

## Article

# Algorithmic Sangfroid? The Decline of Sensitivity of Crude Oil Prices to News on Potentially Disruptive Terror Attacks and Political Unrest

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**Abstract:** The paper postulates that enhanced informational efficiency and signal processing capacity, which have characterized the evolution of commodity markets' architecture during the last two decades, have rendered commodity prices more robust with respect to external shocks. Our econometric analysis of times series over 2001–2015 revealed a persistent decline in the responsiveness of crude oil prices to inflows of information concerning potentially supply-disruptive events. International news on terrorist attacks involving damage to oil infrastructure including those occurring in proximity to oil extraction sites, political unrest, and conflicts of rivaling factions are all documented to exercise a decreasing impact on oil price volatility both over short and medium observation spans. The previously observed spikes in oil prices accompanying similar disruptive events in OPEC countries are also shown to flatten over time as price sensitivity to information shocks declines. The discovered weakening of market response becomes more pronounced from the mid-2000s, which corresponds to the period of rapid algorithmization of commodity trading.

**Keywords:** oil prices; commodities; informational efficiency

**Citation:** Mielcarz, P.; Osiichuk, D.; Cymerski, J. Algorithmic Sangfroid? The Decline of Sensitivity of Crude Oil Prices to News on Potentially Disruptive Terror Attacks and Political Unrest. *Sustainability* **2021**, *13*, 52. <https://dx.doi.org/10.3390/su13010052>

Received: 6 November 2020

Accepted: 19 December 2020

Published: 23 December 2020

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## 1. Introduction

The growing co-integration and globalization of financial markets fueled by rapid advancements of information transfer technologies have amplified the spillover effects observed across all major asset classes causing uniform reactions to systemic shocks to quickly propagate globally [1]. Inflows of material information tend to be instantly discounted by market participants with immediate price corrections reflecting the markets' fundamental perception of the weight/importance of the event in question. Increased informational efficiency combined with an overall better processing capability of the modern trading platforms should have supposedly contributed to a higher resilience of financial markets with respect to major shocks. We explore this conjecture by inquiring into intertemporal trends in the oil market's reaction to potentially supply-disruptive events such as terrorist attacks and political unrest involving oil extraction/transportation/processing infrastructure. We argue that algorithmization of commodity trading coupled with markets' improved ability to assess and quantify the consequences of any disruptive event for the supply of oil have contributed to the gradual reduction of oil price sensitivity to the occurrence of such events. We test this conjecture by analyzing the dynamics of daily oil prices in response to terrorist attacks/political instability during the period of 2001–2015. We check for the presence of time-variant patterns in oil price volatility by separately studying shorter subperiods within the entire observation span. The selected subperiods encompass major events which shaped medium- and long-term trends on oil markets (e.g., war in Iraq) as well as a gradual evolution of the market mechanisms which transitioned towards automated trading and big-data-driven analytics. Overall, the study attempts to answer the following research questions:

RQ1. Do terrorist activities and political unrest exercise a statistically significant impact on the volatility of oil prices?

RQ2. Is the market response to terror attacks contingent upon geographical scope, types of targets, origin, motives of attacks, involvement of oil/gas infrastructure?

RQ3. Does the magnitude of market reaction to terror attacks change over the analyzed observation period (2001–2015) under the evolving architecture of commodity markets?

The results of our empirical analysis suggest that during the studied period, oil markets have become much more resilient with respect to the disruptive events in question. While at the beginning-mid of 2000s, terrorist attacks and other potentially disruptive events occurring in major oil-exporting countries and involving oil infrastructure were associated with spikes in volatility and increases of contemporaneous oil prices, this nexus weakened and vanished altogether in 2010s. We advance several possible explanations for these changes one of them being the accommodation of the regular occurrence of such events in market participants' expectations. Another complementary factor that could have contributed to the present status quo is the predominance of algorithmic commodity trading, which could have reduced the non-fundamental noise component of market volatility.

To our knowledge, this is the first study that undertakes a comprehensive intertemporal analysis of the impact of terrorism activity on the dynamics of oil prices. The existing studies [2–4] are limited in scope (small samples of large terror attacks are subject to empirical analysis) and span equity markets. In contrast, this study relies on daily terrorism activity data over a prolonged continuous observation span, which allows disentangling the systemic impact that such events exercise on the long-term performance of oil markets. Our empirical findings demonstrate that markets have become accustomed to the occurrence of disruptive supply-side shocks in the form of terrorism activity, which reduced the price-determining role of this factor. Rather than reacting to a specific event, markets appear to be sensitive to trends in global terrorism activity with only the largest events triggering a significant volatility uptick. These results may be of practical interest to oil market traders and hedgers, who are seeking to better understand the underlying forces shaping trends on oil markets.

The remainder of the paper is organized as follows. First, we summarize the existing empirical literature inquiring into the nexus between global terrorist activities and oil market dynamics. Then we present our research methodology, dataset and modeling outcomes. A discussion of key empirical findings concludes the paper.

## 2. Literature Review

The dynamics of oil prices are shaped by a complex interaction between demand- and supply-side factors. The transmission mechanisms between those factors involve multi-stage feedback cycles whereby unidimensional shocks may cause dynamic changes in both demand and supply for oil [5]. For example, supply bottlenecks or interruptions may cause a surge in speculative and precautionary oil demand, which may magnify the impact of the former on oil price volatility. Interactions of oil markets with complementary and substitute commodity markets as well as with the product markets make disentangling the impact of each specific factor from the stochastic price noise methodologically challenging.

The major trends on the crude oil market over the last two decades have been mostly determined by demand-side factors with global economic expansion and monetary softening after 2001 fueling commodity prices in general. Supply shortages have not been causing major market shifts as disruptions have been mostly transient. The market participants have demonstrated remarkable adaptability to such shocks through diversification of supply channels, enhanced security precautions, strategic asset deployment and adequate management of political risks [6]. Statistical decomposition of oil price time series [7] demonstrates that short-term fluctuations in oil prices are primarily driven by precautionary concerns whereby buyers stockpile additional commodity reserves in expectation of short-term supply disruptions. The latter cause short-term convenience yields to spike

driving the prices up. It is rarely the case that such short-term volatility is engendered by actual physical unavailability of oil.

Terrorist attacks and political unrest involving major oil suppliers and oil infrastructure qualify as potentially supply-disruptive events capable of causing short-term shortages and therefore exercising an upside price pressure. The long-term analysis, however, suggests that such events have but a minor impact on oil price fluctuations [8]. What is more, the relative impact of such events on the contemporaneous dynamics of oil prices tends to diminish over time. Such seemingly contradictory observation has two possible explanations. One is that anticipated physical shortages of deliverable commodities do not materialize following supply-disruptive events as major market participants are capable of swiftly adjusting their production volumes to fill in the temporary gaps. Secondly, the short-term price spikes subside as precautionary oil demand is saturated. Econometric repartition of the two effects on short observation spans appears unfeasible. Large-scale supply-side shocks such as the Iranian Revolution of 1979, creation of OPEC, and the commencement of the Iraq war are certainly capable of generating prolonged systemic market effects [9] but the transmission mechanisms underpinning their impact still appears to be predominantly demand-driven with major players stockpiling reserves in anticipation of increased market volatility.

Empirical studies enquiring into the impact of international terrorism and political instability on financial markets remain scarce. In line with casual empiricism, most conclude that the occurrence of such events precipitates transient volatility increased with some particularly exposed assets exhibiting a more pronounced short-term response [10,11]. Orbaneja et al. (2018) [3] investigated the impact of a small sample of large-scale terrorist attacks involving oil infrastructure destruction and casualties on the short-term dynamics of oil prices and demonstrated substantial abnormal market response thereto. At the same time, Blomberg et al. (2009) [12] document a heterogenous intertemporal impact of terrorism activity on oil price fluctuations with the relationship weakening after the late 1970s. The declining oil price sensitivity to potentially disruptive supply-side shocks is explained by the fact that supply became much more resilient while demand shifted downwards thereby allowing for greater market adaptability. At the same time, oil prices remained responsive to terrorist attacks during time spans when demand exceeded supply or the dynamics of the former presaged possible market shortages.

The evidence regarding markets becoming less responsive to the disruptive impact of terrorist attacks and political instability is inconclusive. Event studies (e.g., [13–15]) demonstrate that large-scale attacks may precipitate long-term volatility increases across financial markets. The impact on market equilibria appears to be persistent. Overall, markets appear to remain similarly vulnerable and sensitive to such events with no evidence of declining market response. Deeper and more liquid financial markets with a broader array of participants appear to have somewhat increased investors' information processing capacity, which, however, did not translate into reduced responsiveness to terror attacks. In fact, positive feedback loops could be responsible for magnifying the disruptive effects that such events exercise on financial markets by prompting investors to take momentum investment positions in anticipation of large price fluctuations [16]. Mnasri and Nechi (2016) [17] document that the effect of terror attacks on the dynamics of financial markets may be heterogenous across geographies with emerging markets being more exposed than mature ones: the former appear to experience increased volatility up to 20 days following the event occurrence. The impact on the volatility on developed markets is shorter-lived and smaller in magnitude [18]. The difference in the market reaction may be contingent upon the level of a country's institutional development.

On the other hand, Chesney et al. (2011) [11] advance a conjecture that while exhibiting acute short-term reaction in response to terror attacks, markets have been gradually becoming better at quickly incorporating the repercussions of such events into asset prices with the resulting pattern resembling a v-shaped recovery [19,20]. The market participants appear to have accustomed themselves to perceiving terror attacks as events of limited

scope and therefore relevant only within a short even window. This inference appears to be valid for developed financial markets, where reactions to disruptive events are documented to have shorter spans and smaller magnitudes. Important geographical spillover effects are observed between markets with international trade positions, financial integration and market depth playing the role of transmission mechanisms [21]. The scale of momentum overreaction appears to have declined over time, which may be explained by the increasing scale of investors' diversification. As exposures to particular asset classes diminish and returns tend to exhibit higher cross-class correlations, investors may have become more placid in their perception of the possible repercussions of terror attacks, which mostly have limited geographical scope.

The explanations for the possibly declining markets' sensitivity to terror attacks originate from both institutional and psychological underpinnings. While isolated terror attacks may induce a momentaneous market response, regular occurrence of such events may cause the investors to discount their impact thereby incorporating it into random noise [22,23]. Both markets and societies learn to cope with the negative repercussions of international terrorism by designing more efficient immediate response mechanisms, enhancing security, adopting contingency action plans, running stress tests, diversifying material attack-related risks through both tangible investments and insurance-like financial instruments. Such adaptive measures contribute to improved preparedness and lower intensity of post-event response.

The second half of the 2000s witnessed a rapid proliferation of automated trading solutions including high-frequency trading and algorithmization of order execution. The tasks of orders matching through open books and deal completion without the involvement of brokers have been quite successfully accomplished with the implementation of proprietary software solutions, which allowed for a substantial reduction in transaction costs. At the same time, deal settlement processes gained flexibility as automated platforms permitted partial orders matching thereby mitigating the impact of large block transactions on prices. The widespread reliance on such solutions engendered new empirical patterns observable across major financial markets [24]. Dealing with pre-specified tasks at hand, automated trading systems have been leveraging execution speed while simultaneously attempting to optimize objective function be it the minimization of price volatility or transaction costs [25].

Computer simulations of the trading environment in presence of a representative automated trading agent have demonstrated that the implementation of such solutions may substantially reduce asset price volatility [26]. Newer studies (e.g., [27]) suggest that algorithmic trading may in fact be responsible for increased volatility: reduction in latency is documented to be associated with higher price fluctuations on a liquid stock market with a related uptick in intraday volatility outweighing the impact of any other systemic factors. The activity of algorithmic trading platforms tends to exhibit high correlation, which makes them more likely to magnify sudden price shifts. Concomitantly, it may reduce the scope of action for arbitrageurs causing prices to deviate further from fundamentals. Chaboud et al. (2014) [28] reach the opposite conclusion finding no causal or associative link between the highly correlated decisions taken by algorithmic traders and market volatility: in fact, a reduction in volatility is reported following a more wide-spread implementation of algorithmic dealing. The observed higher market efficiency and a reduction in volatility may be attributable to higher liquidity and depth of the market, more timely deal execution and lower exposure of prices to market emotions and biases. Data suggest that financial markets remain highly efficient within a short-term perspective, but also that they may be better at incorporating information inflows in the long-run [29].

Algorithmic trading has been gradually transforming energy derivatives markets for the last fifteen years. Increasing the speed of information flows, execution and signal processing changed the way analysts approach both speculative and hedging strategies. Empirical studies (e.g., [30]) suggest that the transition to algorithmic trading resulted in lower spreads and higher depth of oil derivatives markets. At the same time, the events of

April 2020, when oil prices plummeted to unprecedented negative levels, demonstrated how the predominance of effective automated trading can cause drastic market disruptions. Even though the price dynamics objectively reflected the anticipated demand–supply imbalances, the recorded fluctuations would have previously been unthinkable. Hence, while making the market much less exposed to investors' emotions, automated trading may drastically improve the markets' ability to accurately assess and discount operationalizable information inflows into prevailing prices, sometimes to investors' detriment.

The existing empirical studies investigating the impact of disruptive events on commodity prices and commodity-tracking securities suggest that valid statistical inference with regards to determinants shaping short-term market response remains challenging. Methodological difficulties as well as the evolving architecture of commodities markets appear to be at play. For example, an analysis of stock market response to potash mine accidents revealed substantial heterogeneity of investors' reactions with disasters of natural origin (seemingly less predictable) precipitating a more significant correction of mining firms' stocks than man-made accidents [31]. Petrochemical companies' stocks similarly experience a significant decline (ca. 1.3%) over a 2-day observation window following plant accidents with the ensuing chemical pollution being the strongest predictor of investors' response [32]. The unpredictability of disruptive events appears to be generally perceived as a major factor shaping short- and medium-term market outcomes. The events' geographical scope, however, is frequently mentioned as a confounding factor with the directly affected assets recording higher volatilities [33]. Empirical studies suggest that commodities may be better insulated from the impact of disruptive events due to high substitutability and geographical diversification of extraction and transportation infrastructure. However, investors' responses may nevertheless exhibit substantial intertemporal and cross-market heterogeneity, which merits an in-depth statistical analysis.

Since most of the cited empirical studies are relatively old-dated, it seems relevant to analyze the dynamics of markets' sensitivity to the occurrence of terror attacks over the last two decades.

### 3. Research Design

The present study inquires into the short-term effect of terror attacks and political instability on the dynamics of crude oil prices. Our quantitative analysis relies on three datasets. The first one is the Global Terrorism Database administered by the National Consortium for the Study of Terrorism and Responses to Terrorism [34]. The database contains the records of all terror attacks, which occurred around the world starting from the 1970s. We limit the scope of our analysis to the subperiod of 2001 through 2015, which spans the time starting from the 9/11 attacks and englobes the annexation of the Crimean peninsula by the Russian Federation. The latter event marked a global transition towards hybrid and proxy warfare with dominant players participating in armed conflicts indirectly mostly through the involvement of mercenary agencies [35], cyberwarfare, political intrusion and proxy insurgency support. We aggregated the data on terror attacks on daily intervals in order to study the impact of daily terrorist activities on oil prices. The second database used in the study contains the geographical locations of 662 oil and natural gas deposits compiled by Lujala et al. (2007) [36]. We rely on this database to verify the relationship between the impact of terrorism activities on oil prices depending on the proximity of terror attacks from the exploited sources of oil and natural gas. Thirdly, we compiled daily crude oil price data, which serve as the key experimental variable for our econometric analysis.

We chose daily intervals of analysis as longer spans or lower frequency of observations make disentangling the impact of terror attacks from the price noise a practical impossibility. Introducing time lags into the analysis suffers from similar shortcomings. The time-varying weight-combination approach appears to alleviate some of the methodological challenges inherent in the statistical analysis of crude oil prices time series [37].

We start by processing the raw oil price data. In view of the non-stationarity of price data confirmed by the augmented Dickey–Fuller test, we proceed with data transformation by disentangling trend and seasonality components from the stationary stochastic error term. Error-trend-seasonality decomposition allows us to obtain residual price volatility estimates which are further used for econometric modeling.

The decomposition is done relying on the standard time series analysis framework [38]. We assume an additive relationship between the key components of the time series with the following form:

$$Y_t = T_t + S_t + E_t \quad (1)$$

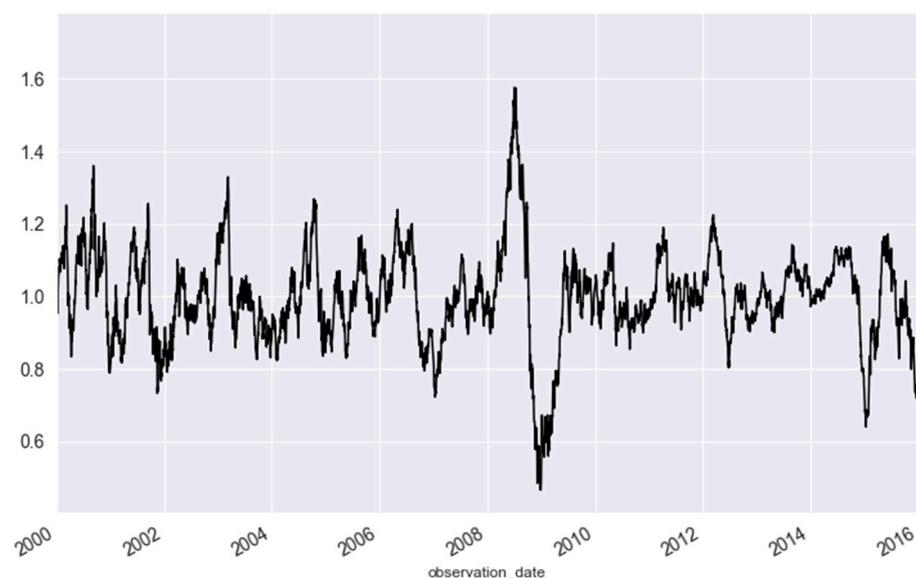
where  $T_t$ ,  $S_t$ ,  $E_t$  are the trend, seasonality and error term components. Seasonal fluctuations are presumed to remain stable in time, the expected value of seasonal variations of time series is assumed to be zero. The trend component is disentangled by estimating 12-month moving average of the time series. Subtracting the trend components from the raw data allows us to proceed with estimates of monthly seasonal fluctuations relying on the assumption that the sum of estimated seasonal components over a yearly observation span is zero, i.e.,

$$\sum_{t=1}^n \hat{S}_t = 0 \quad (2)$$

where  $n$  represents the monthly frequency of seasonality estimates,  $\hat{S}_t$ —monthly seasonal component estimated on detrended data. The stationary error term is estimated by subtracting trend and seasonal components from the raw data:

$$\hat{E}_t = Y_t - \hat{T}_t - \hat{S}_t \quad (3)$$

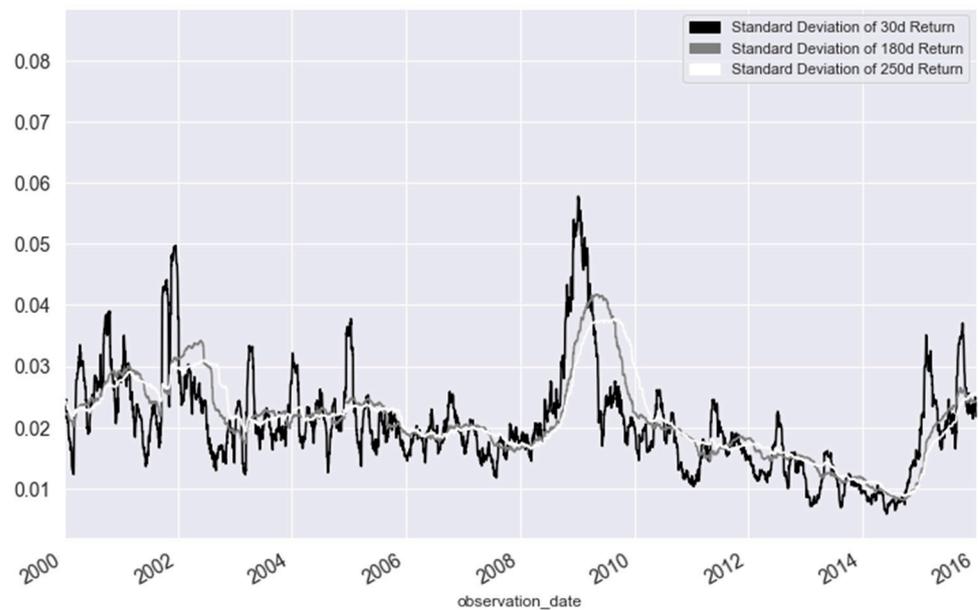
The stationary residual terms are depicted in Figure 1. The residual oil price fluctuations (RESID.PRICE.VOL) are used as an experimental variable in the first set of regression models. The graphical representation of raw data, trend and seasonality components of crude oil prices may be found in a Supplementary File (Figures S1–S3).



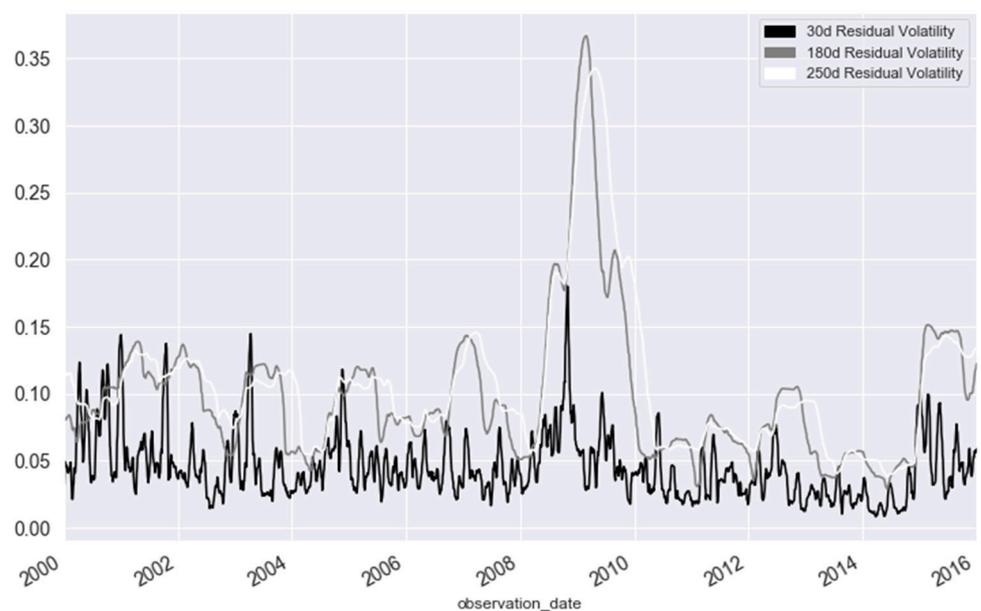
**Figure 1.** Residual oil price fluctuations (following the removal of trend component with Hodrick–Prescott filter), seasonality-adjusted.

In addition to residual oil price volatility, our set of experimental variables includes various measures of oil price volatility. In particular, we measure rolling standard deviation of logarithmic returns of oil over the spans of 3, 30, 180 and 365 days to verify whether terrorism activity has short- and long-term repercussions for oil price volatility. Additionally,

we measure the rolling standard deviation of residual oil price volatility (RES.PR.VOL). The utilization of varying observation spans allows us to corroborate initial findings, while the reliance on both raw and decomposed time series data constitutes an additional set of robustness checks. The estimates of the standard deviation of logarithmic returns and residual oil price fluctuations are presented in Figures 2 and 3 respectively.



**Figure 2.** Rolling standard deviation of logarithmic return of oil prices.



**Figure 3.** Rolling standard deviation of residual oil price fluctuations.

The data on global terrorism activities were aggregated on daily intervals. We analyze several key characteristics of terror attacks which may be of particular relevance from the standpoint of price fluctuations on the oil market. To start with, we estimate the sensitivity of oil prices to the occurrence of terror attacks contingent upon the latter's proximity to the currently exploited oil/gas deposits. We estimate straight-line distance between the

location where a terror attack occurred and the closest oil/gas well. To do that, we use the following formulae commonly relied on for the purposes of geospatial analysis:

$$Distance_{ij} = 2 \times Atn \left( \frac{Sqr(1 - [Cosine_{ij}]^2)}{1 + [Cosine_{ij}]} \right) \times 6371 \quad (4)$$

where

$$Cosine_{ij} = \cos((90 - [Lat_i]) \times \pi / 180) \times \cos((90 - [Lat_j]) \times \pi / 180) + \sin((90 - [Lat_i]) \times \pi / 180) \times \sin((90 - [Lat_j]) \times \pi / 180) \times \cos(( [Long_j] - [Long_i] ) \times \pi / 180) \quad (5)$$

where  $Distance_{ij}$ —distance (measured in km.) between the place of attack and an oil/gas deposit;  $Lat_i$  and  $Lat_j$ ;  $Long_i$  and  $Long_j$  are the latitude and longitude of the place where a terrorist attack occurred, and of the closest oil/gas deposit. Having estimated pairwise distances between the locations of terrorist attacks and sources of oil/natural gas, we aggregate the data on daily basis to estimate the total number of attacks, which occurred within a radius of 10, 50, 150, 200 and 300 km. from all the oil/gas sources on any given date. The resulting variables (DIST.n as defined in Table 1) allow us to track the intermediating impact of distance on the associative link between terrorism activity and oil price fluctuations. We also aggregate daily casualties resulting from terrorism activities (CASUALT) and use it in our empirical analysis to check for the impact of the scale of atrocities on oil price fluctuations.

**Table 1.** Definitions of variables used in the study.

Variable Name	Definition of the Variable
PRICE.CH	Daily percentage change in oil price
RESID.PRICE.VOL	Residual daily oil price fluctuations compared to previous-day closing price after filtering out the trend (using Hodrick–Prescott filter) and seasonality components (observation span = 365 days)
LOG.RET	Daily logarithmic change in oil prices
3d.ST.DEV	3-day rolling standards deviation of logarithmic return
30d.ST.DEV	30-day rolling standards deviation of logarithmic return
180d.ST.DEV	180-day rolling standards deviation of logarithmic return
365d.ST.DEV	365-day rolling standards deviation of logarithmic return
3d.RES.PR.VOL	3-day rolling standard deviation of residual oil price fluctuations
30d.RES.PR.VOL	30-day rolling standard deviation of residual oil price fluctuations
180d.RES.PR.VOL	180-day rolling standard deviation of residual oil price fluctuations
365d.RES.PR.VOL	365-day rolling standard deviation of residual oil price fluctuations
DIST.DEP	Distance from the location of terrorist attack to the nearest major exploited oil/natural gas deposit
N.ATTACK	Number of terrorist attacks which took place during a given day
DIST.10	Number of terrorist attacks which took place during a given day within a radius of 10 km from a major exploited oil/natural gas extraction site
DIST.50	Number of terrorist attacks which took place during a given day within a radius of 50 km from a major exploited oil/natural gas extraction site
DIST.150	Number of terrorist attacks which took place during a given day within a radius of 150 km from a major exploited oil/natural gas extraction site
DIST.200	Number of terrorist attacks which took place during a given day within a radius of 200 km from a major exploited oil/natural gas extraction site
DIST.300	Number of terrorist attacks which took place during a given day within a radius of 300 km from a major exploited oil/natural gas extraction site

Table 1. Cont.

Variable Name	Definition of the Variable
INFR	Number of attacks on oil/natural gas infrastructure during a given day (infrastructure includes storage facilities, pipelines, refineries, wells, rigs)
OIL.GAS	Number of attacks on oil/natural gas extraction facilities
CASUALT	Number of terrorist attacks which resulted in casualties (regardless of the number thereof)
PROP.DAM	Number of terrorist attacks which resulted in infrastructure damage (explosions, arsons etc.)
MAJ.DAM	Number of terrorist attacks during a given date which resulted in major material losses (>1 million USD)
OPEC	Number of terrorist attacks which happened during a given day on the territory of OPEC countries
OPEC.INFR	Number of terrorist attacks on oil/gas infrastructure which happened during a given day on the territory of OPEC countries
OPEC.OIL.GAS	Number of terrorist attacks on oil/gas extraction sites which happened during a given day on the territory of OPEC countries
OPEC.MAJ.DAM	Number of terrorist attacks resulting in infrastructural damage of >1 million USD which happened during a given day on the territory of OPEC countries
OPEC.PROP.DAM	Number of terrorist attacks resulting in infrastructural damage which happened during a given day on the territory of OPEC countries
OPEC.CASUALT	Number of terrorist attacks resulting in casualties which happened during a given day on the territory of OPEC countries
OPEC.DIST.10	Number of terrorist attacks which occurred during a given date within a radius of 10 m from an exploited oil/natural gas deposit in OPEC countries
OPE.CDIS.50	Number of terrorist attacks which occurred during a given date within a radius of 50 m from an exploited oil/natural gas deposit in OPEC countries
OPEC.DIST.150	Number of terrorist attacks which occurred during a given date within a radius of 150 m from an exploited oil/natural gas deposit in OPEC countries
OPEC.DIST.200	Number of terrorist attacks which occurred during a given date within a radius of 200 m from an exploited oil/natural gas deposit in OPEC countries
OPEC.DIST.300	Number of terrorist attacks which occurred during a given date within a radius of 300 m from an exploited oil/natural gas deposit in OPEC countries
REBEL	Number of attacks during a given date, which happened due to actions of organized rebellious factions
STATE	Number of attacks during a given date, which happened due to actions of state controlled armed factions
FACTIONS	Number of attacks during a given date, which happened due to conflicts between factions/religious groups/militias
POL.UNR	Number of attacks during a given date, which were engendered by political/social unrest
POL.UNR.OIL.GAS	Number of attacks on oil/gas facilities during a given date, which were engendered by political/social unrest
POL.UNR.INFR	Number of attacks on infrastructure objects (pipelines, storage, refining) during a given date, which were engendered by political/social unrest
POL.UNR.OPEC	Number of attacks in OPEC countries during a given date, which were engendered by political/social unrest

We separately aggregate the attacks which involved infrastructural damages (INFR) or which were directly targeting oil/gas infrastructure (pipelines, refineries, storage facilities, etc.). Separating these attacks from the remainder of the sample allows us to tackle the potentially supply-disruptive events, as material damages to energy infrastructure directly translate into short-term disequilibria with repercussions for oil price volatility. Of the subsample of infrastructure attacks, we separately analyze those which resulted in large quantifiable property damage (PROP.DAM is a variable encoding the number of attacks on a given date resulting in the infliction of any material damage; MAJ.DAM encodes attacks that resulted in measurable damage exceeding USD 1 million).

A distinct part of our econometric tests concerns the impact of terrorism activities in OPEC countries on the dynamics of oil prices. For the last five decades, OPEC has played a substantial market-making role by shaping both demand and supply-side forces. Its direct impact on market equilibrium resulted from concerted interventions in the form of extraction quotas, while the indirect impact on oil demand was intermediated by key importers' propensity to accumulate precautionary reserves [9]. Despite a gradual decline in its relative weight and some strategic coordination failures, OPEC remains a dominant force shaping oil market outcomes. Political instability and terrorism activities in OPEC countries have been historically perceived as having a potential to disrupt oil supply at least in the short term prompting a significant market reaction [39]. As the supply side of the oil market has undergone major changes over the last decade with non-OPEC countries filling a substantial niche and therefore pushing the equilibrium price down, it would be interesting to verify whether the effect of instability in OPEC countries continues to exercise an impact of oil prices similar to that which was historically observed since OPEC entered the global stage. To that end, we aggregate daily data on terrorist activities in OPEC countries (variable OPEC). The historical instability across the MENA region resulted in a relatively high frequency of occurrence of terror attacks. While an average of ca. 15.98 attacks occurred daily on the global scale, almost a third of the total (ca. 4.59 per day) occurred in OPEC countries. We separately encode the subsample of attacks that involved infrastructural damage (OPEC.INFR) in those countries, which targeted the exploited sources of oil/gas (OPEC.OIL.GAS), which resulted in any measurable property damage (OPEC.PROP.DAM), which involved property damage in excess of USD 1 million (OPEC.MAJ.DAM). We also track the number of daily casualties (OPEC.CASUALT) resulting from the terrorism activities in OPEC countries.

Finally, we explore a set of variables, which describe the intensity of political instability and social unrest. In particular, we aggregate the daily data on terror attacks committed by organized insurgents or rebellious groups (REBEL). The market participants may perceive such attacks as a signal of future turmoil or possibly worsening of political instability. Therefore, such events may trigger longer-term volatility spikes despite the limited impact on crude supply. Similarly, we assemble the data on terrorist attacks involving state-backed actors such as organized militias, state-supported paramilitary organizations (STATE). Attacks resulting from the intra-state conflicts between religious/political/tribal/ethnic factions (FACTIONS) are aggregated separately.

We also aggregate the data on terrorism activities, which were engendered by political (POL.UNR) and social unrest (civil war, long-term religious or political conflicts, etc.). Such attacks usually target police, party offices, other objects of political, administrative and social significance. The occurrence of such events may presage a deterioration of the political situation in a given country and may therefore carry a higher signaling content from the standpoint of market participants. We further encode a subsample of such attacks which involve oil/gas infrastructure (POL.UNR.INFR) and oil/gas extraction sites (POL.UNR.OIL.GAS) as such attacks usually accompany a struggle for control of energy resources and financial flows accompanying oil/gas exports. Political unrest in OPEC countries (POL.UNR.OPEC) also makes part of our empirical analysis, as it is commonly associated with elevated uncertainty on the oil markets with regards to short- and medium-term supply of oil.

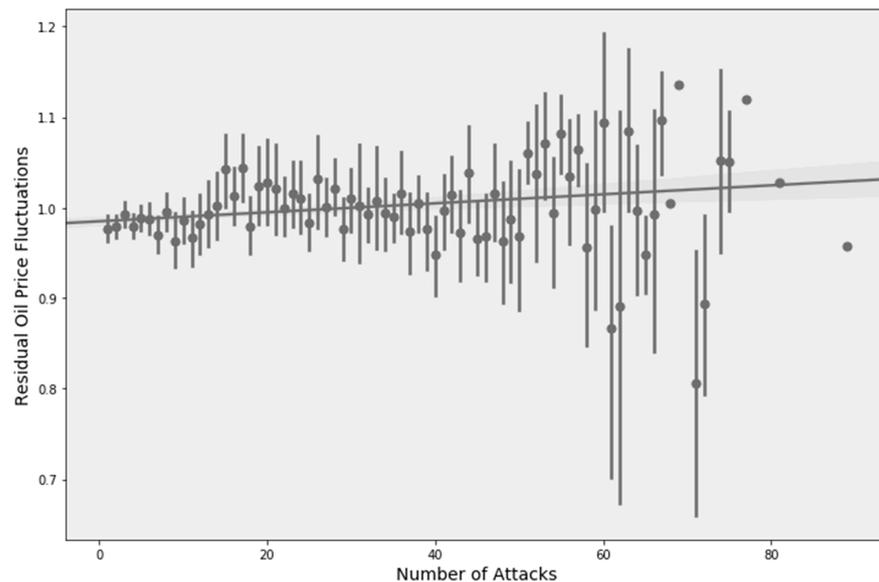
The definitions of all variables used in our econometric analysis are presented in Table 1. Descriptive statistics are summarized in Table 2.

Overall, our empirical analysis pursues two key goals. First, we would like to verify whether terrorism activities are associated with any significant changes in the dynamics and volatility of oil prices. If the significant link between the two is found to exist, we want to further verify how particular characteristics of terror attacks (geographical dimensions, types of targets, origin and motives of attacks as well as the involvement of oil/gas infrastructure) influence the magnitude of this interrelation. Secondly, we attempt to investigate whether the strength of the impact of terrorism activity on oil prices has been evolving

in time as the structure of the market, the dominant form of transaction settlement, the speed of information flows and efficiency of signal processing have undergone a substantial overhaul. To that latter end, we subdivided the entire observation span (2001–2015) into overlapping 5-year subperiods (2001–2005; 2004–2008; 2007–2011; 2010–2014; 2013–2015). Having run additional tests on subsamples selected based on different sampling frequencies with and without overlaps, we noted qualitatively similar results. The choice of overlapping time subsamples allows us to track the changes in the sensitivity of oil prices with respect to the occurrence of terror attacks without the worry that time-variant subsample-specific variables may be distorting the results. We run simple OLS regressions (similar to the one presented in Figure 4) for each of our experimental variables and report the respective coefficients in the following part of the paper.

**Table 2.** Descriptive statistics.

Variable Name	Mean	Sd	Min	Max
OILPRICECH	0.0004	0.0221	−0.1804	0.1988
RESID.PRICE.VOL	0.9932	0.1319	0.4802	1.5768
LOG.RET	0.0001	0.0221	−0.1989	0.1813
3d.ST.DEV	0.8934	0.7161	0.0000	6.5512
30d.ST.DEV	2.8493	1.7727	0.4189	15.1966
180d.ST.DEV	7.2640	6.1562	1.4857	37.1002
365d.ST.DEV	10.3393	7.9298	2.4774	32.8651
3d.RES.PR.VOL	0.0137	0.0098	0.0002	0.1210
30d.RES.PR.VOL	0.0432	0.0219	0.0108	0.1584
180d.RES.PR.VOL	0.0987	0.0559	0.0308	0.3599
365d.RES.PR.VOL	0.1151	0.0551	0.0358	0.2921
DIST.DEP	3981.0911	4136.0743	0.0000	27,972.8904
N.ATTACK	15.9784	15.0213	1.0000	89.0000
DIST.10	0.0728	0.3057	0.0000	4.0000
DIST.50	2.1163	2.9706	0.0000	29.0000
DIST.150	7.3453	7.7747	0.0000	53.0000
DIST.200	9.1378	9.2916	0.0000	57.0000
DIST.300	11.6167	11.2939	0.0000	63.0000
INFR	0.7494	1.4495	0.0000	19.0000
OIL.GAS	0.2784	0.6113	0.0000	7.0000
CASUALT	8.1149	7.7973	0.0000	48.0000
PROP.DAM	6.3523	6.4128	0.0000	76.0000
MAJ.DAM	0.0963	0.5450	0.0000	23.0000
OPEC	4.5886	5.6282	0.0000	45.0000
OPEC.INFR	0.0680	0.5902	0.0000	24.0000
OPEC.OIL.GAS	0.0817	0.3135	0.0000	3.0000
OPEC.MAJ.DAM	0.0259	0.2499	0.0000	11.0000
OPEC.PROP.DAM	1.7899	2.7198	0.0000	36.0000
OPEC.CASUALT	15.8843	41.0115	0.0000	1511.0000
OPEC.DIST.10	0.0521	0.2684	0.0000	4.0000
OPEC.DIST.50	1.4036	2.2638	0.0000	26.0000
OPEC.DIST.150	3.9158	4.9411	0.0000	43.0000
OPEC.DIST.200	4.0513	5.1036	0.0000	43.0000
OPEC.DIST.300	4.1718	5.2304	0.0000	43.0000
REBEL	1.8608	3.0865	0.0000	25.0000
STATE	0.0386	0.2775	0.0000	5.0000
FACTIONS	0.0933	0.3657	0.0000	7.0000
POL.UNR	1.9927	3.2233	0.0000	26.0000
POL.UNR.OIL.GAS	0.0008	0.0284	0.0000	1.0000
POL.UNR.INFR	0.0051	0.0714	0.0000	1.0000
POL.UNR.OPEC	0.4683	0.9939	0.0000	8.0000
N	3707			



**Figure 4.** The associative link between residual oil price fluctuations and the daily number of terrorist attacks.

#### 4. Empirical Findings

The initial set of regressions tested within the present study feature residual oil price fluctuations as explained variable. The results are presented in Table 3. Our results point to a persistent decrease in the sensitivity of oil prices to the occurrence of terror attacks. The number of attacks occurring on a given day is found to be positively associated with oil price dynamics over the entire observation span. The highest sensitivity coefficient is documented for the subperiod of 2004–2008 with a gradual 4-fold reduction thereafter (the respective regression coefficient drops from 0.0041 to 0.001 while maintaining statistical significance at 1% level). Our inquiry into the link between distance from oil/gas extraction sites to the place of attack and subsequent oil price increase allows us to draw two important conclusions. First, the price response to the occurrence of a terrorist attack is inversely related to the distance between attack location and exploited sources of oil (the respective coefficients are monotonically decreasing in the distance from the attack location from 0.008 for attacks occurring 50 km away from the oil extraction site to 0.004 for those occurring 300 km away while the coefficients remain statistically significant). Secondly, the sensitivity of oil prices has been steadily decreasing over the analyzed period reaching the maximum value in 2004–2008 and following a pronounced downward trajectory ever since (a ca. 4-fold decrease in regression coefficients are documented for all tested explanatory variables with the levels of statistical significance remaining persistent). Attacks targeting infrastructure are evidenced to elicit a much stronger market response in the form of higher residual price change. By far, the highest sensitivity coefficients are observed in case of terrorism events targeting oil/gas extraction sites with the magnitude of price response steadily decreasing across the later subperiods of econometric analysis.

The number of casualties resulting from terrorist activities is found to exhibit a positive associative link with the contemporaneous oil price fluctuations (the CASUALT variable is statistically significant at 1% level). Likewise, we find a gradual decrease in the respective sensitivity coefficients in time from 0.0047 in 2001–2005 to 0.0015 in 2010–2014 (all coefficients are statistically significant at conventional levels). While the number of attacks resulting in material property damage is documented to cause an uptick in prices (variable PROP.DAM exhibits robust statistical significance at 1% level), attacks resulting in major property damage exceeding USD 1 million are shown to have no pronounced repercussions for oil price volatility across the selected subperiods of analysis (the respective regression coefficients at MAJ.DAM are insignificant).

**Table 3.** The link between terrorist attacks and residual oil price fluctuations.

Period of Observation	2001–2015	2001–2005	2004–2008	2007–2011	2010–2014	2013–2015
Explained Variable	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL
<b>Number of terror attacks within the vicinity of major oil deposits</b>						
N.ATTACK	0.0005 *** (3.43)	0.0041 *** (4.76)	0.0054 *** (8.11)	0.0034 *** (4.63)	0.0010 *** (6.44)	0.0002 (0.53)
DIST.10	0.0099 (1.39)	−0.0037 (−0.13)	0.0380 (1.69)	0.0112 (0.54)	0.0076 (1.37)	0.0063 (0.77)
DIST.50	0.0027 *** (3.66)	0.0085* (2.43)	0.0101 *** (4.04)	0.0083 ** (3.28)	0.0028 *** (4.47)	0.0021 (1.87)
DIST.150	0.0008 ** (2.79)	0.0057 *** (3.66)	0.0064 *** (5.57)	0.0041 *** (3.44)	0.0014 *** (5.40)	−0.0001 (−0.24)
DIST.200	0.0007 ** (3.01)	0.0049 *** (4.01)	0.0066 *** (6.55)	0.0038 *** (3.64)	0.0014 *** (6.06)	0.0000 (0.06)
DIST.300	0.0005 ** (2.73)	0.0042 *** (4.26)	0.0063 *** (7.36)	0.0033 *** (3.63)	0.0011 *** (5.62)	−0.0003 (−0.62)
<b>Attacks on oil extraction/transportation/storage infrastructure</b>						
INFR	0.0029 (1.95)	0.0119 ** (2.75)	0.0272 *** (6.06)	0.0069 * (1.98)	0.0041 ** (3.06)	−0.0038 (−1.76)
OIL.GAS	0.0098 ** (2.78)	0.0191 * (2.14)	0.0300 ** (3.00)	0.0101 (1.11)	0.0075 * (2.49)	0.0069 (1.44)
<b>Casualties/infrastructural damage as a result of attacks</b>						
CASUALT	0.0010 *** (3.45)	0.0047 ** (3.22)	0.0059 *** (4.69)	0.0041 ** (3.05)	0.0015 *** (5.44)	0.0013 * (2.18)
PROP.DAM	0.0017 *** (5.01)	0.0053 *** (3.76)	0.0114 *** (7.40)	0.0050 *** (3.84)	0.0023 *** (7.08)	0.0019 ** (3.23)
MAJ.DAM	0.0114 ** (2.86)	0.0076 (1.04)	0.0095 (1.80)	0.0113 (1.89)	0.0006 (0.03)	0.0345 (0.90)

Table 3. Cont.

Period of Observation	2001–2015	2001–2005	2004–2008	2007–2011	2010–2014	2013–2015
Explained Variable	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL
<b>Attacks on infrastructure in OPEC countries</b>						
OPEC	0.0013 *** (3.47)	0.0039 (1.77)	0.0070 *** (4.60)	0.0043 ** (2.89)	0.0015 *** (4.37)	0.0008 (1.22)
OPEC.INFR	−0.0064 (−1.75)	−0.0092 (−0.30)	−0.0068 (−0.17)	−0.0533 (−1.79)	0.0262 *** (5.04)	−0.0064 (−1.95)
OPEC.OIL.GAS	0.0134 (1.94)	0.0259 (1.64)	0.0237 (1.72)	0.0110 (0.76)	0.0102 (1.45)	0.0119 (1.11)
OPEC.MAJ.DAM	0.0037 (0.43)	−0.0015 (−0.08)	0.0010 (0.09)	0.0023 (0.18)	0.0188 (0.45)	0.1801 (1.58)
OPEC.PROP.DAM	0.0040 *** (5.03)	0.0011 (0.27)	0.0126 *** (3.60)	0.0064 * (2.51)	0.0035 *** (5.35)	0.0041 *** (4.01)
OPEC.CASUALT	0.0001 (1.81)	−0.0001 (−0.41)	−0.0002 (−1.18)	−0.0000 (−0.22)	0.0002 *** (4.55)	0.0001 * (2.05)
<b>Attacks within the vicinity of major oil/gas deposits in OPEC countries</b>						
OPEC.DIST.10	0.0087 (1.08)	−0.0185 (−0.26)	0.0435 (1.62)	0.0266 (1.04)	0.0059 (0.97)	−0.0010 (−0.11)
OPEC.DIST.50	0.0027 ** (2.84)	0.0070 (1.25)	0.0134 *** (3.84)	0.0097 ** (2.92)	0.0017 * (2.10)	0.0008 (0.59)
OPEC.DIST.150	0.0015 *** (3.33)	0.0037 (1.58)	0.0067 *** (4.32)	0.0040 * (2.58)	0.0011** (2.97)	0.0009 (1.29)
OPEC.DIST.200	0.0014 ** (3.22)	0.0041 (1.76)	0.0067 *** (4.36)	0.0040 ** (2.61)	0.0013 *** (3.48)	0.0007 (1.07)
OPEC.DIST.300	0.0013 ** (3.10)	0.0037 (1.62)	0.0068 *** (4.46)	0.0040 ** (2.65)	0.0013 *** (3.66)	0.0005 (0.83)

Table 3. Cont.

Period of Observation	2001–2015	2001–2005	2004–2008	2007–2011	2010–2014	2013–2015
Explained Variable	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL	RESID.PRICE.VOL
<b>Political instability/upheavals involving major political factions</b>						
REBEL	0.0021 ** (2.98)	−0.0019 (−0.48)	0.0194 *** (3.73)	0.0261 *** (4.24)	0.0038 *** (6.33)	0.0034 ** (2.93)
STATE	−0.0036 (−0.46)	0.0000 (.)	0.3319 * (2.08)	0.0207 (0.29)	0.0198 ** (2.66)	−0.0073 (−1.03)
FACTIONS	0.0059 (0.99)	0.0112 (0.36)	0.0468 ** (2.68)	0.0246 (1.94)	0.0186 ** (2.98)	−0.0106 (−1.50)
POL.UNR	0.0020 ** (2.93)	−0.0017 (−0.43)	0.0217 *** (4.39)	0.0262 *** (4.72)	0.0040 *** (6.74)	0.0027 * (2.41)
POL.UNR.OIL.GAS	0.1977 ** (2.60)	0.0000 (.)	0.3319 * (2.08)	0.2068 (1.70)	0.0977 (1.67)	0.1785 (1.56)
POL.UNR.INFR	0.0435 (1.43)	0.0046 (0.08)	0.3842 *** (3.41)	0.1524 (1.53)	−0.0296 (−0.94)	0.0523 (1.20)
POL.UNR.OPEC	0.0045 * (2.07)	−0.0011 (−0.17)	0.0257 ** (3.10)	0.0397 *** (3.62)	0.0024 (1.32)	0.0009 (0.31)
N	3707	1200	1229	1247	1254	760

Source: own elaboration. This table presents OLS regression estimates. Each estimate results from a separate regression equation with one experimental variable. The t statistics for each regression coefficients are provided in parentheses beneath each coefficient. \*\*\*, \*\*, and \* indicate significance at the 1%, 5%, and 10% levels, respectively. The constant terms, F-statistics and R2 are not reported for brevity of presentation. However, complete statistics for each equation are available upon request.

Attacks taking place in OPEC countries have also been associated with higher oil prices. The distance between the place of attack and oil/gas extraction sites in OPEC countries is evidenced to be negatively associated with the sensitivity of oil price fluctuations in response to the occurrence of terrorism events. The magnitude of the respective relationship is higher than that reported for the entire research sample pointing to the preponderant role that stability in OPEC countries plays in ensuring the steadiness of oil prices.

We note a persistent significant response of oil prices to terror attacks perpetrated by rebels, organized insurgency, state-supported actors, militias and those organized by rivaling political/religious factions (variables STATE, REBEL and FACTIONS are persistently significant at conventional levels). Such events have been shown to incite substantial upward oil price fluctuations. The sensitivity coefficients are documented to decline over time and eventually lose statistical significance in the 2013–2015 observation subperiod.

Overall, we demonstrate that before 2008, terrorism activity was associated with persistent statistically significant positive oil price fluctuations. After 2007–2008, the link weakened and vanished altogether in 2013–2015. All major characteristics of terror attacks such as casualties, material damage, the involvement of infrastructure and proximity to oil/gas extraction sites are documented to carry a strong associative link with contemporaneous oil price fluctuations.

We cross-check our initial results derived from decomposed time series data on alternative regressands. Table 4 features the rolling standard deviation of the logarithmic rate of return calculated from raw oil prices as a dependent variable. We estimate standard deviations over varying observation spans: 3 days, 30 days, 180 days and 365 days. Testing several different volatility measures allows us to track both short- and long-term repercussions of terrorism activities for the volatility of oil prices. For reasons of brevity, we report only test results obtained for 3-days standard deviation of returns (Table 4). The results documented over the longer observation spans are qualitatively equivalent to those obtained from our prior analysis of residual oil price fluctuations and are available upon request (Supplementary Tables S1–S3). The statistical significance of regression coefficients is found to persist across all model specifications. The volatility of logarithmic rate of return is found to be increasing in the total number of attacks (including those involving property damage, perpetrated by organized factions and militias, and prompted by political and social unrest), casualties, decreasing in the distance between the place of attack and oil/gas extraction sites. Similar links hold for attacks occurring in OPEC countries. At the same time, just as previously, we document a gradual decline of the sensitivity of oil price volatility to terrorism activity in time across all the studied characteristics of the analyzed attacks.

Finally, we utilize the rolling standard deviation of residual oil price fluctuations (RES.PR.VOL) as an alternative measure of oil price volatility. The results of univariate regression analysis with this dependent variable are presented in Table 5. In order to ensure the statistical robustness of empirical results, we measure the standard deviation of residual oil price fluctuations on different observation spans ranging from 3 to 365 days following the occurrence of potentially disruptive events. For brevity of presentation, only results obtained for the 3-day observation window are reported with those for longer rolling observation spans being qualitatively similar (Supplementary Tables S4–S6). The magnitude and signs of the respective regression coefficients accord with the previously reported results. The qualitative interpretation of the results and statistical inference remains unchanged regardless of the utilized measures of oil price volatility and selected frequency of observation. Alternative specifications of observation subperiods have been found to generate similar results.

Table 4. 3-day rolling standard deviation of logarithmic return of oil prices.

Period of Observation	2001–2015	2001–2005	2004–2008	2007–2011	2010–2014	2013–2015
Explained Variable	3d.ST.DEV	3d.ST.DEV	3d.ST.DEV	3d.ST.DEV	3d.ST.DEV	3d.ST.DEV
<b>Number of terror attacks within the vicinity of major oil deposits</b>						
N.ATTACK	0.0034 *** (4.40)	0.0040 (1.24)	0.0306 *** (9.11)	0.0071 (1.83)	−0.0095 *** (−7.58)	−0.0006 (−0.34)
DIST.10	0.0222 (0.58)	0.0128 (0.12)	0.3497 ** (3.10)	0.0650 (0.60)	−0.1426 ** (−3.09)	−0.0316 (−0.80)
DIST.50	0.0117 ** (2.96)	0.0414 ** (3.20)	0.0639 *** (5.11)	0.0242 (1.83)	−0.0254 *** (−4.87)	−0.0103 (−1.92)
DIST.150	0.0058 *** (3.86)	0.0126 * (2.18)	0.0428 *** (7.41)	0.0096 (1.53)	−0.0144 *** (−6.53)	−0.0019 (−0.75)
DIST.200	0.0049 *** (3.91)	0.0020 (0.45)	0.0413 *** (8.21)	0.0098 (1.79)	−0.0130 *** (−6.89)	−0.0018 (−0.81)
DIST.300	0.0043 *** (4.17)	0.0009 (0.24)	0.0377 *** (8.89)	0.0103 * (2.16)	−0.0114 *** (−7.07)	−0.0011 (−0.53)
<b>Attacks on oil extraction/transportation/storage infrastructure</b>						
INFR	0.0370 *** (4.57)	−0.0094 (−0.59)	0.1065 *** (4.68)	0.0370* (2.04)	−0.0204 (−1.85)	0.0119 (1.13)
OIL.GAS	0.0476 * (2.48)	0.0712 * (2.17)	0.1077 * (2.13)	0.0294 (0.62)	−0.0968 *** (−3.86)	−0.0105 (−0.45)
<b>Casualties/infrastructural damage as a result of attacks</b>						
CASUALT	0.0055 *** (3.62)	0.0115 * (2.12)	0.0367 *** (5.83)	0.0059 (0.83)	−0.0154 *** (−6.61)	−0.0009 (−0.32)
PROPDAM	0.0074 *** (4.05)	−0.0004 (−0.07)	0.0578 *** (7.41)	0.0042 (0.62)	−0.0178 *** (−6.59)	−0.0030 (−1.04)
MAJ.DAM	0.0102 (0.47)	0.0238 (0.89)	0.0182 (0.69)	0.0049 (0.16)	−0.0790 (−0.53)	−0.1628 (−0.87)
<b>Attacks on infrastructure in OPEC countries</b>						
OPEC	0.0084 *** (4.03)	0.0576 *** (7.23)	0.0356 *** (4.67)	0.0024 (0.30)	−0.0134 *** (−4.78)	−0.0018 (−0.59)
OPEC.INFR	−0.0174 (−0.87)	0.0245 (0.22)	−0.0481 (−0.24)	−0.0421 (−0.27)	−0.1187 ** (−2.72)	−0.0071 (−0.44)
OPEC.OIL.GAS	0.0912 * (2.43)	0.1445 * (2.49)	0.0103 (0.15)	0.0416 (0.55)	−0.0645 (−1.10)	0.0289 (0.55)
OPEC.MAJ.DAM	0.0251 (0.53)	0.2644 *** (3.89)	−0.0142 (−0.26)	−0.0465 (−0.71)	−0.3289 (−0.95)	−0.3246 (−0.58)
OPEC.PROPDAM	0.0119 ** (2.75)	0.0661 *** (4.37)	0.0462 ** (2.60)	−0.0135 (−1.02)	−0.0213 *** (−3.90)	−0.0091 (−1.80)
OPEC.CASUALT	0.0001 (0.33)	0.0015 (1.88)	−0.0006 (−0.73)	−0.0012 (−1.33)	−0.0007 * (−2.20)	0.0002 (0.83)
<b>Attacks within the vicinity of major oil/gas deposits in OPEC countries</b>						
OPEC.DIST.10	0.0013 (0.03)	0.3800 (1.43)	0.2914 * (2.15)	−0.0276 (−0.21)	−0.1481 ** (−2.94)	−0.0393 (−0.91)
OPEC.DIST.50	0.0198 *** (3.82)	0.1382 *** (6.80)	0.0762 *** (4.35)	0.0145 (0.84)	−0.0216 ** (−3.29)	−0.0075 (−1.13)
OPEC.DIST.150	0.0116 *** (4.88)	0.0660 *** (7.77)	0.0363 *** (4.68)	0.0039 (0.49)	−0.0124 *** (−3.98)	−0.0017 (−0.52)
OPEC.DIST.200	0.0105 *** (4.58)	0.0631 *** (7.52)	0.0367 *** (4.75)	0.0040 (0.51)	−0.0129 *** (−4.29)	−0.0018 (−0.56)
OPEC.DIST.300	0.0096 *** (4.29)	0.0608 *** (7.41)	0.0361 *** (4.70)	0.0038 (0.48)	−0.0132 *** (−4.47)	−0.0024 (−0.76)

Table 4. Cont.

Period of Observation	2001–2015	2001–2005	2004–2008	2007–2011	2010–2014	2013–2015
Explained Variable	3d.ST.DEV	3d.ST.DEV	3d.ST.DEV	3d.ST.DEV	3d.ST.DEV	3d.ST.DEV
<b>Political instability/upheavals involving major political factions</b>						
REBEL	−0.0049 (−1.29)	0.0461 ** (3.14)	0.0428 (1.63)	0.0336 (1.04)	−0.0333 *** (−6.70)	−0.0112 * (−2.00)
STATE	−0.0483 (−1.14)	0.0000 (.)	2.9358 *** (3.66)	0.3124 (0.85)	−0.1263 * (−2.04)	−0.0226 (−0.65)
FACTIONS	0.1481 *** (4.62)	0.3332 ** (2.93)	0.5187 *** (5.97)	0.1043 (1.58)	−0.0453 (−0.87)	0.0391 (1.14)
POL.UNR	−0.0030 (−0.82)	0.0507 *** (3.49)	0.0836 *** (3.35)	0.0497 (1.71)	−0.0335 *** (−6.85)	−0.0100 (−1.84)
POL.UNR.OIL.GAS	0.8923 * (2.16)	0.0000 (.)	2.9358 *** (3.66)	1.3050 * (2.06)	−0.2774 (−0.57)	−0.5582 (−1.00)
POL.UNR.INFR	0.2209 (1.34)	−0.2565 (−1.18)	2.6959 *** (4.77)	1.6533 ** (3.21)	0.1749 (0.67)	−0.2982 (−1.41)
POL.UNR.OPEC	−0.0082 (−0.69)	0.1084 *** (4.74)	0.0396 (0.95)	0.0595 (1.04)	−0.0744 *** (−5.03)	−0.0197 (−1.46)
N	3707	1200	1229	1247	1254	760

Source: own elaboration. This table presents OLS regression estimates. Each estimate results from a separate regression equation with one experimental variable. The t statistics for each regression coefficients are provided in parentheses beneath each coefficient. \*\*\*, \*\*, and \* indicate significance at the 1%, 5%, and 10% levels, respectively. The constant terms, F-statistics and R2 are not reported for brevity of presentation. However, complete statistics for each equation are available upon request.

Table 5. 3-days rolling residual volatility of oil prices.

Period of Observation	2001–2015	2001–2005	2004–2008	2007–2011	2010–2014	2013–2015
Explained Variable	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL
<b>Number of terror attacks within the vicinity of major oil deposits</b>						
N.ATTACK	−0.0001 *** (−9.59)	0.0000 (0.15)	0.0002 *** (3.60)	0.0001 (1.59)	−0.0001 *** (−7.55)	0.0000 (0.44)
DIST.10	−0.0018 *** (−3.42)	0.0001 (0.04)	0.0026 (1.92)	0.0007 (0.53)	−0.0014 ** (−3.08)	−0.0009 (−1.61)
DIST.50	−0.0004 *** (−7.12)	0.0004 (1.02)	0.0004 ** (2.60)	0.0002 (1.60)	−0.0003 *** (−4.96)	−0.0001 (−1.69)
DIST.150	−0.0002 *** (−8.83)	0.0000 (0.27)	0.0002 ** (3.19)	0.0001 (1.03)	−0.0001 *** (−6.41)	−0.0000 (−0.62)
DIST.200	−0.0002 *** (−9.17)	0.0000 (0.15)	0.0002 *** (3.51)	0.0001 (1.29)	−0.0001 *** (−6.65)	−0.0000 (−0.90)
DIST.300	−0.0001 *** (−9.18)	0.0000 (0.07)	0.0002 *** (3.79)	0.0001 (1.84)	−0.0001 *** (−6.98)	−0.0000 (−0.31)
<b>Attacks on oil extraction/transportation/storage infrastructure</b>						
INFR	−0.0002 * (−1.97)	0.0002 (0.41)	0.0006 * (2.12)	0.0006 ** (3.06)	−0.0002 * (−2.08)	0.0001 (0.57)
OIL.GAS	−0.0010 *** (−3.94)	0.0004 (0.41)	0.0010 (1.59)	0.0004 (0.66)	−0.0009 *** (−3.46)	−0.0002 (−0.61)

Table 5. Cont.

Period of Observation	2001–2015	2001–2005	2004–2008	2007–2011	2010–2014	2013–2015
Explained Variable	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL
<b>Casualties/infrastructural damage as a result of attacks</b>						
CASUALT	−0.0002 *** (−9.56)	−0.0002 (−1.34)	0.0001 (1.58)	0.0000 (0.44)	−0.0002 *** (−6.89)	0.0000 (1.06)
PROP.DAM	−0.0002 *** (−9.75)	0.0001 (0.55)	0.0003 ** (3.28)	0.0000 (0.16)	−0.0002 *** (−6.23)	−0.0001 ** (−2.66)
MAJ.DAM	0.0008 * (2.57)	0.0013 (1.73)	0.0002 (0.50)	0.0002 (0.65)	0.0001 (0.05)	−0.0030 (−1.09)
<b>Attacks on infrastructure in OPEC countries</b>						
OPEC	−0.0002 *** (−8.19)	−0.0001 (−0.63)	0.0002 (1.88)	−0.0000 (−0.16)	−0.0001 *** (−4.29)	−0.0000 (−0.53)
OPEC.INFR	−0.0004 (−1.43)	0.0009 (0.29)	−0.0017 (−0.72)	0.0004 (0.22)	−0.0010 * (−2.23)	0.0001 (0.47)
OPEC.OIL.GAS	−0.0001 (−0.28)	0.0001 (0.05)	−0.0003 (−0.35)	0.0006 (0.73)	−0.0007 (−1.16)	0.0007 (0.89)
OPEC.MAJ.DAM	0.0007 (1.11)	0.0042 * (2.21)	−0.0000 (−0.04)	−0.0003 (−0.36)	−0.0015 (−0.45)	−0.0081 (−0.97)
OPEC.PROP.DAM	−0.0005 *** (−8.59)	−0.0001 (−0.20)	0.0001 (0.66)	−0.0003 * (−2.15)	−0.0002 ** (−3.25)	−0.0002 ** (−2.94)
OPEC.CASUALT	−0.0000 *** (−3.64)	−0.0000 (−1.75)	−0.0000 (−1.11)	−0.0000 (−0.22)	−0.0000 (−1.75)	0.0000 (0.60)
<b>Attacks within the vicinity of major oil/gas deposits in OPEC countries</b>						
OPEC.DIST.10	−0.0022 *** (−3.73)	0.0056 (0.75)	0.0020 (1.19)	−0.0003 (−0.21)	−0.0014 ** (−2.82)	−0.0012 (−1.93)
OPEC.DIST.50	−0.0005 *** (−6.93)	0.0003 (0.48)	0.0005 * (2.15)	0.0001 (0.49)	−0.0002 ** (−3.19)	−0.0002 (−1.72)
OPEC.DIST.150	−0.0002 *** (−7.30)	−0.0002 (−0.68)	0.0002 (1.90)	0.0000 (0.24)	−0.0001 *** (−3.51)	−0.0001 (−1.11)
OPEC.DIST.200	−0.0002 *** (−7.38)	−0.0002 (−0.70)	0.0002 (1.91)	0.0000 (0.25)	−0.0001 *** (−3.71)	−0.0000 (−0.90)
OPEC.DIST.300	−0.0002 *** (−7.53)	−0.0002 (−0.72)	0.0002 (1.90)	0.0000 (0.23)	−0.0001 *** (−3.88)	−0.0000 (−0.94)
<b>Political instability/upheavals involving major political factions</b>						
REBEL	−0.0005 *** (−10.23)	0.0002 (0.42)	0.0001 (0.17)	−0.0003 (−0.77)	−0.0003 *** (−7.04)	−0.0001 (−1.38)
STATE	−0.0013 * (−2.23)	0.0000 (.)	0.0255 ** (2.62)	0.0017 (0.40)	−0.0008 (−1.30)	0.0002 (0.39)
FACTIONS	0.0004 (0.95)	0.0066 * (2.07)	0.0042 *** (3.96)	0.0006 (0.82)	−0.0005 (−1.00)	0.0014 ** (2.77)
POL.UNR	−0.0005 *** (−9.87)	0.0003 (0.68)	0.0004 (1.36)	−0.0001 (−0.31)	−0.0003 *** (−7.14)	−0.0001 (−0.83)
POL.UNR.OIL.GAS	0.0044 (0.77)	0.0000 (.)	0.0255 ** (2.62)	0.0094 (1.30)	−0.0033 (−0.67)	−0.0045 (−0.54)

Table 5. Cont.

Period of Observation	2001–2015	2001–2005	2004–2008	2007–2011	2010–2014	2013–2015
Explained Variable	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL	3d.RES.PR.VOL
<b>Political instability/upheavals involving major political factions</b>						
POL.UNR.INFR	0.0006 (0.27)	−0.0033 (−0.54)	0.0189 ** (2.75)	0.0139 * (2.35)	0.0021 (0.79)	−0.0005 (−0.15)
POL.UNR.OPEC	−0.0011 *** (−6.70)	−0.0002 (−0.27)	0.0008 (1.59)	0.0005 (0.70)	−0.0008 *** (−5.15)	−0.0003 (−1.40)
N	3707	1200	1229	1247	1254	760

Source: own elaboration. This table presents OLS regression estimates. Each estimate results from a separate regression equation with one experimental variable. The t statistics for each regression coefficients are provided in parentheses beneath each coefficient. \*\*\*, \*\*, and \* indicate significance at the 1%, 5%, and 10% levels, respectively. The constant terms, F-statistics and R2 are not reported for brevity of presentation. However, complete statistics for each equation are available upon request.

## 5. Discussion of Empirical Findings

The empirical findings obtained from time series analysis suggest that the oil market has become much more resilient with respect to external shocks such as terror attacks, political unrest and upheavals. Volatility spikes that previously accompanied potentially disruptive events flattened. The statistically significant effect that terror attacks exercised on oil prices vanished in 2010–2014. We postulate that multiple factors played a role in shaping this phenomenon. It might be the case that investors got accustomed to sporadic occurrence of events that had earlier been perceived as predictors of large-scale market turmoil. The coordination of investors' decisions has improved: even precautionary demand for commodities became much more predictable. The improved management of supply-side risks also plays a role. Large importers benefited from geographical diversification. Infrastructure became much safer as the financial industry engineered solutions allowing to insure material risks. Market saturation with new entrants made filling temporary supply gaps easier and less costly. The period of our analysis coincides with rapid changes in the architecture of commodity markets consisting of gradual transition towards algorithmic trading. Proprietary software solutions have undoubtedly increased the markets' signal processing capacity, thereby refining investors' reactions to inflows of relevant information. As the role of individual investors' psychology in shaping price dynamics diminished, markets could have become better at quantifying the repercussions of specific events. Unlike human decision makers, whose orders are subject to qualitative perceptions of the analyzed events, algorithmic solutions are primarily driven by quantitative information. Since the majority of terror attacks and guerilla actions are constrained geographically and have only minor (if any) impact on the market fundamentals—like actual projected demand and supply of oil—the occurrence of such events may henceforth entail only limited market response. It is worth noting, that attacks involving oil/gas infrastructure or occurring in close proximity to oil extraction sites remain a relevant price factor. The consequences of such attacks are easier to quantify and incorporate into the dynamic equilibrium price.

The selected period of analysis raises additional questions regarding the possible alternative factors shaping the volatility of commodity prices. The observation span encompassed by the present study incorporates the period of the financial crisis of 2007–2008 and the subsequent takeoff of quantitative easing. The softening monetary policy has undoubtedly fueled financial markets, but the impact on commodities has been heterogenous [40]. In conjunction with the evolving architecture of commodity markets, monetary stimulus has led to precipitous financialization of commodities resulting in a growing impact of financial investors on commodity prices [41]. The long-term trends of commodity prices have thus been significantly altered by non-conventional monetary policies. At the same time, it is worth noting that the rapid growth of the monetary base has not lead to any

significant inflationary pressure [42]. The aggregate commodity indices, which represent one of the major drivers of inflation, have not experienced any persistent upward pressure either with interactions of demand- and supply-side factors still playing a predominant role in price discovery. The impact of quantitative easing of commodity prices appears to be reasonably controlled through an application of time series decomposition [43]. Since the present study focuses on daily residual price volatility, it seems reasonable to expect that monetary policy has no systematic day-to-day impact on the oil price fluctuations.

## 6. Conclusions

Casual empiricism and broad media coverage suggest that international terrorism activity plays an important role in shaping investors' expectations and conjuncture, particularly on energy markets. Such events are conventionally perceived as a signal of possible supply disruptions and shortages, which may prompt an increase in short-term precautionary demand. Several empirical papers established that terrorism activities may play an important role in shaping equilibrium oil prices.

The present study undertook an attempt to verify the persistence of the impact of terrorism activities on oil price fluctuations and answer three specific research questions. Empirical findings strongly suggest that terror attacks exercise a statistically significant impact on the volatility of oil prices thus positively answering RQ1. At the same time, the discovered impact is heterogenous with the magnitude varying depending on specific features of disruptive events. In the quest for an answer to RQ2, we found that the number of terrorist attacks occurring on a given date as well as the number of casualties, type of target (particularly attacks involving infrastructural objects and oil/gas extraction sites), the involvement of organized paramilitary groups/insurgency and the proximity to oil extraction sites are associated with a contemporaneous increase in oil prices as well as with short- and medium-term increase in oil price volatility. Attacks involving oil/gas infrastructure especially in OPEC countries are documented to exercised the most pronounced impact on the key experimental variables. Most importantly, we demonstrate that the sensitivity of oil price to the occurrence of terrorist attacks diminished significantly over the studied observation period and vanished altogether by 2013–2015 (RQ3). We thus evidence that oil markets have become more resilient and less responsive to the potentially supply-disruptive events.

Several possible explanations emerge for the declining responsiveness of oil prices with respect to international terrorism activities. To start with, it may be the case that diversification of the sources of energy resources coupled with major geographical shifts in supply structure have caused regional instability and singular terror events to carry less weight in investors' reaction. Over the years, markets have demonstrated superior nimbleness in adjusting short-term supply to fill any intermittent shortages. That resulted in a reduced need for precautionary reserve accumulation thus reducing the demand-driven shocks to oil prices. The second explanation may stem from the overall accommodation of the occurrence of terrorism events in investors' expectations. Markets may expect such events to occur with a certain frequency (already discounted in price noise) and generate a more significant response only if the actual frequency, intensity or consequences of terrorist attacks exceed the historical dynamics substantially. Similar accommodative mechanisms have been shown to manifest across other major asset classes with prices frequently being less responsive to short-term information inflows but rather reflective of the longer-term investors' expectations. Thirdly, as the markets' information processing capacity and the speed of transaction settlement have increased dramatically over the last two decades, the pricing mechanisms have become much more efficient with only major fundamental events causing lasting effects for volatility and equilibria. Since most terrorist attacks are local in scope and limited in their repercussions for the supply of energy resources, they are not expected to have a major impact on dynamic market equilibrium. The dissemination of automated trading solutions has further reduced the human information processing factor therefore possibly contributing to the weakening market response to the events

which mostly do not translate into supply disruptions. It appears impossible at this stage to establish which of the three enumerated explanation stands behind the weakening responsiveness of oil price to terrorism activities, but it bears several important implications for commodity traders.

Some studies (e.g., [44]) emphasize the need to closely monitor events, which may presage political instability in the regions responsible for a major part of global oil supply as they may substantially influence market outcomes. Our results suggest that the impact of international terrorism activity on oil price dynamics has been declining. Therefore, commodity investors should be focusing on long-term fundamental factors underlying equilibrium formation rather than anticipating a short-term market response to the occurrence of terror events. Short-term hedging against such events also appears to be devoid of substantial financial rationale. The increasing efficiency of commodity markets suggests that short-term speculation may carry excessive risks.

The question remains as to how automated trading impacts the markets' sensitivity to terrorist attacks, which are local in their scope and have measurable repercussions for both demand and supply of oil. The findings reported in existing empirical studies would suggest that algorithmic trading may reduce the impact that acts of terror exercise on market volatility precisely thanks to the improved signal processing capacity and ability to correctly quantify the consequences of such events for market fundamentals. We leave this conjecture open for verification in further corroboratory studies.

When interpreting the empirical results documented in the present paper, one should be mindful of the caveats of the methodological approach adopted by the authors. While regression analysis of decomposed time series appears to be well-suited to investigate the problem in question, most prior empirical studies relied on event study methodology. It should be noted that event studies are more suited to samples of events, which are clearly separated in time, thereby allowing for investigation of the dynamics of experimental variables over different observation windows. In the present study, the number of terror attacks is tracked on daily basis thereby making time series analysis a more suitable research tool. Despite being the longest for similar studies on the effects of terrorism on commodities markets, the chosen period of the analysis is nevertheless limited and has a number of inherent time-specific features (e.g., quantitative easing, important geopolitical events), which proved to be difficult to operationalize and incorporate into high-frequency time-series analysis.

Further research may focus on the hitherto ignored factors shaping markets' response to terror attacks such as the degree of media coverage, which may approximate and presage the scale of investors' response. Analysis of other commodity markets may yield divergent findings or further corroborate conjectures presented in this study. Finally, a further in-depth investigation of the possible hedging strategies may be necessary to clarify how investors may insulate themselves from volatility shocks produced by terrorism activities and political unrest.

**Supplementary Materials:** The following are available online at <https://www.mdpi.com/2071-1050/13/1/52/s1>. Table S1: 30-day rolling standard deviation of logarithmic return of oil prices, Table S2: 180-day rolling standard deviation of logarithmic return of oil prices, Table S3: 365-day rolling standard deviation of logarithmic return of oil prices, Table S4: 30-days rolling residual volatility of oil prices, Table S5: 180-days rolling residual volatility of oil prices, Table S6: 365-days rolling residual volatility of oil prices, Figure S1: Raw oil price data (crude BRENT oil quote; spot prices; close), Figure S2: Trend component of crude oil prices removed from raw data using Hodrick-Prescott filter, Figure S3: Seasonality component of crude oil prices removed from raw data using trend-seasonality-error decomposition.

**Author Contributions:** Conceptualization—J.C. and P.M.; methodology—D.O. and P.M.; formal analysis—D.O. and J.C.; data curation—J.C.; writing—D.O. and P.M.; project administration—J.C. and P.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Data Availability Statement:** Restrictions apply to the availability of these data. Data on terror attacks was obtained from National Consortium for the Study of Terrorism and Responses to Terrorism (START), University of Maryland.

**Conflicts of Interest:** The authors declare no conflict of interest.

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