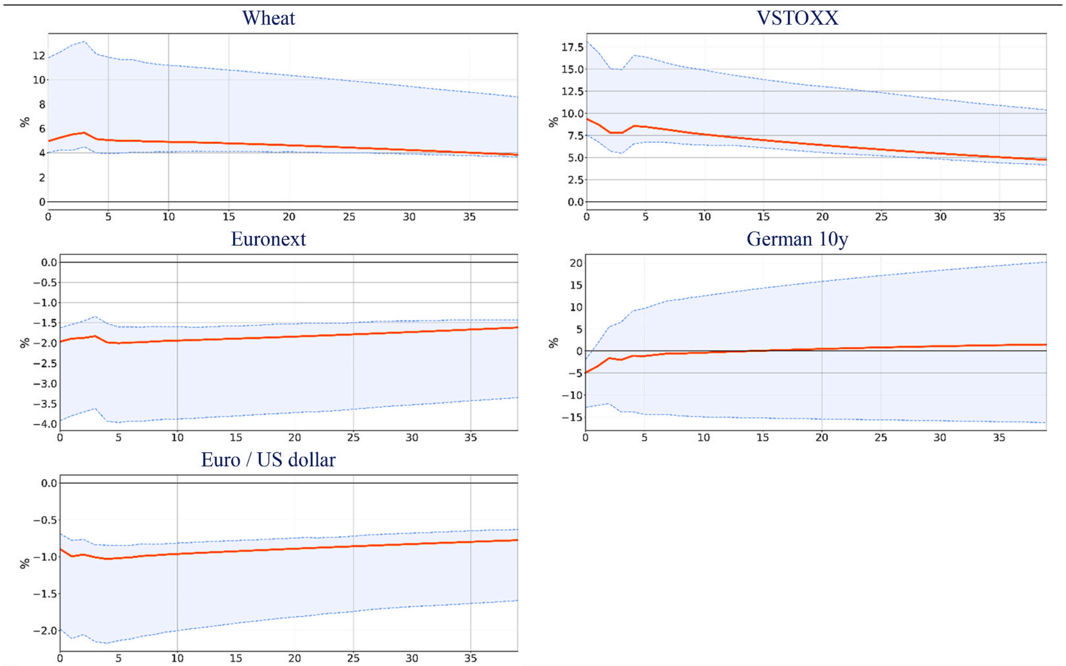

Fig. 6. The effect of heteroskedasticity based war shock on wheat future and financial variables. Results of “Restricted” events in Table 3.
Notes. The red line represents the impulse response function. The shaded area is the bootstrapped (n = 1000) confidence interval of 95%. The x-axis is expressed in days.

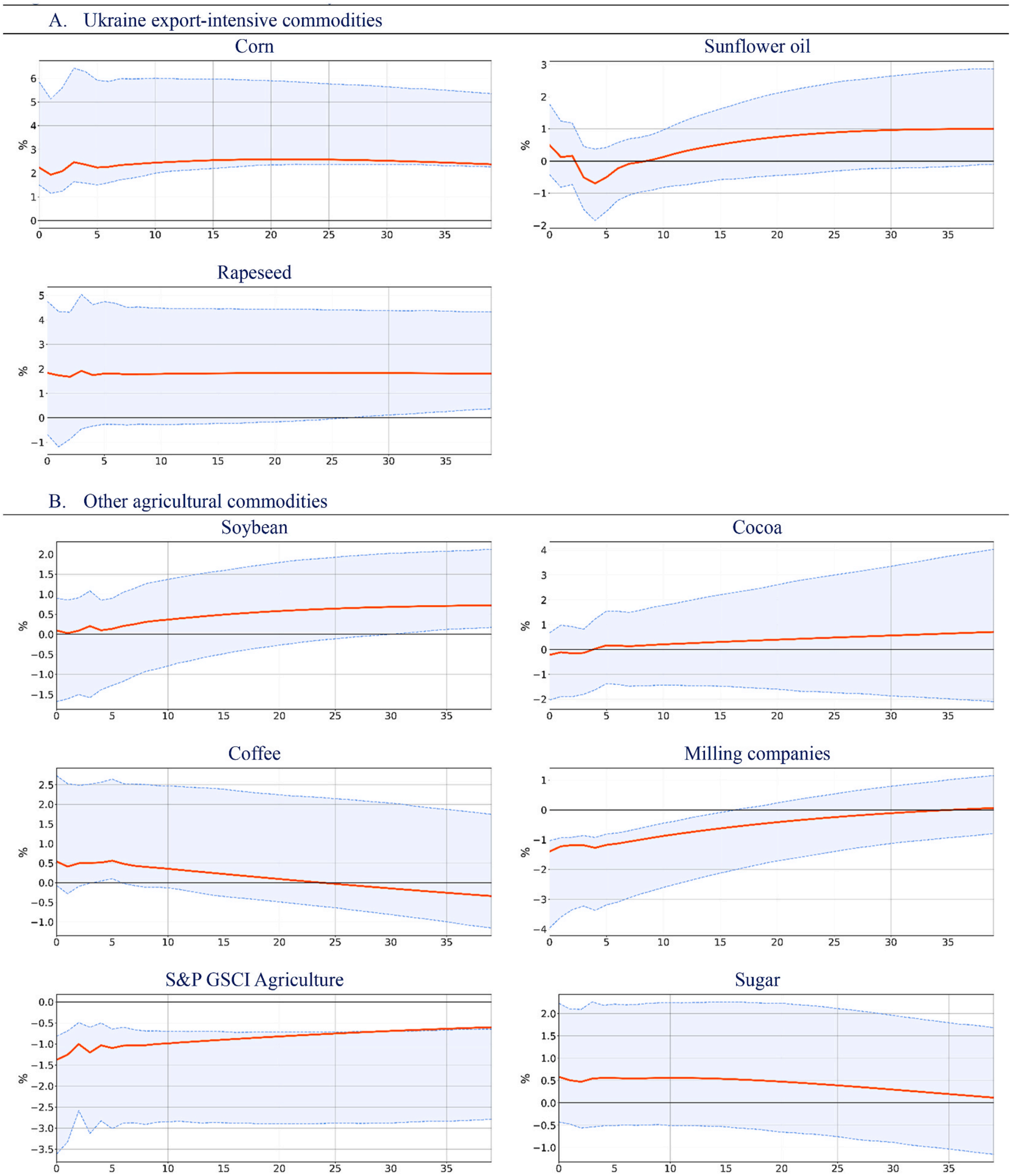

Fig. 7. The effect of heteroskedasticity based war shock on commodities. Results of "Restricted" events in Table 3.

Notes. The red line represents the impulse response function. The shaded area represents the bootstrapped (n = 1000) confidence interval of 95%. The x-axis is expressed in days. All variables in this table are run in a model similar to that of Fig. 1 but replacing the wheat series and maintaining the other four financial variables.

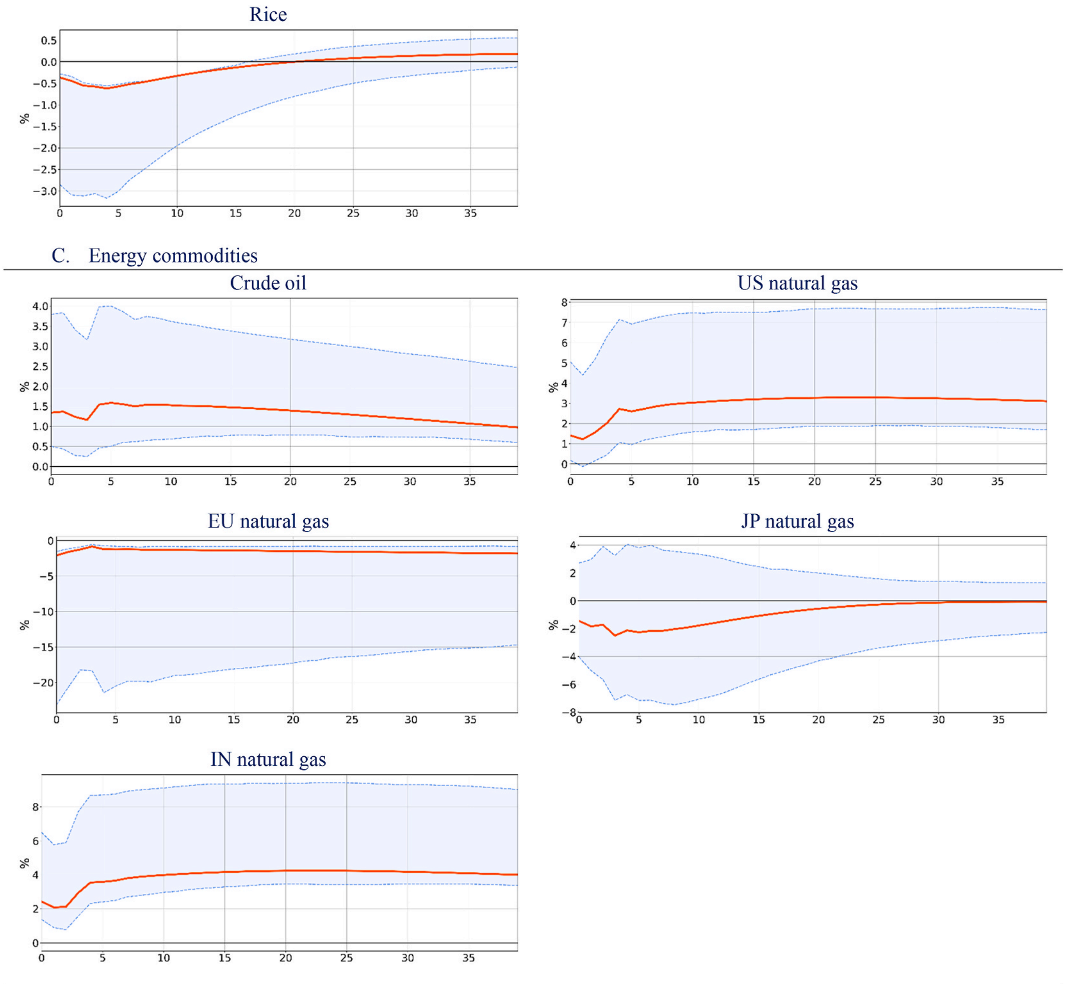

Fig. 7. (*continued*).

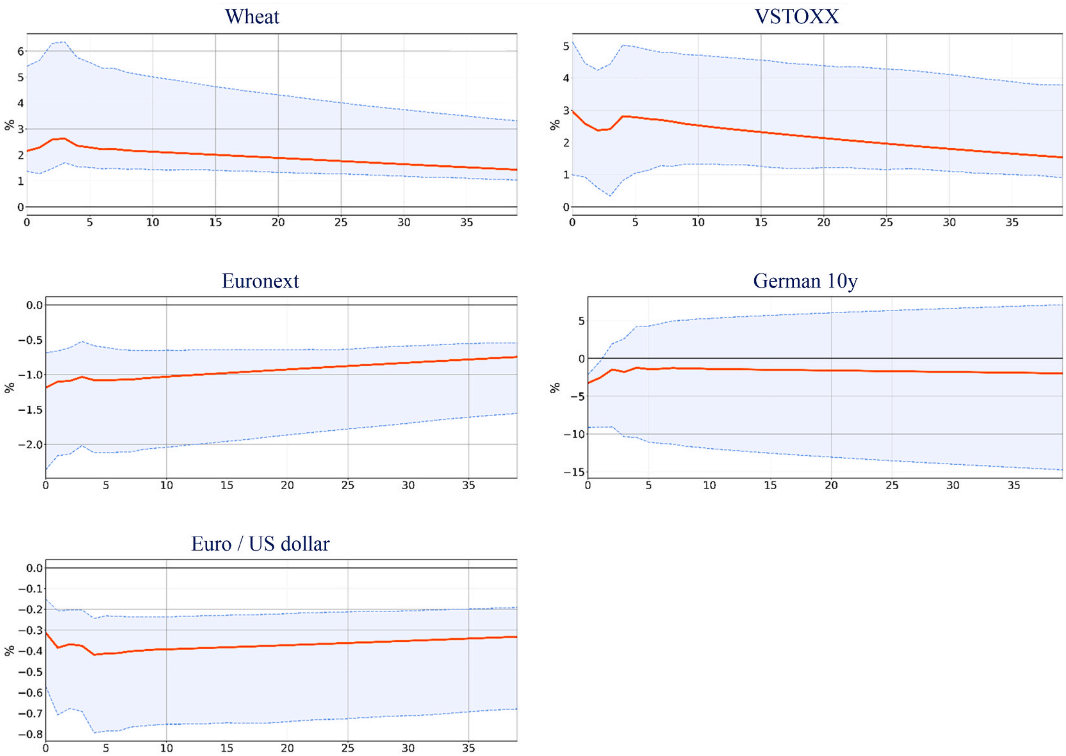

Fig. 8. The effect of heteroskedasticity based war shock on wheat future and financial variables. Results of "Attacks" events in Table 3.
Notes. The red line represents the impulse response function. The shaded area is the bootstrapped (n = 1000) confidence interval of 95%. The x-axis is expressed in days.

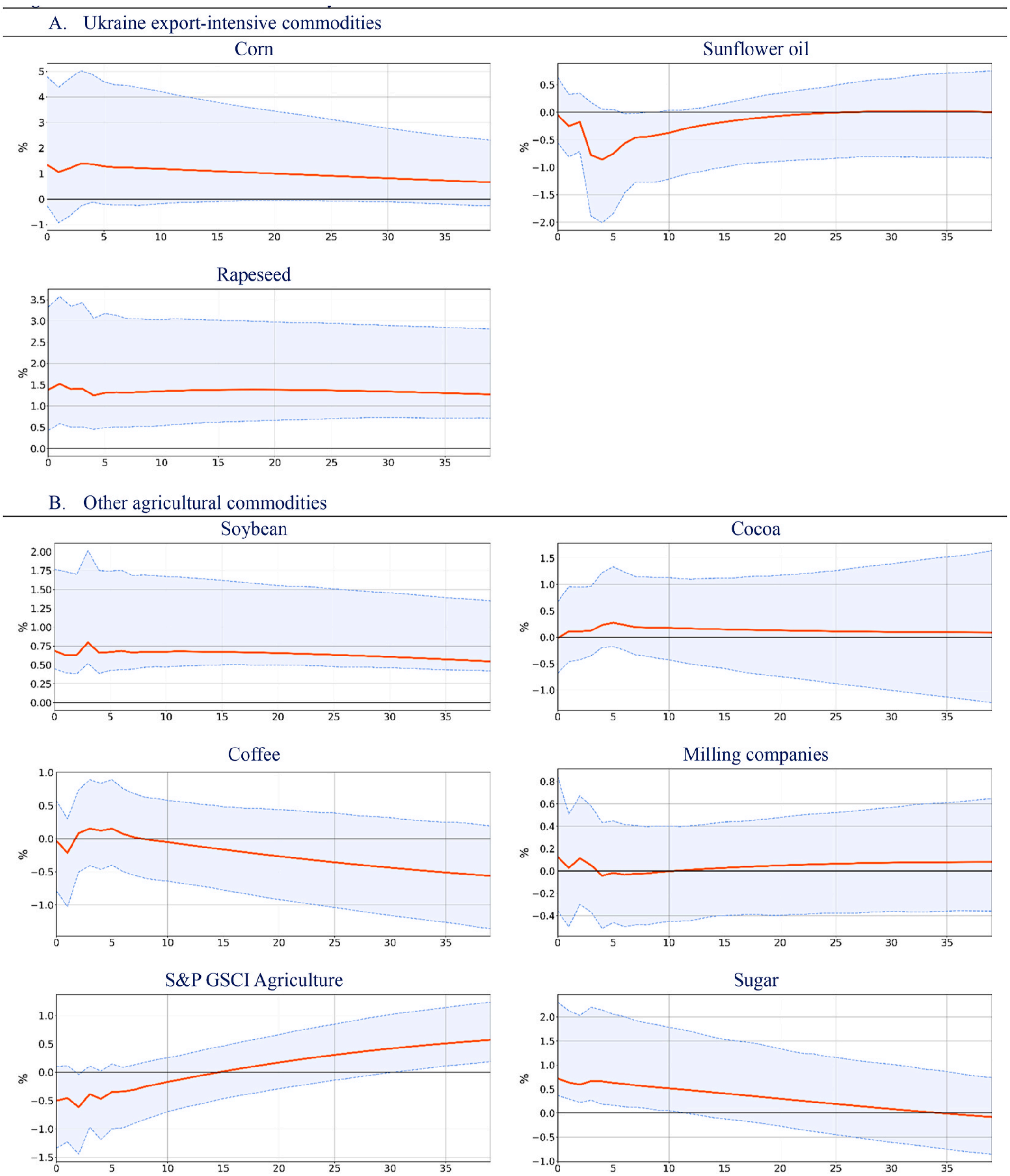

Fig. 9. The effect of heteroskedasticity based war shock on commodities. Results of “Attacks” events in Table 3.
Notes. The red line represents the impulse response function. The shaded area represents the bootstrapped (n = 1000) confidence interval of 95%. The x-axis is expressed in days. All variables in this table are run in a model similar to that of Fig. 1 but replacing the wheat series and maintaining the other four financial variables.

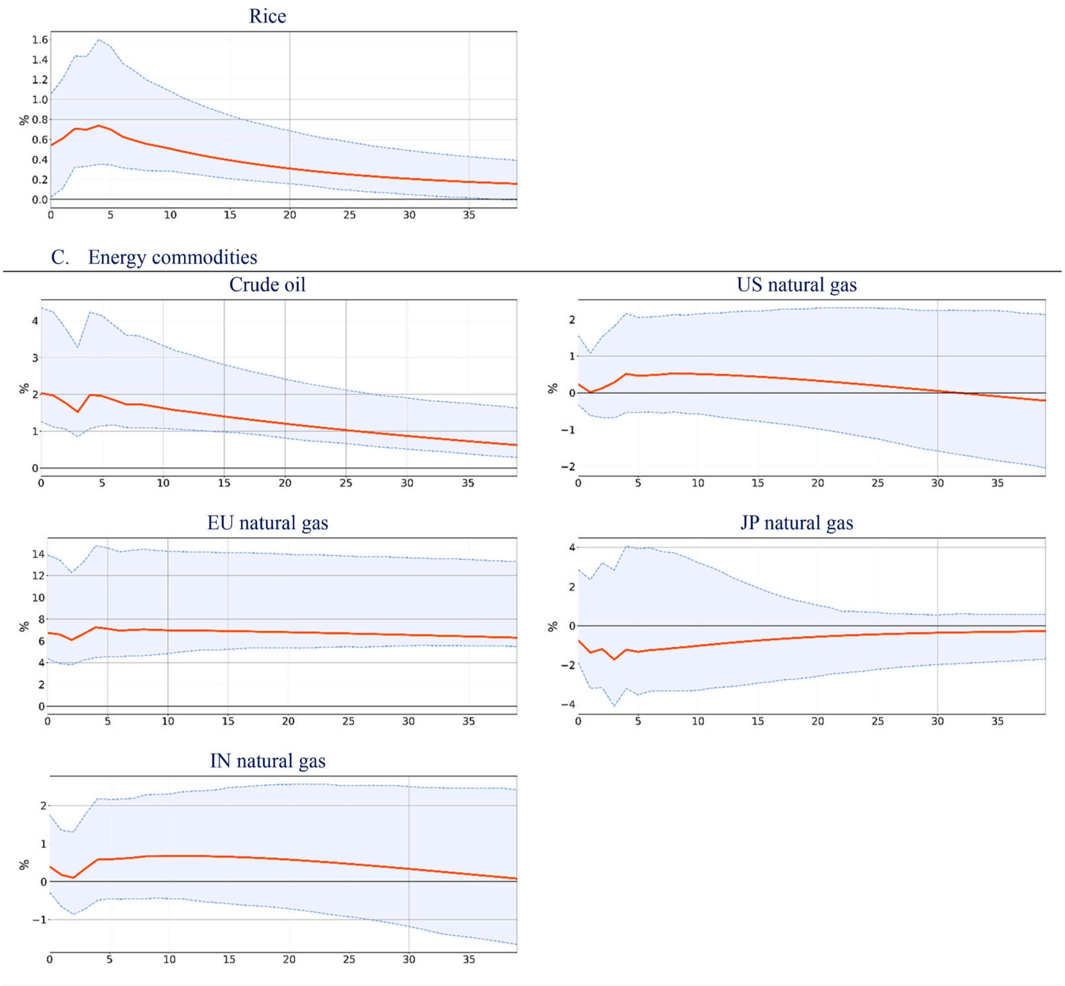

Fig. 9. (*continued*).

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