

From Signals to Outcomes: Evidence from Slovakia¹

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Abstract

This paper examines how selected policy announcements and realized supply shocks affected Slovak electricity prices between 2015 and 2025. Using an event study framework, it shows that announcements produced only modest and short-lived price responses, while realized disruptions, especially gas supply interruptions, led to much stronger and more persistent increases. The results further indicate that Slovak electricity prices are closely linked to movements in natural gas, carbon allowance, and major regional markets. The study provides new evidence that even a relatively small and predominantly nuclear based market such as Slovakia remains highly exposed to external shocks through European market integration.

Keywords: *electricity prices, event study, energy policy, carbon costs, natural gas prices, market integration*

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Introduction

Electricity prices in Europe have exhibited increasing volatility over the past decade, reflecting shifts in fuel costs, the integration of renewable energy sources, regulatory interventions, and supply disruptions (Pavlík et al., 2025; Cevik and

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Zhao, 2025). The 2021 – 2022 energy crisis, driven by tight gas supply and rising carbon costs, clearly demonstrated this vulnerability: wholesale electricity prices in Central Europe surged more than fourfold, and price volatility intensified further following the outbreak of the war in Ukraine (CSIS, 2022). For Slovakia, the nuclear-based generation mix might suggest relative price stability. However, the evidenced price development in Central European countries including Slovakia underscored the country's degree of exposure to external dynamics via integrated wholesale markets (Janda, 2018).

Carbon allowance prices have been shown to pass through into wholesale electricity costs (Caporin et al., 2021). The EU Emissions Trading System is therefore an important determinant of electricity price formation in Europe. Furthermore, the joint effects of renewable expansion and rising carbon prices explain much of the increased volatility observed in European markets after 2015 (Pavlík et al., 2025). Cross-border integration further amplifies this dependence, for example, more than 70% of price variance across European countries can be traced to spillovers from external markets (Cevik and Zhao, 2025). Notably, crises alter the strength of these linkages: while the COVID-19 pandemic reduced return spillovers, the war in Ukraine intensified them, leading to stronger and more synchronized price spikes (Do et al., 2023).

This paper contributes to the literature on electricity price responses to policy and supply shocks in three ways. First, using evidence from the Slovak market, it shows that electricity price formation is partly anticipatory, as announcements related to supply conditions and energy policy affect market expectations before the underlying disruption occurs. Second, it finds that realized shocks, particularly gas supply interruptions, produce stronger and more persistent price effects than announcements, which highlights the importance of using longer event windows when analyzing electricity markets. Third, the paper provides evidence that even a relatively small and predominantly nuclear based market such as Slovakia remains strongly exposed to external influences transmitted through integrated European electricity markets.

Based on the existing literature and the characteristics of integrated electricity markets, the empirical analysis is guided by three hypotheses. First, policy announcements are expected to be associated with weaker short term electricity price responses than realized supply disruptions. Second, gas supply disruptions are expected to produce stronger cumulative abnormal returns than policy related events. Third, longer event windows are expected to capture more persistent abnormal price responses than very short windows, reflecting the gradual adjustment of electricity markets to new information.

The paper is structured as follows. Section 1 reviews the related literature. Section 2 describes the data and methodology. Section 3 presents empirical results and provides robustness checks. The last section concludes.

1. Literature Review

The literature on energy markets has shifted toward analyzing the effects of external events and policy interventions as key drivers of price dynamics in Europe. Initially, earlier research focused primarily on long-term fundamentals, including fuel costs, carbon pricing, and infrastructure integration (Janda, 2018; Mosquera-López et al., 2017; Sitarz et al., 2024). However, more recent work highlights event-based analyses that distinguish between announcement effects and realized effects (Goodell et al. 2023; Liu and Lee, 2025). This distinction has become particularly relevant as electricity markets, regardless of their national generation mix, are deeply integrated into European wholesale trading and thus exposed to external developments.

Recent studies show that energy markets react immediately to political announcements related to supply security. Goodell et al. (2023) find that 24 Nord Stream-related announcements between 2013 and 2022 significantly moved European gas futures, with stronger effects during periods of heightened uncertainty such as the COVID-19 pandemic and the Russia-Ukraine war. This highlights that announcements can shift markets well before any actual disruption occurs. A similar dynamic is evident in carbon markets. Sitarz et al. (2024) demonstrate that the sharp rise in EU ETS prices after 2017 was driven not only by reforms but also by credible policy signals, such as the “Fit for 55” package, which shifted market behavior from short-term to long-term oriented. Here, the announcement effect is closely tied to policy credibility.

Realized events tend to cause stronger and more lasting price effects. For example, the Russia-Ukraine war in 2022 drove euro area electricity prices to record highs, with gas prices increasing by 180% in just weeks (ECB, 2022). Liu and Lee (2025) estimate an average 9% rise in OECD energy prices, with the largest impact in Southern Europe. Such evidence confirms that wars and supply cuts have more profound effects than mere announcements. Furthermore, natural gas price shocks have a significant impact on electricity, even in markets with limited gas generation. Zhu et al. (2024) demonstrate significant pass-through in the Nordics after 2022, indicating that integrated markets effectively spread supply disruptions. Energy variables, particularly heating needs and gas prices, significantly increase living costs across European cities (Ingoglia et al., 2024). These findings highlight how

energy shocks extend beyond wholesale markets, affecting broader inflation dynamics and urban cost of living disparities.

Carbon pricing is another key driver. Bai and Okullo (2023) demonstrate that ETS costs are fully or more than fully passed through to electricity prices in several countries. This indicates that carbon prices, shaped by both fundamentals and policy, directly increase power costs and reinforce the electricity link. Market integration further spreads such effects across borders. Cevik and Zhao (2025) find that over 70% of price variance in 24 European countries is attributed to cross-border spillovers. Kłopecka and Bonar (2025) demonstrate that convergence is limited and influenced more by national energy mixes than by interconnections.

The literature also documents how governments respond to realized energy price shocks with direct interventions. Enerdata (2024) reports that Slovakia extended its household electricity price cap at EUR 61/MWh until 2025 in order to protect consumers from elevated market prices. While announcements may briefly unsettle markets, actual supply disruptions or escalations often compel governments to intervene, with long-term fiscal and market implications. Beyond direct policy interventions, financial structures also play a crucial role in shaping energy outcomes. Horký and Fidrmuc (2024) demonstrate that while banks tend to support carbon-intensive industries, well-developed capital markets promote the adoption of renewable energy, underscoring the systemic channels through which financial development influences the energy transition.

2. Data and Methods

The empirical analysis uses a daily dataset covering the period from January 1, 2015, to January 1, 2025. The dataset includes wholesale day ahead electricity prices for the Slovak bidding zone, together with a set of domestic and external variables that capture the main determinants of electricity price formation. Specifically, it contains Slovak electricity demand and supply obtained from OKTE.sk, the national market operator, as well as natural gas, coal, and oil prices, EU ETS allowance prices, average daily temperature in the European Union, and day ahead electricity prices in selected major regional markets collected from Montel, Investing.com, and Power Statistics. Electricity prices are measured in EUR/MWh and are reported as closing values from day ahead market sessions.

The selection of variables follows the literature on electricity price formation, which identifies fuel costs, carbon prices, demand conditions, and cross border integration as key determinants of wholesale electricity prices (Bunn and Gianfreda, 2010; Weron, 2014). Together, these variables capture both cost side and demand side pressures and provide an appropriate basis for analyzing the effects of major

external events on Slovak electricity prices. The ten-year sample was chosen to capture several major episodes of stress in European energy markets, including the Green Deal announcement in 2019, the Russia Ukraine war in 2022, and the Nord Stream 1 gas supply disruptions in 2022.

Prior to estimation, the time series properties of the variables were examined using augmented Dickey Fuller tests. The results indicated mixed stationarity properties across the variables in levels, while all first differences were stationary. For consistency across the empirical specification, all variables were transformed into first differences before estimation. This transformation was applied to mitigate the risk of spurious regression and is consistent with the literature on electricity price modelling, where persistence and seasonality are well documented (Weron, 2014).

Table A1 in the Appendix reports descriptive statistics for the first differenced series used in the empirical analysis. The reported values show substantial variation across variables, which is consistent with the volatile nature of electricity and energy related markets. Some variables exhibit pronounced non normality. Coal prices display very high kurtosis, which points to extreme observations, while EU temperature shows slight negative skewness. These distributional features are considered in empirical design by using robust standard errors in the regression analysis.

Table A2 in the Appendix reports the correlation matrix and VIF statistics for the first differenced series used in the empirical analysis. The strongest correlations with Slovak electricity prices are observed for the Czech, German, and French markets, which points to close co-movement with major regional electricity markets. Correlations among the explanatory variables remain moderate overall, which suggests that multicollinearity is not severe. This conclusion is further supported by the VIF results. None of the variables exceed the threshold value of 5. The highest VIF values are reported for the German and Czech electricity prices, at 4.76 and 4.71 respectively, while the average VIF of 1.89 indicates an acceptable degree of collinearity among the regressors.

As an additional check of the benchmark regression specification, residual diagnostics were conducted to assess autocorrelation, heteroskedasticity, and normality. The results indicated serial correlation, heteroskedasticity, and departures from normality in the residuals, which is consistent with the volatile nature of electricity market data. For this reason, robust standard errors are reported throughout the regression analysis.

The event study methodology has been increasingly applied in energy economics to assess how markets respond to major disruptions (Du et al., 2022). It is particularly suitable for electricity markets, where both announcements and realized shocks can affect prices through changing expectations and actual supply conditions. In

this framework, abnormal returns capture the extent to which observed electricity price changes deviate from the changes predicted by the benchmark model around a given event. This makes it possible to isolate the market reaction associated with the event itself.

Abnormal returns are defined as:

$$AR_{i,t} = R_{i,t} - \hat{R}_{i,t} \quad (1)$$

where $R_{i,t}$ denotes the observed daily change in the electricity price and $\hat{R}_{i,t}$ is the expected daily change predicted by the benchmark model.

The expected daily price changes are estimated using a multivariate regression model based on the main determinants of electricity price formation identified in the literature. The selected regressors reflect domestic market conditions, input cost factors, and cross market influences that jointly shape Slovak wholesale electricity prices. In this way, the benchmark model is designed to capture the normal price dynamics that would be expected in the absence of the event.

To assess the relative importance of different groups of determinants, the benchmark model is estimated in progressively extended specifications. The initial specification includes domestic demand and supply only, while subsequent models gradually add temperature, carbon prices, fuel prices, and regional electricity prices.

The specification is as follows:

$$\hat{R}_{i,t} = \alpha + \beta_1 \Delta Demand_t^{SK} + \beta_2 \Delta Supply_t^{SK} + \beta_3 \Delta Temp_t + \beta_4 \Delta EUA_t + \beta_5 \Delta Oil_t + \beta_6 \Delta Coal_t + \beta_7 \Delta Gas_t^{TTF} + \beta_8 R_t^{DE} + \beta_9 R_t^{FR} + \beta_{10} R_t^{NO} + \beta_{11} R_t^{CZ} \quad (2)$$

The explanatory variables include Slovak electricity demand and supply [MWh], average daily temperature in the European Union [°C], EU ETS allowance prices [EUR/tCO₂], international fuel prices represented by oil [EUR/bbl], coal [EUR/tonne], and natural gas [EUR/MWh], and electricity prices in major regional markets, namely Germany (DE), France (FR), Norway (NO), and the Czech Republic (CZ) [EUR/MWh]. Slovak demand and supply capture domestic market conditions, fuel and carbon prices reflect key input cost pressures, and foreign electricity prices account for cross market linkages within the integrated European power system. EU average temperature is included as a proxy for broader weather-related demand conditions across the European market, which can affect regional electricity price formation beyond purely domestic conditions (Bunn and Gianfreda, 2010; Mosquera-López et al., 2017). The Czech and German markets were included because of their close regional links with the Slovak electricity market. France and

Norway were included because they are major electricity exporters in Europe and therefore contribute to broader European electricity market dynamics. The selected markets thus capture both regional price linkages and wider European market conditions.

A potential limitation of the benchmark specification is that electricity prices in major regional markets may be jointly determined with Slovak electricity prices within the integrated European electricity market. This means that the estimated coefficients on foreign electricity prices should not be interpreted as strictly causal effects. Instead, these variables are included primarily to capture short-term co-movement and broader regional market conditions relevant for the construction of expected price changes in the event study framework. Their role in the benchmark model is therefore to approximate normal price dynamics rather than to identify structural transmission channels.

For each event, two dates are distinguished. The announcement date refers to the date when information about the forthcoming event became publicly available. The realization date refers to the date when the corresponding policy measure or physical disruption occurred. The time interval between these two dates therefore varies across the events considered in the analysis.

The parameters are estimated using ordinary least squares over an estimation window of 60 trading days prior to each event. This window was chosen to provide enough observations for parameter estimation while limiting the influence of more distant shocks that could distort the benchmark relationship. The event window is defined as ± 15 trading days around the event date. A wider event window is appropriate in electricity markets because price adjustment may begin before the event through changing expectations and may continue after the event as the shock is gradually incorporated into market prices. This approach is consistent with the literature emphasizing that electricity markets differ from standard financial markets in their adjustment dynamics and often exhibit anticipatory and multistage responses to new information (Weron, 2014; Goodell et al., 2023). To assess the sensitivity of the results to this choice, the analysis also considers narrower event windows of ± 10 , ± 5 , and ± 2 trading days in the robustness section.

To capture the overall impact of an event, daily abnormal returns are aggregated into cumulative abnormal returns denoted as CAR_i :

$$CAR_i(t_1, t_2) = \sum_{t=t_1}^{t_2} AR_{i,t} \quad (3)$$

For multiple events of the same type, cumulative average abnormal returns ($CAAR$) are computed as:

$$CAAR(t_1, t_2) = \frac{1}{N} \sum_{i=1}^N CAR_i(t_1, t_2) \quad (4)$$

where N is the number of events. CAARs allow for generalization of findings across events of a similar nature (Du et al., 2022; Mosquera-López et al., 2017).

Statistical significance of abnormal returns and cumulative abnormal returns was assessed using standard t tests. For each event, the estimated abnormal return and cumulative abnormal return were evaluated against their corresponding standard errors, and statistical significance was reported at the 1%, 5%, and 10% levels.

Most selected events were chosen to avoid substantial overlap of event windows. A partial overlap remains in the case of the Nord Stream 1 shutdown and the announcement of the EU price cap on Russian oil. The estimates for these two events should therefore be interpreted with caution, since some abnormal price movements may reflect the close timing of both developments.

3. Results

Slovakia represents a useful case for examining electricity price responses to external shocks because its domestic generation structure is largely based on nuclear power, while its wholesale electricity prices are shaped within the integrated European electricity market. Therefore, Slovak prices reflect not only domestic demand and supply conditions, but also broader developments in regional fuel, carbon, and electricity markets.

Figure 1 presents the development of wholesale electricity prices in Slovakia over the period 2015 to 2025. The figure includes major energy related events and allows a visual inspection of price movements around key market developments. Early events, such as the Grafenrheinfeld nuclear shutdown in 2015 and the temporary outage of French nuclear plants in 2016, are associated with only limited price responses, which may reflect the relative stability of European fuel markets at that time. By contrast, the COVID 19 crisis in 2020 coincides with a temporary decline in demand and electricity prices, suggesting that wholesale electricity markets were sensitive to broader macroeconomic disruptions.

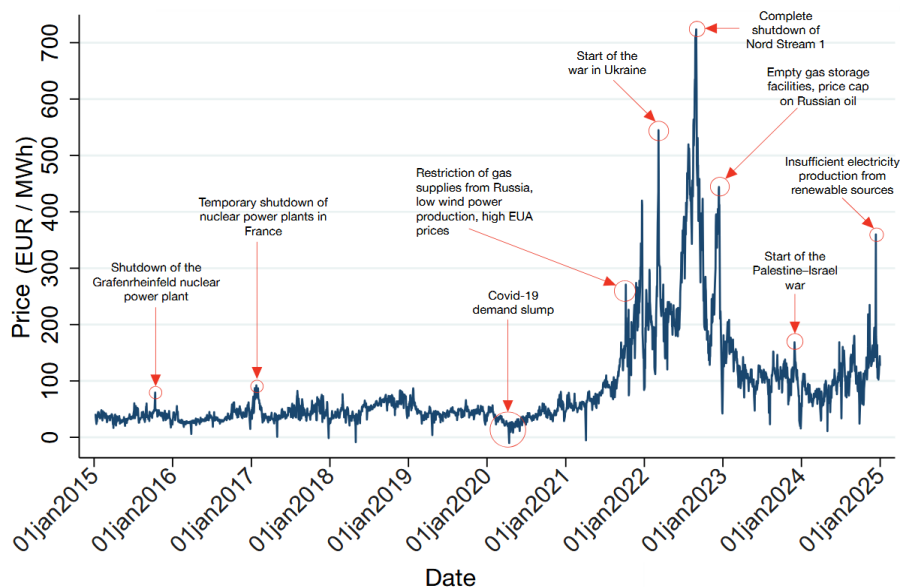
The most dramatic surge is observed around the Russia Ukraine war in 2022 and the complete shutdown of Nord Stream 1 in 2022, when wholesale electricity prices rose above EUR 600/MWh. These developments illustrate how strongly Slovak wholesale electricity prices reacted to major disruptions in European energy supply conditions, despite the important role of nuclear generation in the domestic production mix.

Subsequent events, including the EU price cap on Russian oil (2022) or renewable underproduction (2023 – 2024), also coincided with heightened volatility. However, their effects were less extreme compared to the initial gas supply shock, suggesting that markets had already internalized the structural shift toward higher and more uncertain energy costs.

Overall, the results suggest that Slovak electricity prices were influenced not only by domestic supply and demand conditions but also by broader developments in European energy markets. In particular, the largest price increases appear to coincide with realized disruptions, which are consistent with stronger market reactions once uncertainty turned into actual supply shocks.

Figure 1

Slovak Wholesale Electricity Prices, 2015 – 2025



Note: The figure displays the daily Slovak wholesale electricity price (in EUR/MWh) from January 2015 to January 2025. Red markers indicate selected geopolitical and policy-related events that significantly affected European energy markets, including nuclear plant shutdowns, the COVID-19 demand slump, the Russia-Ukraine war, and disruptions in natural gas supplies. Data source: electricity prices from OKTE, event visualization by the author(s).

Source: Author's calculations.

Table 1 reports the regression estimates from the benchmark model used to explain daily changes in Slovak electricity prices. The columns present progressively extended specifications. The initial model includes domestic electricity demand and supply, while the following specifications gradually add temperature conditions, carbon prices, fuel prices, and electricity prices in major regional markets. This modelling strategy makes it possible to assess how the estimated relationships

change as additional determinants of electricity price formation are included. The results indicate that Slovak electricity demand and supply are generally not statistically significant in explaining short term changes in Slovak electricity prices, whereas external market variables appear to play a more important role.

Among the market fundamentals, the coefficient on EU average temperature is negative and statistically significant in specifications (2), (3), and (4). This pattern is consistent with the view that increases in temperature may be associated with lower short-term increases in electricity prices, although the relationship between temperature and electricity market outcomes may be more complex and potentially nonlinear. In Model 5, however, the temperature coefficient becomes statistically insignificant once additional controls are included.

By contrast, changes in EU ETS allowance prices are positively and statistically significantly associated with short term changes in Slovak electricity prices across all model specifications. This result suggests that carbon cost movements were closely related to short term electricity price dynamics over the sample period. Similarly, the change in the natural gas price at the TTF hub has a positive and statistically significant coefficient in model (3), which points to the importance of gas market developments for short term movements in Slovak electricity prices.

In the extended models, electricity prices in major regional markets emerge as the strongest correlates of short-term changes in Slovak electricity prices. In particular, the coefficient on the Czech electricity price change is positive, close to one, and statistically significant at the 1% level. German and French electricity price changes are also statistically significant, although their coefficients are smaller. These results are consistent with strong short-term co-movement between the Slovak market and other major regional electricity markets.

One coefficient that requires cautious interpretation is the negative sign on the German electricity price variable in the full specification. Although Slovak and German electricity prices are positively correlated in pairwise terms, the multivariate regression captures the conditional relationship after controlling for the Czech market and other common determinants. A plausible explanation is that the German price variable partly reflects broader regional effects associated with periods of high renewable generation, while the Czech price variable captures the more immediate regional transmission relevant for Slovak price movements.

Overall, the regression results suggest that short term changes in Slovak electricity prices were more closely associated with developments in European energy markets, particularly changes in carbon and gas prices and electricity prices in major regional markets, than with domestic demand and supply conditions. By contrast, domestic demand and supply variables appear to play a more limited role in explaining short-term price movements.

Table 1

OLS Estimates for Daily Changes in the Slovak Day Ahead Electricity Price

	(1)	(2)	(3)	(4)	(5)
Electricity Demand in Slovakia [MWh]	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)
Electricity Supply in Slovakia [MWh]	0.000 (0.001)	0.000 (0.000)	0.000 (0.001)	0.000 (0.001)	0.001* (0.000)
Average Temperature in the EU [°C]		-0.299* (0.144)	-0.325* (0.143)	-0.326* (0.140)	0.014 (0.83)
EUA Carbon Allowance Price [EUR/tCO ₂]			1.130*** (0.179)	1.136*** (0.175)	0.419*** (0.103)
Brent Crude Oil Price [EUR/bbl]				0.431 (0.238)	0.480*** (0.138)
Coal Price [EUR/tonne]				0.029 (0.067)	0.001 (0.039)
Natural Gas Price (TTF hub) [EUR/MWh]				0.843*** (0.091)	0.075 (0.054)
Electricity Price - Germany [EUR/MWh]					-0.202*** (0.019)
Electricity Price - Norway [EUR/MWh]					0.052* (0.022)
Electricity Price - France [EUR/MWh]					0.037** (0.014)
Electricity Price - Czech Republic [EUR/MWh]					0.980*** (0.024)
Constant	0.035 (0.379)	0.036 (0.379)	0.007 (0.376)	-0.007 (0.368)	-0.0110 (0.214)
No of Observations	2580	2580	2580	2580	2580
Adjusted R ²	0.002	0.004	0.019	0.058	0.683

Note: The table reports OLS estimates for daily changes in the Slovak day ahead electricity price. The model includes domestic demand and supply variables, EU average temperature, EU ETS allowance prices, fuel prices, and electricity prices in major regional markets as explanatory variables. The dependent variable is the daily change in the Slovak day ahead electricity price. Coefficients are reported with robust standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Source: Author's calculations.

Table 2 reports cumulative abnormal returns for selected events, distinguishing between the announcement of each event and its subsequent realization phase. For each event, expected daily price changes are estimated using the full benchmark specification reported in Model 5 over a 60-trading day estimation window preceding the relevant event date. The estimated coefficients are then used to calculate abnormal returns and cumulative abnormal returns over the ± 15 trading day event window. The results suggest that announcement effects were generally weaker, while realized disruptions were associated with larger and more persistent price adjustments. These findings are consistent with the first hypothesis that realized disruptions are associated with stronger market responses than announcements.

The temporary outage of French nuclear plants in late 2016 provides an example of how news about supply constraints may be reflected in short term changes in Slovak electricity prices. At the announcement stage, the market reaction was already statistically significant, which is consistent with expectations of tighter

nuclear availability in the broader European market. Once the outages were realized, the estimated effect became even stronger. This pattern suggests that developments affecting French nuclear generation were associated with short term price responses in the Slovak market.

A similar pattern is observed for the German nuclear shutdown. When the closure of Gundremmingen B was announced in 2017, Slovak electricity prices showed a moderate positive abnormal response, which is consistent with expectations of lower future generation capacity. The realization phase was associated with a stronger market reaction, suggesting that the event had a more pronounced effect once the capacity reduction occurred. These results indicate that changes in nuclear availability in major European markets may be associated with short term price movements in the Slovak market.

Policy related events appear to follow a different pattern. The Green Deal announcement in 2019 was associated with only a modest decline in Slovak electricity prices, which is consistent with the interpretation that the policy was initially perceived as a longer-term signal rather than an immediate market shock. When the package began to be implemented in mid-2021, the estimated effect became more pronounced. This pattern suggests that policy announcements may influence market expectations gradually, while the realization of policy measures may be associated with stronger short term price responses.

The Russian gas supply shocks stand out in magnitude. The announcement of the Nord Stream 1 shutdown in July 2022 was associated with a particularly strong abnormal response in Slovak electricity prices, which is consistent with heightened concerns about European gas supply conditions. Although Slovakia relies heavily on nuclear generation, the result suggests that domestic electricity prices remained highly sensitive to disruptions in broader European energy markets. By the time the shutdown was realized in August 2022, much of the price adjustment had already taken place, resulting in a smaller but still statistically significant reaction. This pattern is consistent with the view that the announcement phase carried substantial market relevance, leaving less room for further adjustment once the disruption was fully realized. The particularly strong response to the Nord Stream 1 disruption is also in line with the second hypothesis that gas supply shocks are associated with stronger abnormal price responses than policy related events.

Finally, the EU price cap on Russian oil points to more limited announcement effects in cases where the market relevance of the measure may have been weaker. The initial announcement was associated with a negative reaction, but the realization phase did not produce a statistically significant effect. One possible explanation is that oil plays a less direct role in European electricity generation than other energy inputs, which may have reduced the immediate relevance of the measure

for wholesale electricity price dynamics. Another possibility is that market participants attached limited credibility or effectiveness to the policy at the time of its implementation.

Table 2

Market Reactions to Selected Announcements and Realized Events

Estimation window [60]

Event window [15,15]

Event	Date of Announcement	Announcement CAR	Date of the realization	Event CAR
Temporary outage of French nuclear plants	30.12.2016	−13,153*** (3,094)	9.1.2017	−26,954*** (4,866)
Shutdown of a nuclear power plant in Germany – Gundremmingen B	13.12.2017	2,671 (1,377)	2.1.2018	−4,822*** (1,078)
Green Deal policy	11.12.2019	−5,244* (2,271)	21.6.2021	−6,741*** (1,188)
Shutdown of Nord Stream 1	10.7.2022	−88,431*** (12,406)	31.8.2022	−24,264*** (6,334)
EU price cap on Russian oil	2.9.2022	−14,824 (7,555)	5.12.2022	−6,664 (8,700)

Note: The table reports cumulative abnormal returns for selected event announcements and their subsequent realization phases in the Slovak day ahead electricity market. Expected daily price changes are estimated separately for each event using the full benchmark specification reported in Model 5 and a 60-trading day estimation window prior to the relevant event date. Abnormal returns are then aggregated over the ± 15 trading day event window. Announcement CARs capture market reactions following the announcement of the event, while event CARs capture reactions around its realization. CAR estimates are reported with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Source: Author's calculations.

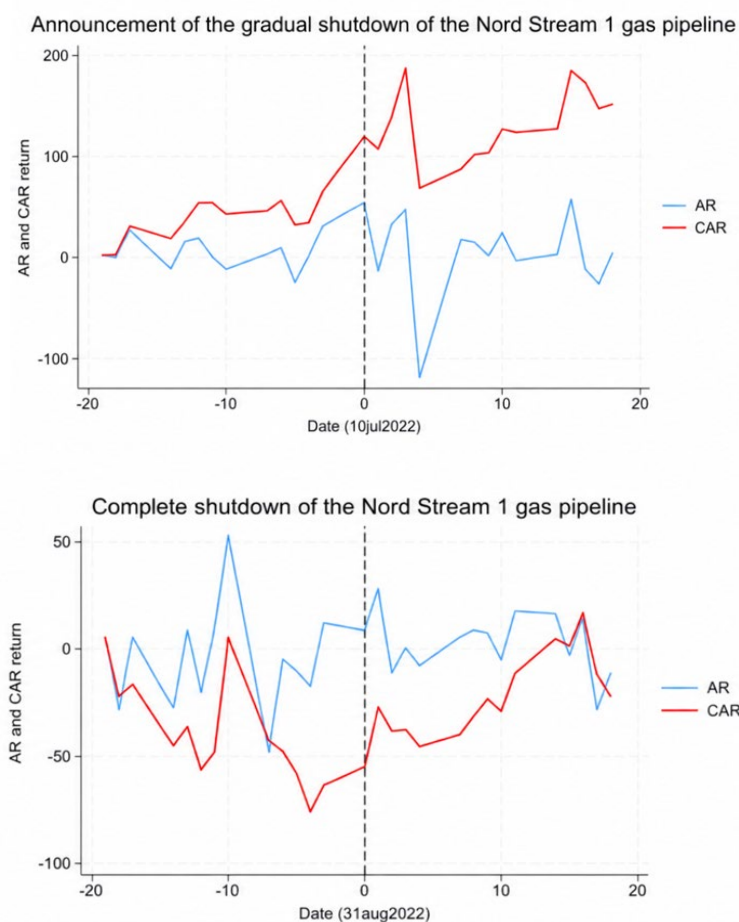
Figure 2 displays abnormal returns shown by the blue line and the cumulative abnormal return curve shown by the red line around the announcement of the gradual shutdown of Nord Stream 1 in the left panel and its complete shutdown in the right panel. Abnormal returns capture the deviation of observed daily electricity price changes from the changes predicted by the benchmark model. The cumulative abnormal return curve aggregates these deviations day by day over the event window and illustrates how the total abnormal effect evolves over time.

In the case of the announcement on July 10, 2022, the AR series shows mixed short-term movements around the event date. AR captures the abnormal price change on a given day, that is, the deviation of the observed daily price change from the benchmark prediction. By contrast, CAR aggregates these daily abnormal changes over the event window and therefore reflects the cumulative abnormal effect associated with the event. For this reason, a temporary decline in AR does not prevent CAR from rising if the cumulative abnormal response remains positive overall. In this case, the CAR curve increases over the post event period, indicating that the cumulative abnormal response became more positive as the event window unfolded.

For the complete shutdown on August 31, 2022, the dynamics differ. Here, AR fluctuates around zero with occasional spikes, indicating short term uncertainty and mixed daily reactions. By contrast, the CAR curve turns negative in the days immediately following the shutdown. This pattern consists of smaller additional adjustment at the realization stage than at the earlier announcement stage. The subsequent rebound of CAR after day +10 suggests that the cumulative effect became less negative as the market adjusted over time. For completeness, AR and CAR plots for the other analyzed events are provided in the Appendix.

Figure 2

Abnormal and Cumulative Abnormal Returns around Nord Stream 1 Shutdown Events



Note: The figure displays abnormal returns (AR, blue line) and cumulative abnormal returns (CAR, red line) for Slovak wholesale electricity prices around two key events related to the Nord Stream 1 pipeline. The left panel displays the announcement of the gradual shutdown on July 10, 2022, while the right panel depicts the complete shutdown on August 31, 2022.

Source: Author's calculations.

3.1. Robustness Analysis

To ensure the robustness of the results, the analysis is extended by varying the length of the event window. While the baseline specification employed an event window of ± 15 trading days, alternative specifications with event windows of ± 10 , ± 5 , and ± 2 trading days are also considered. This procedure follows recommendations from the event study literature, where robustness checks are necessary to confirm that the identified effects are not artifacts of a specific modeling choice (Sorokina et al., 2013). The rationale for using a longer event window in the baseline is that energy markets differ from financial markets in their adjustment dynamics. Anticipatory behavior is common, as traders and utilities react to information signals before the actual event, while the materialization of shocks often unfolds gradually (Weron, 2014; Goodell et al., 2023). Thus, capturing the full adjustment requires an extended time frame.

Table 3 presents the results for the ± 10 trading day event window. The estimates remain broadly consistent with the baseline specification. Nuclear related events continue to show strong and statistically significant effects on cumulative abnormal returns, particularly in the case of the temporary outage of French nuclear plants, which generated substantial announcement and realization effects. The shutdown of Nord Stream 1 in 2022 also remains highly significant, although the magnitude of cumulative abnormal returns is somewhat smaller than in the ± 15 specification. Policy related events such as the Green Deal continue to exhibit measurable but less pronounced effects, which is consistent with the view that market participants treated them as more gradual and longer-term signals rather than immediate disruptions.

Table 4 reports the results for the ± 5 trading day event window. In this specification, the estimated effects become substantially weaker. The remaining nuclear related events show smaller cumulative abnormal responses than in the longer event windows, while statistical significance is substantially reduced. The Nord Stream 1 shutdown also produces a smaller CAR relative to the broader specifications. Policy related announcements largely lose statistical significance within this shorter horizon. These results suggest that a narrow event window may not fully capture the adjustment process in electricity markets. Price responses in energy markets may unfold gradually, with part of the reaction occurring before the event and part after its realization. As a result, restricting the event window to only a few trading days may understate the full market response to major shocks.

The weaker statistical significance observed in the shorter event windows suggests that the market response was not concentrated in only a few trading days around the event date. Instead, the adjustment appears to have been distributed over a broader period, which is consistent with the gradual incorporation of new information in electricity markets. Shorter windows may therefore capture a higher

proportion of short-term noise relative to the event related signal. At the same time, this pattern does not necessarily imply model misspecification. Rather, it indicates that narrow event windows may be less suitable for detecting the full response when electricity prices adjust in a multistage manner.

Table 3

Event Study Results with Event Window [10,10] and Estimation Window [60]

Estimation window [60]

Event window [10,10]

Event	Date of Announcement	Announcement CAR	Date of the realization	Event CAR
Temporary outage of French nuclear plants	30.12.2016	-9,848* (3,370)	9.1.2017	-18,195*** (4,959)
Shutdown of a nuclear power plant in Germany – Gundremmingen B	13.12.2017	1,568 (1,031)	2.1.2018	-1,970 (0,970)
Green Deal policy	11.12.2019	8,238* (2,311)	21.6.2021	6,174*** (1,598)
Shutdown of Nord Stream 1	10.7.2022	-9,118 (24,479)	31.8.2022	-26,929*** (8,019)
EU price cap on Russian oil	2.9.2022	-13,939 (8,443)	5.12.2022	-8,327 (9,935)

Note: The table reports cumulative abnormal returns for selected event announcements and their subsequent realization phases in the Slovak day ahead electricity market. Results are estimated using the full benchmark specification reported in Model 5, an estimation window of 60 trading days, and an event window of ± 10 trading days. Announcement CARs capture market reactions following the release of information, while CARs reflect market reactions around the realization of the event. CAR estimates are reported with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Source: Author's calculations.

Table 4

Event Study Results with Event Window [5,5] and Estimation Window [60]

Estimation window [60]

Event window [5,5]

Event	Date of Announcement	Announcement CAR	Date of the realization	Event CAR
Temporary outage of French nuclear plants	30.12.2016	-4,769 (3,321)	9.1.2017	-8,297 (7,606)
Shutdown of a nuclear power plant in Germany – Gundremmingen B	13.12.2017	1,230 (0,895)	2.1.2018	-1,464 (0,991)
Green Deal policy	11.12.2019	4,632 (3,034)	21.6.2021	-2,253 (1,309)
Shutdown of Nord Stream 1	10.7.2022	45,252 (34,359)	31.8.2022	-6,994 (9,809)
EU price cap on Russian oil	2.9.2022	-9,705 (9,169)	5.12.2022	12,168 (10,971)

Note: The table reports cumulative abnormal returns for selected event announcements and their subsequent realization phases in the Slovak day ahead electricity market. Results are estimated using the full benchmark specification reported in Model 5, an estimation window of 60 trading days, and an event window of ± 5 trading days. Announcement CARs capture market reactions following the release of information, while CARs reflect market reactions around the realization of the event. CAR estimates are reported with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Source: Author's calculations.

Table 5 presents the most restrictive specification, based on an event window of ± 2 trading days. Under this setting, most events lose statistical significance, and the estimated cumulative abnormal returns become more volatile. Although some physical disruptions, such as nuclear outages and the shutdown of Nord Stream 1, still show directional effects, the estimates are less stable and provide a less complete picture of market adjustment than the longer event windows. These results suggest that very short event windows may be less appropriate for electricity markets, where price adjustment can extend beyond only a few trading days.

Table 5

Event Study Results with Event Window [2,2] and Estimation Window [60]

Estimation window [60]

Event window [2,2]

Event	Date of Announcement	Announcement CAR	Date of the realization	Event CAR
Temporary outage of French nuclear plants	30.12.2016	-5,018 (4,354)	9.1.2017	-0,853 (6,742)
Shutdown of a nuclear power plant in Germany – Gundremmingen B	13.12.2017	0,506 (0,574)	2.1.2018	0,499 (2,342)
Green Deal policy	11.12.2019	2,303 (3,502)	21.6.2021	-2,253 (1,309)
Shutdown of Nord Stream 1	10.7.2022	-1,382 (37,471)	31.8.2022	4,264 (9,354)
EU price cap on Russian oil	2.9.2022	6,761 (12,746)	5.12.2022	17,431 (16,238)

Note: The table reports cumulative abnormal returns for selected event announcements and their subsequent realization phases in the Slovak day ahead electricity market. Results are estimated using the full benchmark specification reported in Model 5, an estimation window of 60 trading days, and an event window of ± 2 trading days. Announcement CARs capture market reactions following the release of information, while CARs reflect market reactions around the realization of the event. CAR estimates are reported with standard errors in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Source: Author's calculations.

Taken together, the robustness analysis suggests that the main findings are broadly stable across alternative event window specifications. Physical supply shocks, nuclear outages, and gas pipeline disruptions tend to generate the largest and most persistent cumulative abnormal returns, although their magnitude varies with the chosen event window. Policy announcements, by contrast, generally produce weaker and less robust effects, which are consistent with their more gradual implementation and lower immediate market relevance. The comparison across event windows further indicates that longer horizons may be better suited to capturing the adjustment process in electricity markets. This interpretation is consistent with earlier research emphasizing the anticipatory and multistage nature of price formation under uncertainty (Weron, 2014; Goodell et al., 2023). This

pattern is consistent with the third hypothesis that longer event windows are better able to capture the gradual adjustment of electricity prices to major events.

Overall, the robustness checks provide additional insight into the timing of electricity price responses to major events. The results suggest that electricity markets may require a broader event window to capture the full evolution of price adjustment, especially when shocks unfold gradually or when part of the response occurs before the event is fully realized.

Conclusion

This paper examined the announcement and realized effects of major geopolitical and policy events on Slovak electricity prices between 2015 and 2025. The analysis contributes to the literature on electricity price reactions to external events by providing systematic evidence from Slovakia. Using an event study approach, the study suggests that realized disruptions were generally associated with stronger price responses than announcements.

The results demonstrate that announcements primarily shape expectations but rarely generate lasting price adjustments. Events such as the European Green Deal or sanctions on Russian energy exports triggered only modest and short-term responses. Markets appear to weigh credibility and relevance when processing announcements. Policy signals influence prices only if backed by strong institutional commitment, while oil-related announcements have little effect given the limited role of oil in European power generation.

The broader market development around the Nord Stream 1 disruptions was associated with a sharp increase in European electricity prices. This reflected growing concerns about gas scarcity and the important role of gas in marginal electricity price formation. Slovakia was affected despite its predominantly nuclear generation mix because it is part of the integrated European electricity market, where domestic electricity prices remain closely linked to broader regional market conditions.

However, the event study provides a more nuanced picture. The announcement phase was associated with a strong positive cumulative abnormal response, while the complete shutdown was followed by a negative and statistically significant CAR. This suggests that a substantial part of the upward market adjustment had already occurred before the physical shutdown was fully realized. The negative CAR at the realization stage should therefore not be interpreted as evidence that the shutdown has reduced electricity prices. Rather, it indicates that prices had already incorporated much of the expected disruption before the event date.

The robustness analysis confirms that short event windows underestimate the true impact of shocks, while longer windows capture the gradual adjustment typical of energy markets. Across all specifications, physical supply disruptions remained the most influential and consistent drivers of price volatility, whereas policy-related events showed weaker effects.

Our findings have several implications for policymakers and market participants. First, the results suggest that domestic electricity prices in Slovakia remained highly exposed to developments in European fuel and carbon markets. This is particularly visible in the case of natural gas. The regression results indicate that changes in gas prices were significantly associated with short term changes in Slovak electricity prices, which is consistent with the strong rise in European gas prices during the energy crisis. Although gas prices corrected substantially during 2023, electricity prices did not immediately return to their pre-crisis levels, which suggests that the adjustment of wholesale electricity prices reflected a broader combination of market pressures rather than gas prices alone. Second, the results also point to the importance of carbon costs. The positive and statistically significant coefficient on EU ETS allowance prices indicates that carbon market developments were closely related to short term electricity price movements. In this context, the tightening of European climate policy and the stronger market relevance of emission allowances after 2021 may have reinforced cost pressures in electricity markets. Third, these findings imply that energy intensive firms should manage not only direct electricity price risk, but also indirect exposure to gas and carbon market developments. For policymakers, the results suggest that domestic energy strategies can mitigate some vulnerabilities, but they cannot fully shield Slovakia from external shocks transmitted through the integrated European electricity market.

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Appendix

Table A1

Univariate Descriptive Statistics for the First Difference Series

Variable	Mean	Standard Deviation	Min	25%	Median	75%	Max	Skewness	Kurtosis
(1) Electricity Price – SK	0,03	19,28	–202,29	–5,22	0,01	5,20	111,22	–0,93	21,66
(2) Electricity Demand in SK	6,82	4776,17	–22000,00	–1558,80	15,00	1534,05	27098,00	0,04	8,76
(3) Electricity Supply in SK	6,26	4250,40	–21000,00	–2027,55	–78,05	1937,95	24749,00	0,21	6,74
(4) Average Temp. in the EU	0,00	2,63	–14,10	–1,50	0,10	1,60	11,10	–0,18	4,58
(5) EUA Price	0,03	2,11	–58,77	–0,31	0,01	0,37	59,00	–0,18	473,47
(6) Natural Gas Price (TTF)	0,01	4,26	–66,59	–0,35	0,00	0,37	45,42	–1,65	67,36
(7) Brent Crude Oil Price	0,01	1,59	–16,84	–0,72	0,09	0,84	8,80	–0,96	13,12
(8) Coal Price	0,02	5,86	–96,65	–0,40	0,00	0,50	121,50	0,94	156,13
(9) Electricity Price – DEU	0,01	24,55	–250,87	–5,47	–0,09	5,49	175,81	0,76	18,77
(10) Electricity Price – NO	0,00	12,44	–141,50	–1,70	0,00	5,68	160,65	0,17	41,27
(11) Electricity Price – FRA	0,02	19,70	–240,88	–4,31	–0,05	4,51	227,84	–0,83	32,82
(12) Electricity Price – CZ	0,03	19,44	–206,52	–5,02	–0,13	4,93	111,10	–0,87	21,51

Source: Author's calculations.

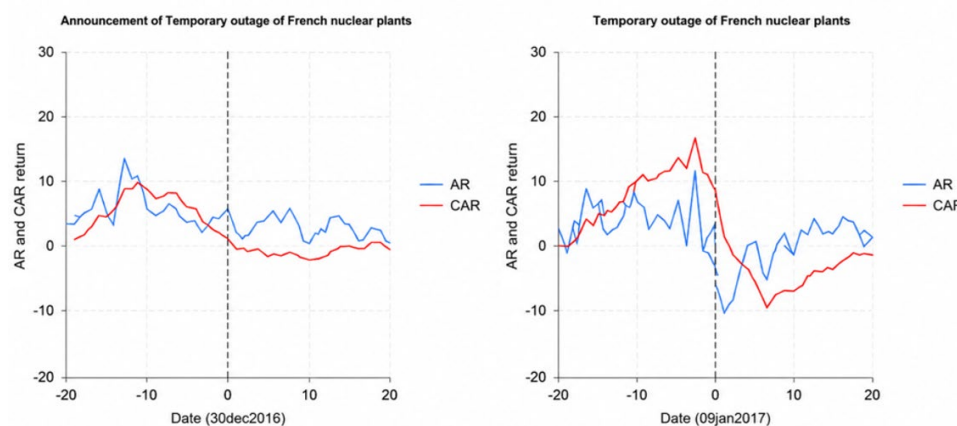
Table A2

Cross Correlation Matrix and Variance Inflation Factor Statistics for the First Difference in Series

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	VIF
(1) Electricity Price – SK	1.000												NaN
(2) Electricity Demand in SK	–0.047	1.000											1,330
(3) Electricity Supply in SK	0.038	–0.493	1.000										1,330
(4) Average Temp. in the EU	–0.041	–0.010	–0.010	1.000									1,030
(5) EUA Price	0.125	–0.057	0.037	0.029	1.000								1,020
(6) Natural Gas Price (TTF)	0.194	–0.009	0.017	0.000	–0.001	1.000							1,160
(7) Brent Crude Oil Price	0.061	–0.041	0.018	0.006	–0.007	0.125	1.000						1,050
(8) Coal Price	0.075	–0.030	0.009	–0.013	0.005	0.304	0.195	1.000					1,140
(9) Electricity Price – DEU	0.654	0.003	–0.029	–0.122	0.074	0.150	0.026	0.087	1.000				4,760
(10) Electricity Price – NO	0.475	0.024	–0.016	–0.070	0.098	0.127	0.015	0.036	0.626	1.000			1,690
(11) Electricity Price – FRA	0.503	–0.015	0.006	–0.127	0.102	0.167	0.032	0.025	0.558	0.424	1.000		1,600
(12) Electricity Price – CZ	0.813	–0.009	0.001	–0.069	0.090	0.203	0.023	0.082	0.874	0.587	0.593	1.000	4,710

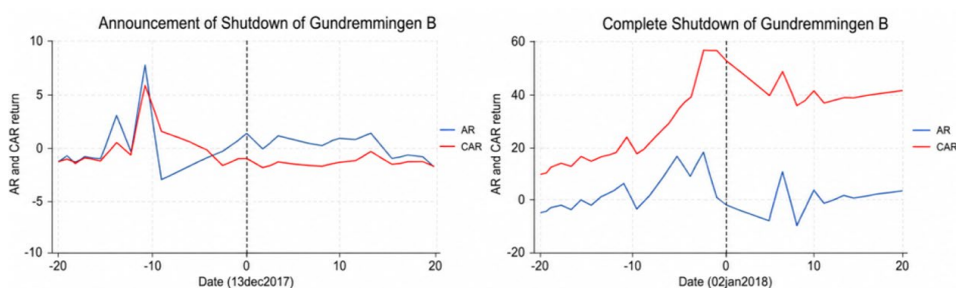
Source: Author's calculations.

Figure A1
Abnormal and Cumulative Abnormal Returns around Temporary Outage of French Nuclear Plants



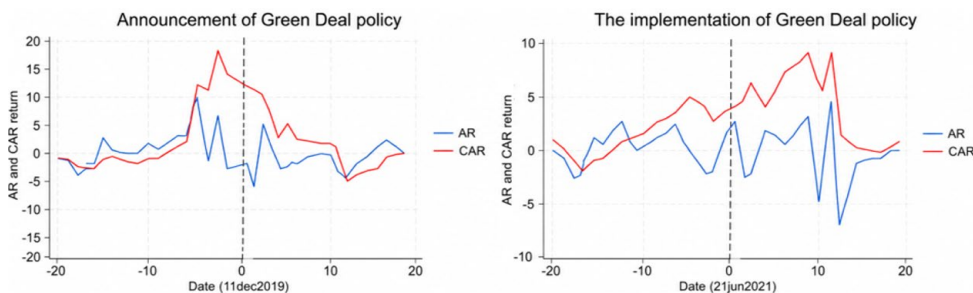
Source: Author's calculations.

Figure A2
Abnormal and Cumulative Abnormal Returns around Shutdown of Nuclear Power Plant Gundremmingen B



Source: Author's calculations.

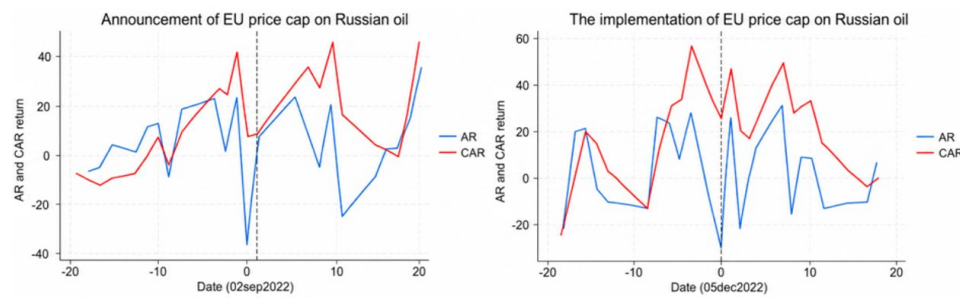
Figure A3
Abnormal and Cumulative Abnormal Returns around Implementation of Green Deal Policy



Source: Author's calculations.

Figure A4

Abnormal and Cumulative Abnormal Returns around EU Price Cap on Russian Oil



Source: Author's calculations.