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Faculty of Social Sciences

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MASTER THESIS

Terrorism and market risk assessment

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature, and the thesis has not been used to obtain a different or the same degree.

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Prague, May 10th 2015

Signature

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Abstract

Terrorist attacks are one of the best examples of fast evolving institutional framework. In that context investors are impacted by a lot of pieces of information in a limited period of time. This disturbs the trading behavior and consequently the distribution of returns on the period following the attack (the information was not predicted and directly affects the investment choices). The present thesis focuses on the risk aspect of such disturbances. If terrorist attacks reshape the distribution of returns, it may modify the risk measures (multivariate and univariate). The particularity of the change in distribution implies that the observed translation into financial measures of risk will not be equal among all indicators. First a distinction exists between univariate and multivariate measures but also among univariate measures (as some of them better report the impact of kurtosis or skewness in the sample). Finally observations of these evolutions of risks measures are useful tools to determine a nomenclature of countries with respect to their reactions towards terrorist risk and more globally fast changing geopolitical framework. Such a comparison also allows for studying the particularity of returns' distribution after a terrorist attack.

JEL Classification	C32, F51, F65, G14,G15
Keywords	terrorism, risk measures, heteroskedasticity, event studies

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ACRONYMS

VaR Value-at-Risk

FDI Foreign Direct Investment

ES Expected Shortfall

EVT Extreme value theory

IT Information technology

Master Thesis Proposal

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Proposed Topic:

Terrorism and market risk assessment.

Topic Characteristics

Terrorist attacks on September 11, 2001 raise the question of the management of terrorism risk. They change the insurance market with the Terrorism Risk Insurance Act in 2002. Each insurer in the United States should propose an insurance policy against terrorism to all of their clients.

Due to problems in measuring the impact of attacks on the market (see Straetmans in 2008), it is hard to catch a precise idea of the mechanisms ruling market reactions in response to the increase of such uncertainty. After 9/11, it seemed obvious that markets are negatively impacted by attacks (see Johnston & Nedelescu in 2006).

The variable of interest in our work is the change in the volatility on the market and not abnormal returns. As a consequence, we study whether the uncertainty created by attacks leads to higher market risk in the period that follows. One important channel from attacks to increase in market risk is consequently the perception of the investors (see Garvey & Mullins in 2006) on different markets and how this perception could change from one country to another. These investors evolve in a globalized world and thus the effect of terrorist's attacks could spread on the whole world with different impacts (see Abadie & Gardeazabal in 2008). This perception depends moreover on the tools used by the analysts to measure risks. These tools are often a variance-based analysis. In changing the variance of a portfolio, and creating large deviations, terrorism may change the value of these measures and their accuracy.

Hypotheses:

1- Hypothesis #1: Terrorist attacks have an impact on markets.
2- Hypothesis #2: This effect spreads to the world markets.
3- Hypothesis #3: The market risk perception depends on the region and on the terrorist history of each country.
4- Hypothesis #4: Some markets benefit from terrorist attacks.

Methodology:

The paper will focus on the influence of the terrorist events from 1990 to 2010 (considered as an increase in the terrorist risk) on a number of stock indices. I will use a heteroskedasticity-based estimation model and identify periods of stress due to an increase in terrorism risk perception. A comparison between the variance covariance matrix for the common factors of the indices on terrorism during stress period (basically after the main terrorist attacks of the period) and non-stress period (before the main terrorist attacks) will lead to an estimation of the impact of terrorism on market volatility. I will compare variance-covariance estimations on different markets' indices differing by their geographical and cultural linkage to the targeted countries. Afterwards I will demonstrate the effects of such heteroskedasticity on classical risk-measurement tools (such as VaR, results of Extreme Value Theory).

Expected Contribution:

This paper will treat an original topic using a heteroskedasticity-based estimator. The effect of a hardly predictable threat like terrorism on financial markets has not been largely discussed yet. The expected contribution is consequently to use known tools (like heteroskedasticity based estimator, traditionaly used to study confidence during political crisis‘ times) to approach a new type of threat. These tools will enable us to construct a critical way of thinking concerning the traditional measures of market risk.

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INTRODUCTION

> "Il n'est pas certain que tout soit incertain.
> It is not certain that everything is uncertain."
>
> Blaise Pascal, Pensées (Introduction)

By its nature terrorism is conceptualized as an uncertain event. Its randomness may have some impact on the markets. Terrorist attacks create fear in society and consequently change the behavior of its actors including market participants. Fear is thus coming from the feeling of uncertainty created in the investor's mind. The notion of market rationality is not matching with the uncertainty and the fear induced in the society. The uncertainty and the panic created by terrorism are useful examples of testing the theory of efficient market developed by Fama (1969). According to this theory, market participants assess the current and future impact of information as it becomes available. As terrorism relies more on terror than on material destruction, this impact is hardly assessable. As a consequence, market movements are more intense in the period following terrorist attacks. These movements created by fear have an impact on the volatility of market indexes in the aftermath of an attack. Therefore the risk borne by a whole class of assets will be affected. Moreover, these changes in the risk perception across markets can be also correlated with the geographical, political, ideological proximity of a country with the attacks or with the history this country has with terrorism (it can be desensitized to terrorism risk as proposed by Eldor & Melnik in 2004; or even more sensitive).

The aim of this thesis is to assess the effect of terrorist attacks on the measures of market risks using variance-covariance metrics and to take this effect into account for a comparison between different types of risk measures. Moreover it will be possible to compare both univariate measures of risk and multivariate measures, as a change in correlation between two sets of assets returns does not imply a change of variance for one of them. It has indeed been proven that terrorism affects the whole economy through a large spectrum of channels (Sandler & Enders, 2008). Specific sectors are more concerned than others (like tourism, or insurance markets). Consistent causality and correlation have been proven between the occurrence of terrorist attacks and market movements (Johnston & Nedelescu, 2006). As the behavior of market participants changes after attacks, risk and volatility borne by assets can change too. Catastrophic events relate to extraordinary trading periods which cannot be related to the previous trading period's characteristics. As a consequence, the distribution of financial variables for these periods should be modeled separately. For this reason, classical measures of risk (VaR, Beta, Sharpe ratio…) may not be the best tools to capture extreme losses notably after terrorist attacks. In the aftermath of terrorist attacks, the robustness of such instruments is thus questionable due to their inadequacy to extreme events.

On the next pages, the first overview of the previous literature on terrorist risk is introduced. The methodological issues follow in the second part with a survey of previous studies raising the issue of the assessment of terrorist risk and the description of the model and hypotheses as well as a presentation of the data used. The third part presents the results used and the fourth discusses them. The final part concludes.

I. TERROR AND MARKET RISKS: PREVIOUS ANALYSIS AND STUDIES' ISSUES

Despite the difficulties in assessing terrorist risk as such, an academic work has been done to better understand the relationship between terrorism and financial markets.

A. HISTORY: THE IMPACT OF DIFFERENT TERRORIST ATTACKS ON MARKET RISK

i. MACRO-ANALYSIS

The first approach performed by academics was a pure observation of markets' reaction after terrorist attacks. That is the reason why event studies have been a useful tool to understand the dynamic behind markets' movements. An example is the study done by Eldor and Melnik (2004) on the impact of Palestinian attacks on Israeli economy. They noted a decline in return on stock markets as in the study made on more markets (including 33 market indexes) by Chen and Siems (2004) and confirmed by Chesney, Reshetar and Karaman (2011). These authors demonstrated that the attacks had a bigger effect on some markets compared to others. Swiss market experience has been indeed "affected by the higher number of attacks" whereas United States (US) markets have been affected by the lowest number of attacks within the sample. They also demonstrated differences in reactions across sectors. As a consequence of the differences observed a diversification strategy to cover a so called "terrorist risk" is possible.

Another method to demonstrate the impact of terrorism was to focus on a geographic zone and to determine the impact on the whole economy (impacting normally the finance too). For instance Abadie & Gardeazabal (2003) simulate the economy of Basque country without terrorism and with terrorism. Their observations of stock markets during the cease-fire of 1998-1999 showed that during time of conflict the markets were under-performing. Abadie and Gardeazabal explained that this poor performance could have been caused by uncertainty.

These studies of the overall impact have been deepened by distinction between sectors and geographical consideration. Such an approach has been completed by focusing on the distinction between developed and developing countries. Enders and Sandler (2008) argued that small and developing countries faced a higher impact of terrorist attacks on their macroeconomic variables than developed countries. These countries were more prone to spend a huge share of their national revenues on a counter-terrorist agenda.

As a conclusion, academics agreed on the negative impact of terrorism on market returns. This impact is a consequence of a multiplicity of factors: increase of the defense budget, changing regulatory framework, due to official sanctions towards some countries known as supportive with terrorism (in terms of trade but also in terms of geopolitical impact), destruction of assets being the most obvious ones. This impact could be however explained by the uncertainty investors faced (e.g. Abadie & Gardeazabal, 2003). The risk factor in their study is thus not directly treated but appears as a result of the markets' movements following the attacks, or the academics take the increase in the perception of risk as given. These studies also prove that the market reactions are not the same across countries, markets and geopolitical groups of countries.

ii. Micro-analysis

The analyses on a macro-level can be completed by studies on a micro-level. Two types of studies have been conducted. The first relies on revealed preferences on "happiness metric" and the second one relies on a behavioral approach of financial markets' movements.

Frey and Luechinger (2003) computed a utility loss function based on terrorist activities, happiness and life satisfaction data. They noted the difference between an objective terrorist activity and the individual perception of this activity. Another dimension of their work is that the money spent by governments for the fight against terrorism changes the utility-loss function. Finally a pure assessment of the impact of terrorism on people is not easy.

The behavioral approach has been used by Drakos (2011) and gives some keys to better understand markets movements in time of terror. He used the Heckit approach to determine the effect of attacks on investors. Abnormal returns increased with the concern of the investors about terrorism and the experience of a country with terrorism. Drakos argues for a memory based utility. Moreover the risk could be amplified by a scared society (or by "risk concern" in the article).

Finally, articles dealing with abnormal returns are useful to identify different types of reaction and different particularities explaining differences of reaction among investors.

B. STUDIES PURELY BASED ON TERRORIST RISK ASSESSMENT.

Several academics have been interested in the measurement of terrorist risk using two approaches: market approach and econometric approach.

The first one is based on the study of market movements of financial instruments reflecting the perception of risk. Garvey and Mullins (2008) used the London's options market's reactions from 1998 to 2004. The put option purchases increased right after the attacks showing a higher perception of risk and a will of protection against the risk. The reactions after 9-11 were rather intense for terrorist attacks and attacks warnings even if it is not directly correlated with London financial markets. Authors noted "a lack of expertise to price the timing and consequences of terrorist risk". This fly to option markets is moreover costly as the capital for firms could be reduced.

The other one, an econometric method to have an idea of terrorist risk measurement, uses the formula of basic risk measurement tools. The work of Cotter (2006) using Extreme Value Theory (EVT) to model catastrophic risk is a good illustration of this approach. This method has been used for catastrophic risk or extreme events in general but not for terrorist risk in particular. As a conclusion, the academic approach of terrorist risk is very restrained and the specificities of this risk have not been taken into account or really computed using econometrics tools.

C. Terrorist attacks: transmission channels to financial markets

Even if terrorist risk on markets has not been the center of interest of academics for the moment, some studies focused on the transmission channels from terrorist attacks to the specific movements on the markets.

The work of Johnston and Nedelescu (2005) observes that markets or markets' participants are "direct (74% of civilians casualties of the 9/11 were linked with financial jobs) and indirect victims of terrorism":

The new direction taken by terrorist groups may cause this phenomenon. They redirect their actions against a capitalist order (markets places, markets' participants being the best representation of this order). The economic activity is directly connected with a country financial health but also represents a barometer for the capitalistic culture. As a consequence, places of commercial or trading activities are first tier targets for terrorist (as it has been reiterated by the group Al-Sheebab in February 2015). If they can be directly targeted by terrorists, markets are also impacted by other indirect consequences. The article of Johnston and Nedelescu (2005) sums up the main consequences of such attacks on the economy and on markets. The four main consequences of attacks on markets are: the reduction of capital stock (markets' indexes usually descrease after the attacks), higher level of uncertainty (materialized by higher markets' movements, higher commodities prices…), increase in counter-terrorism expenditures (lowering public expenditures efficiency) and a negative impact on specific industries.

Finally there is a significant diversity in the transmission channels from terrorism attacks to markets movements. These transmission channels have been cited but not even studied. Their interconnections and importance are still hard to assess and to understand. Moreover the different correlations could be amplified by political actions (i.e. a new legislative framework) or by feelings (i.e.fear-driven decisions).

D. Attacks and international finance: How can we explain the spillover and contagion effects?

Another often studied aspect is the transmission of this effect through markets. As Chen and Siems (2004) noted "global capital markets today are tightly inter-linked". As a consequence the terrorist risk would not have an effect just on the impacted country or market.

The first contagion takes place through sectoral spillover. According to Straetsman and Verschoor (2008) all sectors are not impacted at the same level. They distinguished the linkage between old and new sectors. They observe that a transmission or a correlation exists between sectors but on the contrary 9/11 implied some structural changes in the connections between markets.

The second level of contagion is international spillover, notably studied by Chen and Siems (2004). Markets are highly connected all over the world and they observe similar movements on very different markets. They also observe differences in resilience according to the quality of the banking sector. As a consequence, the resilience of different markets to terrorist attacks has several dimensions which are inter-linked but also hardly assessable (i.e. fear or trust in the banking sector).

The contagion effect can be higher through the impact of terrorism on foreign direct investment (FDI) (basically investors are less interested if the country-specific political risk increases). Therefore the global economic activity is impacted by this restructuration of FDI's flows. If terrorist risk is considered as a country-specific risk, it can be spread by the integration of currency risk during transactions. Terrorism can also impact the currency risk and, as a consequence, spread in other regions. The impact of an attack is therefore not just reflected on the place where it took place but also on other places.

II. Empirical Model: From 1993 to 2007: Terrorists attacks and financial markets risks adjustments

A. DEFINITION OF KEY CONCEPTS:

Before writing about terrorism and the risks it involves, it is necessary to build a conceptual framework around the two basic notions of terrorism and market risk assessment. Whereas the definition of terrorism can be somehow blurred, the one of market risk is strictly defined thanks to a set of precise tools and regulations for its measurement.

i. TERRORISM ANALYZED AS A RISK

Terrorism can be defined as a risk from the financial perspective because of one aspect: it changes the distribution of the assets returns (Chen and Siems 2004). As a consequence, terrorism is perceived as a threat on a daily life but also according to a financial perspective.

A first dimension brought by terrorism to risk is the impact of terrorism on market participants' behavior. This dimension is described by Drakos (2009). By definition, terrorism relies on terror; this terror, the feeling of fear and uncertainty impact the behavior of market participants. Drakos noted that the change in market participants' behavior is more important if the psychosocial impact of attacks is higher. He named it the "sentiment effect." Finally, this uncertainty changes the distribution of financial variables.

This logic applies to all market risks. The first one is equity risk (the risk studied in the empirical part), basically defined as the risk induced by holding equity. This risk is impacted by the specificity of the trade period following terrorist attacks. Secondly, the interest rate risk can be increased by the uncertainty of the consequences of future attacks; the risk of assets destruction, as the world is defined as less secure than before. Thirdly, the currency risk can be affected by the difference in effect of attacks on different currency areas (based on different perceptions of the other risks). Finally, the commodity risk is influenced if people consider that if an attack occurs, the future risk of destruction of an asset increases. The impact of attacks on these different categories of risks is based on the perception of attacks' participants and their trading activities based on this perception.

Another dimension which should be underlined is the risk-timing. People may think that one attack will not change the risk, because a terrorist risk is already borne by the assets held in their portfolios. Actually, this pragmatic assumption does not hold because the financial risk induced by attacks is not based on the physical risk of destruction or damages. This risk is based on the behavior of other market participants. If an attack occurs, people will believe that the world is less secure and consequently will increase their risk perception. This logic is reflected by the market behavior approach. For example, 9/11 changed the insurance legislative framework in the US: insurance providers now have to propose an insurance policy to all their customers according to the Terrorism Risk Insurance Act of 2002. The change in risk on the markets is based on the reactions of its participants and not on an actual higher level of risk.

ii. *RISK-MANAGEMENT:*

Considered as a specific type of risk, terrorism needs to be regarded in a certain extent in the risk management policy of a firm. In the risk management procedure, two stages are crucial: the identification and the assessment of the risk. A good example applying to terrorism risk is Composite risk index (= probability of the event occurrence x impact of this event), dealing with these two stages. The problem here is not the probability of the event (major attacks having a real impact on markets are quite rare), but the impact of the event dealing with behavioral finance. These stages lead to the prioritization of the risks and to the financial decision.

In this process, the identification and assessment stages are crucial because they represent the basis of an efficient risk management.

iii. *PROBLEM TO MEASURE TERRORIST RISK*

The problem lies in having efficient assessment of the terrorist risk and therefore efficient risk management. In this context, the issues come from the "Probability of occurrence" part of the Composite Risk Index.

Terrorist attacks are by definition random (or perceived as random), or hardly predictable. It is also hard to define them logically (cause, consequence, actors…). It is even truer during the first hours following the attacks. The first day following the attacks is often a day when a lot of information is delivered (remember the post 9-11 and the uncertainty to define the perpetrators and the reason of the attacks). A lot of interpretations are made. This lack of certitude can create an apocalyptic frame also for financial markets. As a consequence, we can observe contrary moves on stock markets.

Terrorism belongs to political risks. However due to the abovementionned characteristics these risks are very likely to bring some changes in the short-term because the political and security environment changes in short-term (whereas institutional and political changes are often driven by slow dynamics). Moreover the labeling of terrorist activities is done by the legal power (per se terrorism is the use of political violence to create terror and consequently depends on the meaning given to "political violence" and the understanding of its goals). Basically a terrorist is "a terrorist" because he/she is defined as such by a political authority (i.e during the Ukrainian conflict in 2014 both government and rebels from the eastern part were defined as terrorists either by the Ukrainian government or by the Russian one). Consequently by accepting to define an attack as a terrorist attack, we admit the legitimacy of the authority labeling perpetrators as terrorists. Therefore, a proper geopolitical analysis is claimed to be best suited to assess the risk of occurrence of an attack than pure computed tools. In the following study, the task of defining terrorists devolves to RAND[1] organization. The choice of taking RAND's review of terrorist attacks allows for balancing consistency in the choice of the attack and the objectivity of their selection (governmental sources are by definition quite biased, whereas sociological studies could lead to numerous examples which could be contradictory).

After raising the abovementioned issues we can conclude that measuring market risk due to terrorist attacks is a hard task because it depends on the perception of the risk by market participants. This task is even harder due to the blurred definition of terrorism and a moving geopolitical framework in which the attacks take place.

iv. *How to measure risk in this environment? An econometric challenge*

As a consequence of the "fear-based" markets movements, and the huge amount of imperceptible transmission channels, terrorist risk is hardly assessable. As terrorism is often described as a new kind of warfare, it is possible to use the risk measures created to assess war risk.

[1] RAND (Reasearch AN Developpement) is a non profit global think tank aiming at cross-subject studies and cooperation on various quantitative issues. It got its financing both from the US government and from private funds.

The first approach assesses risk through Value-at-Risk (VaR) method. The problem is that we have to deal with high heteroskedasticity. Moreover the terrorist risk can be imperceptible because it is effectively perceived only on a short period of time compared with the studied period.

The second approach is a heteroskedasticity based estimation (developed in Rigobon and Sack, 2005, to assess war risk after 9/11). It compares differences in the covariance-variance matrix of several indexes between two periods of time (defined as high-stress period and no-stress period). This approach also uses the limits of the VaR approach showing that heteroskedasticity could affect basic risk measures.

A complement of the heteroskedasticity based estimation is the Expected Shortfall approach (explained in Acerbi and Tasche, 2002). This measure is very similar to VaR because it measures the expected value of the loss higher than the one given by the confidence interval (i.e the expected value of the loss equal or higher than VaR). This measure is thus more adequate to capture long or fat tails distribution.

The Extreme Value Theory, presented by Parkinson in 1980, appears as a good tool in uncertain environment and for extreme events. Its aim is to model the distribution of outcomes over or under a certain threshold and to define intervals according to this distribution.

In this paper the heteroskedasticy based estimator is the main measure used as it shows the inconstancy of VaR. After showing this inconstancy, a rapid check will show the effect of heteroskedasticity on VaR and ES estimators and evaluate which one is more prone to catch the disturbances due to terrorism.

B. METHODOLOGY

The logic of the following methodology relies on different event-studies. Defined by Chen and Siems[2], event-studies are defined as “a forward-looking approach”. This approach lies on the efficient market theory (Fama, 1969). When an information is available (in our case the information that attacks took place at a given point of time in a given location), markets react to it. As a consequence, they reassess the value of certain firms or the perspectives of certain

[2] Chen and Siems, 2004

markets. This reassessment leads to an increase of market risk due to adjustments in investors' decisions.

The aim of this work is to study the propagation of risks and the extent of the propagation of these risks among different sectors and different countries after terrorist attacks. Terrorist attacks in this case are identified as information which will change the perception of the terrorist risk and consequently investors' behaviors. To lead such estimation, we will use the heteroskedasticity based estimator described in Rigobon and Sack (2005). This estimator assesses the changes of the variances of different market returns as well as the changes of the covariances of two different financial market returns.

This estimator appears as an optimal answer to the two problems we are facing for such estimation. First terrorist risk is unobservable by nature (terrorist attacks aim at surprising societies). Second, other factors are still influencing stock indices in addition to terrorist risk.

This heteroskedasticity based estimator will be used in a two steps analysis. The first one will be an analysis of the variation in the return's variance for each sector of the NASDAQ100. The second one will be an estimation of the variance covariance between the different indexes abroad. As a consequence we will assess two effects. The direct effect of the stress on each sector and one spillover effect due to the connection between the markets but also due to the identification of the attacks abroad as a security threat on the domestic markets.

In three steps:

- Firstly, we evaluate the incidence of selected attacks on each sector.
- Secondly, we evaluate the incidence on international market using heteroskedasticity.
- Thirdly, we study the effect of such changes in the variance covariance matrix on basic risk measures.

In order to create some structure for the first two steps of the estimation, we assume (as in Rigobon and Sack in 2004) that the daily change in the indices can be explained by this structural equation.

$$\text{Structural equation: } A.\begin{bmatrix}\delta x_{1t}\\ \delta x_{2t}\end{bmatrix} = B.\begin{bmatrix}z_{1t}\\ z_{2t}\\ \dots\end{bmatrix}$$

The matrix A represents the spillover among financial variables, $Z_{1t...3t}$ are factors influencing financial variables, δx_{1t} and δx_{2t} are the changes of our financial variables (these financial variables here are returns of sectoral indices or of market indices), the matrix B represents the direct effect of explanatory variables on financial variables. This equation can be reduced to even simpler one:

.

$$\begin{bmatrix}\delta x_{1t}\\ \delta x_{2t}\end{bmatrix} = D.\begin{bmatrix}z_{1t}\\ z_{2t}\\ \ldots\end{bmatrix}$$

The matrix D takes into account the overall impact of our factors on financial variables. As a consequence, we obtain a basic linear regression equation between our factors and financial variables taking into account spillover effects on all financial variables.

$$D = \begin{bmatrix}1 & d_{12} & \ldots\\ d_{21} & d_{22} & \ldots\end{bmatrix}$$

The influence of the first variable on the variance of the first variable is evaluated at 1. This normalization allows us to compare variance, covariance matrix during stress-period as in non-stress period. As terrorist risk in the markets is hardly measurable, this normalization gives us a benchmark (the change created by the attacks on the variance of the first index is equal to one, as a consequence the change on the variance of the other indices will be directly compared with the intensity of the first one). The normalization creates a metric to compare the measures.

From this equation, a heteroskedasticity based method is used to compare the variance-covariance matrix during our two periods. To define these two periods, we use the description of abnormal returns given by Chen and Siems (2004). Consequently the period of stress is associated for all our indices to the largest period (over the indices used) of abnormal returns right after the attacks. The non-stress period is defined by the same period of time before the attacks.

During these two periods we assume that the only change is the terrorist risk or the perception of this risk increased by the attacks. The period of stress or non-stress is in both cases rather short compared to the speed of important changes regarding innovation or changes of the macroeconomic situation. Other changes of explanatory factors are not likely to happen during these periods (for instance the dividends policy of a company will not affect the whole index on such short samples or will have a minor impact on the volatility of whole indices.) Other factors remain consequently constant on this short sample and will not affect the estimate by their changes.

The variance-covariance matrix for the two periods is defined as follows:

$$\sum_b = E[z_t . z'_t \,] \text{ for } d_{bt} = 1$$

$$\sum_a = E[z_t . z'_t \,] \text{ for } d_{at} = 1$$

The computation of these two matrices is the first two stages to perform before computing the differences of these interaction matrices $\Delta \sum = \sum_a - \sum_b$. The changes are directly correlated with the change of financial variables through the matrix D.

As a result, the computation of the differences for financial variables leads to interlinked results.

We compute also the variance-covariance matrix for the financial variable. The response of financial variables is shaped by two parameters: the heteroskedasticity (denoted λ) created by the augmented perception of terrorist risk and the responsiveness of the financial variables to that factor (d_{21}). It can be summarized by the following equation:

$$\delta\theta = \lambda . \begin{bmatrix} 1 & d_{21} \\ d_{21} & d_{21}^2 \end{bmatrix}$$

The calculation of the coefficient d_{21} requires the use of an instrumental variable (a dummy variable for the definition of the set of days composing the stress period and the non-stress period). The difference between the first financial variable variance during stress day and non-stress day is set as a benchmark to one. Our estimator of the risk propagation to another market is estimated by the following equation:

$$\hat{d} = \frac{\sum_{t=1}^{T} \delta_{a,t}\,\Delta x_{1t}\Delta x_{2t} - \sum_{t=1}^{T} \delta_{b,t}\,\Delta x_{1t}\Delta x_{2t}}{\sum_{t=1}^{T} \delta_{a,t}\,\Delta x_{1t}\Delta x_{1t} - \sum_{t=1}^{T} \delta_{b,t}\,\Delta x_{1t}\Delta x_{1t}} ,$$

where $\delta_{a,t}$ is a dummy variable equal to 1 after the attacks and $\delta_{b,t}$ is a dummy variable equal to1 before the attacks Thefirst indication of higher market risk is the value of the denominator: if the market risk increases, it should be positive. Afterwards the value of $\hat{d}$ explains the difference of impact among markets.

A comparison of countries index with NASDAQ100 explains the propagation effect of such risk. These coefficients (which are rather good proxies for β estimates) can be used afterwards for comparison with VaR's computation, which will be set against other risks measures (Expected shortfall or Extreme value measures). The impact of the heteroskedasticity observed because of the attacks differs on different measures of risk.

The compared measures are VaR, Expected shortfall and Extreme value. Where VaR is the only measure directly related to the variance of the whole sample. The aim of this second part of the analysis is to compare the impact of terrorist attacks on these different measures.

Value-at-Risk is defined as the amount of loss expected according to a certain level of confidence. It can be computed as:

$$VaR = \alpha\sigma - \mu,$$

where α is a cut line given by the confidence interval (often given by a normal rule table), σ is the standard deviation and μ is the expected value of the distribution of financial variables in the sample. Here, the VaR is computed using the historical approach (the statistic variables are the ones of the pre-attacks periods, post-attacks periods and the periods of study as a whole).

Expected shortfall (ES) is defined as the expected average value of the loss for a VaR under a certain threshold and can be computed as:

$$ES_\alpha = \frac{1}{\alpha}\int_0^\alpha VaR_\gamma(X)d\gamma$$

It can also be defined as expected tail loss, conditional VaR, or average VaR (it is the procedure given by this formula).

The last measure is Block minima Extreme Value. It is done in two steps: First the definition of a threshold, then the definition of the distribution of tail values or minima block defined by the letter m (here it will be Fréchet law as heavy tails are expected). The generalized extreme value distribution is defined by three parameters:

$$H_{\mu,\sigma,\varepsilon} = H_{\varepsilon}\left(\frac{x-\mu}{\delta}\right) for\ x\ \epsilon\ D\ and\ D = \left]\frac{\mu-\sigma}{\varepsilon};\ \infty\right[\ for\ Fréchet\ rule$$

The parameter μ is the mean of the distribution of the extreme value, σ is its standard deviation and ε is a shape parameter. The parameters are afterwards computed using log-likelihood estimator and compared from period to period.

The maximum-likelihood estimator maximizes the following function

$$L(\varepsilon,\mu,\sigma;x) = \prod_{i} \log(\, h(x_i))\ for\ x_i \epsilon\ m$$

$$h(\varepsilon,\mu,\sigma;x) = \frac{1}{\sigma}\left(1+\varepsilon\frac{x-\mu}{\sigma}\right)^{\frac{-1}{\varepsilon-1}} \exp\left(-\left(1+\varepsilon\frac{x-\mu}{\sigma}\right)^{\frac{-1}{\varepsilon}}\right)$$

The estimators of the parameter ε,μ and σ afterwards help us to define a confidence interval given the tail distribution. The sample is also bootstrapped 1000 times to recreate a meaningful sample as EVT should derive a block minima from a sufficient amount of values. Moreover EVT is used to compute a 95 confidence interval for 2 days returns. It is the way to construct a much more realistic estimator (in terms of precision), the model is also much more volatile in case of changes in the distribution (differences are squared).

The value of these estimates is computed for two samples: pre and post attacks, then compared to each-other (in their changes according to periods, their values…). An assumption of our model is that the abnormal return period constitutes a coherent period of distribution (representing the whole distribution of returns impacted by the attack). As a consequence, the risk measures are computed on these periods for T = number of days of abnormal return. The pre-period estimators are also computed for a time factor T. The estimators from pre and post attack period are consequently comparable to each-other.

This comparison will be possible thanks to an ANOVA analysis of the results from each observation before and after the attack. This analysis allows us to conclude on the significancy of the created change regarding the risk measures induced by VaR, EVT and ES. It also allows us for checking the robustness of market risks' measures after terrorists attacks. The ANOVA analysis of risk measures relies on a simple regression of the risk measures obtained during a first step on different factors (our factor of interest is terrorism here, the control variables are"attack number" to control for conjectural returns changes and "country" to control for country premia). The model looks as follows :

$$y_i = \beta_0 + A_1 terrorism + A_2 country + A_3 Attack + u_i$$

There are two assumptions: the first one is the normality distribution of our samples and the second one is homoskedasticity (the variance of our two samples should be equal). The heteroskedasticity created in the return dataset does not necessarily induce a heteroskedasticity in the dataset of risk measures. As a consequence, this assumption can be reasonably accepted for the study and will be tested. Thanks to the use of this country variable we can consider that A_1 will only reflect the effect of terrorism on the risk measure.

C. DATA DESCRIPTION

The first phase of the work is based on the study of 15 indexes before and after 9 attacks between 1995 and 2007. The second phase relies on the comparison of 4 sectoral indexes with the NASDAQ 100 during the same period. One of the hypotheses of this work being that disturbances created in the risk-assessment tools could depend on the market and on the sector concerned by the assessment, a comparison between the impacts of the attacks on some classical measurement tools on different markets and sectors is necessary. It will be helpful to isolate the transmission channels of these disturbances.

The studied attacks are summarized in Table 1. They were chosen because of their importance in terms of injuries and fatalities (leading to a higher impact on investors' investment behaviors). This first table defines the time frame of the study. The indexes studied on these time periods are: Amsterdam Exchange Index (AMS), Athens Stock Exchange General Index (ATH), CAC 40 (CAC), DAX (DAX), Footsie 100 (FOOTSIE), Mexico Stock Exchange Index (IPC), Karachi Stock Exchange General Index (KSE), Nikkei (Nikkei), Standards and Poors Index for the Australian Stock Exchange (ASX), Standards and Poors Index for Toronto Stock Exchange (TSX), Shanghai Stock Exchange Index (SSE), Swiss Market Index (SSMI), Strait Times Singapore Index (SING) and the NASDAQ 100 (NASDAQ).

Date	City	Country	Perpetrator	Weapon	Injuries	Fatalities	Both
Attack 1: 20/03/1995	Tokyo	Japan	Aum Shinri Kyo	Chemical	5000	12	5012
Attack 2 : 19/04/1995	Oklahoma City	US	Other	Explosives	500	168	668
Attack 3 : 07/08/1998	Nairobi / Dar Es Salam	Kenya / Tanzania	Al Qaeda	Explosives	5000	224	5224
Attack 4 : 11/09/2001	New York City	US	Al Qaeda	Other	2337	2938	5275
Attack 5 : 24/10/2002	Moscow	Russia	Movsar Barayev Gang	Firearms	650	162	812
Attack 6 : 11/03/2004	Madrid	Spain	Abu Hafs al-Masri Brigade	Explosives	600	191	791
Attack 7 : 01/09/2004	Beslan	Russia	Riyad us-Saliheyn Martyrs' Brigade	Firearms	727	331	1058
Attack 8 : 11/07/2006	Mumbai	India	Unknown	Explosives	625	190	815
Attack 9 : 14/08/2007	Sinjar	Iraq	Unknown	Explosives	1500	500	2000

Table 1: Studied attacks summary. Data: Rand association website

- **For a more precise view on the attacks, refer to Annex 1 (Rand description of each attack)**

Moreover, each attack follows a different process. The short description of each attack is provided in order to understand their motives and the socio-political dynamics behind them. These attacks were the most important in terms of injuries and fatalities on the period 1990-2010

Attack 1 (A1): The Tokyo subway was targeted with nerves gas. The deadly gas was released from packages brought on to five different railway carriages and fifteen stations were infected. The perpetrator was a Buddhist sect (Aum Shinri Kyo).

Attack 2 (A2): A truck bomb demolished a federal building in Oklahoma. The attack was conducted by an individual: Timothy McVeigh close to the Militia movement.

Attack 3 (A3): The third attack is constituted of joint attacks on different American embassies in Africa (in Kenya and Tanzania). These attacks were conducted by Al Qaeda.

Attack 4 (A4): Al Qaeda terrorists highjacked two passenger planes and flew them into the World Trade Center towers, New York City.

Attack 5 (A5): Approximately forty-five Chechen (Movsar Barayev Gang) terrorists stormed into the Palace of Culture Theater in Moscow.

Attack 6 (A6): Ten bombs detonated in four different locations on Madrid's train line. The attack was perpetrated by Abu Hafs al-Masri Brigade on behalf of Al Qaeda.

Attack 7 (A7): A group of 30 to 35 (sources varied) armed Chechen separatists, including men and women, many wearing suicide bomber belts, seized a school in the Southern Russian town of Belsan taking children, parents, and teachers hostages in the school gym. Firefights between Riyad us-Saliheyn Martyrs' Brigade and the state forces induced hundreds of death.

Attack 8 (A8): A series of seven explosions targeted railroad networks in Mumbai. Apparently this attack was linked with Indian Mujahideen activities.

Attack 9 (A9): 4 truck bombs hit a poor rural area near the Syrian border. Perpetrators are still unknown even if regional tensions between Yezidis and Sunnites could be at the origin of the bombing.

For more details on the attacks present in the sample the reader is invited to refer to Annex 1 for the RAND's description of the attacks.

Attacks are also described by the abnormal period associated with each of them. The abnormal period is defined by the longest period for an index of the sample to recover its level from right before the attack. Table 2 summarizes the descriptive statistics for each attack and for each index. These data help to determine the difference in terms of risk perception among the markets and the difference of variance between the pre-terror period and the post-terror period.

	Index	AMS	ATH	BSE	CAC40	ASX	IPC	SING	SSMI	SSE	TSX	NIKKEI	KSE	FOOTSIE	DAX	NASDAQ
A 1 (= 11 days of abnormal return)	Mean	-0,10%	0,05%	0,10%	0,22%	0,18%	1,05%	-0,11%	-0,13%	0,54%	0,19%	-0,27%	-0,37%	0,24%	-0,31%	0,11%
	Var	1,00E-04	8,58E-05	1,14E-04	2,43E-04	7,71E-05	5,31E-04	7,91E-05	9,58E-05	5,51E-04	1,80E-05	3,16E-04	1,90E-04	1,09E-04	1,67E-04	7,66E-05
	Min	-1,94%	-1,45%	-2,23%	-3,01%	-1,19%	-1,69%	-1,64%	-2,32%	-3,19%	-0,66%	-4,02%	-2,79%	-1,57%	-2,74%	-1,88%
	Max	1,43%	3,01%	2,00%	2,19%	2,35%	6,64%	2,02%	1,84%	6,77%	1,13%	3,76%	2,79%	1,85%	1,80%	1,47%
	N° obs	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**	**23**
A 2 (= 233 days of abnormal return)	Mean	0,05%	0,04%	-0,01%	-0,01%	0,02%	0,09%	0,01%	0,07%	0,07%	0,03%	0,00%	-0,07%	0,05%	0,02%	0,12%
	Var	5,46E-05	8,77E-05	1,24E-04	1,30E-04	5,75E-05	3,93E-04	7,90E-05	6,46E-05	1,64E-03	3,59E-05	1,53E-04	1,61E-04	6,51E-05	6,70E-05	1,75E-04
	Min	-2,82%	-2,71%	-3,27%	-3,17%	-3,58%	-6,85%	-5,42%	-3,05%	-16,39%	-2,35%	-9,85%	-4,09%	-2,98%	-2,89%	-4,98%
	Max	2,34%	3,73%	5,90%	3,77%	2,57%	10,27%	3,61%	3,14%	33,46%	4,17%	6,38%	4,36%	2,88%	2,67%	4,92%
	N° obs	**467**	**467**	**467**	**467**	**467**	**467**	**467**	**467**	**467**	**467**	**467**	**467**	**467**	**467**	**467**
A 3 (= 104 days of abnormal return)	Mean	0,09%	0,27%	-0,01%	0,12%	0,02%	-0,11%	0,01%	0,05%	-0,01%	-0,04%	-0,10%	-0,24%	0,02%	0,09%	0,28%
	Var	4,51E-04	6,21E-04	3,87E-04	3,89E-04	9,66E-05	5,80E-04	5,62E-04	4,22E-04	1,75E-04	1,77E-04	2,61E-04	9,34E-04	1,75E-04	3,83E-04	4,43E-04
	Min	-5,91%	-7,70%	-6,80%	-6,03%	-2,52%	-9,71%	-6,56%	-8,44%	-8,36%	-4,28%	-6,00%	-12,38%	-3,99%	-5,35%	-9,86%
	Max	6,69%	7,32%	5,23%	5,55%	2,76%	12,90%	8,62%	5,93%	5,11%	5,34%	5,60%	13,61%	4,03%	6,06%	6,72%
	N° obs	**209**	**209**	**209**	**209**	**209**	**209**	**209**	**209**	**209**	**209**	**209**	**209**	**209**	**209**	**209**
A 4 (= 61 days of abnormal return)	Mean	-0,06%	-0,01%	-0,02%	-0,07%	-0,01%	-0,07%	-0,01%	-0,08%	-0,16%	-0,03%	-0,14%	0,02%	-0,05%	-0,09%	-0,04%
	Var	4,50E-04	3,88E-04	2,76E-04	3,75E-04	8,26E-05	1,92E-04	2,85E-04	3,24E-04	2,85E-04	1,33E-04	2,40E-04	2,55E-04	2,27E-04	4,66E-04	9,27E-04
	Min	-9,84%	-7,74%	-8,14%	-7,14%	-4,15%	-5,29%	-7,57%	-9,15%	-5,27%	-4,35%	-4,70%	-4,22%	-5,72%	-9,85%	-8,70%
	Max	5,80%	5,53%	3,66%	5,91%	2,01%	4,40%	7,09%	4,44%	9,86%	4,55%	3,97%	6,66%	4,06%	6,39%	11,09%
	N° obs	**123**	**123**	**123**	**123**	**123**	**123**	**123**	**123**	**123**	**123**	**123**	**123**	**123**	**123**	**123**
A 5 (= 8 days of abnormal return)	Mean	0,77%	0,14%	-0,04%	0,86%	0,25%	0,20%	0,28%	0,41%	0,08%	0,42%	0,29%	0,52%	0,30%	0,86%	1,15%
	Var	3,74E-04	1,39E-04	9,11E-05	5,73E-04	6,36E-05	1,25E-04	2,30E-04	2,78E-04	9,00E-05	1,38E-04	3,37E-04	2,32E-04	5,26E-04	1,10E-03	1,09E-03
	Min	-2,43%	-1,50%	-1,33%	-3,19%	-1,07%	-1,88%	-1,19%	-2,90%	-1,58%	-1,71%	-3,85%	-3,95%	-3,78%	-5,14%	-3,20%
	Max	4,46%	3,29%	2,06%	3,88%	1,48%	2,98%	4,14%	3,30%	1,72%	2,24%	3,38%	2,44%	5,05%	6,36%	7,14%
	N° obs	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**	**17**
A 6 (= 28 days of abnormal return)	Mean	0,02%	0,04%	0,07%	0,07%	0,09%	0,21%	0,01%	0,02%	0,04%	0,01%	0,19%	0,28%	0,07%	0,01%	-0,05%
	Var	1,26E-04	1,16E-04	2,71E-04	8,32E-05	1,49E-05	8,79E-05	6,68E-05	6,85E-05	1,26E-04	6,79E-05	1,28E-04	8,84E-05	5,31E-05	1,40E-04	1,31E-04
	Min	-2,94%	-3,77%	-4,38%	-3,08%	-1,09%	-2,55%	-1,96%	-3,38%	-2,43%	-2,78%	-2,48%	-2,86%	-2,20%	-3,98%	-2,51%
	Max	2,63%	1,95%	3,48%	2,13%	0,84%	2,23%	1,69%	1,41%	2,50%	1,28%	2,42%	2,65%	1,64%	2,82%	3,02%
	N° obs	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**

A 7 (= 3 days of abnormal return)	Mean	0,25%	0,09%	0,34%	0,15%	0,20%	0,25%	0,19%	0,34%	0,04%	-0,02%	0,17%	-0,60%	0,35%	0,21%	-0,06%
	Var	2,20E-05	1,93E-05	3,54E-05	3,91E-05	1,96E-05	3,66E-05	3,01E-05	3,53E-05	9,62E-05	1,19E-05	7,16E-05	8,10E-05	3,19E-05	4,28E-05	4,20E-05
	Min	-0,60%	-0,54%	-0,56%	-0,81%	-0,40%	-0,84%	-0,71%	-0,52%	-1,53%	-0,46%	-0,85%	-2,32%	-0,69%	-0,93%	-1,03%
	Max	0,95%	0,62%	1,29%	1,03%	0,82%	0,90%	0,92%	1,16%	1,72%	0,46%	1,70%	0,31%	0,96%	0,85%	0,84%
	N° obs	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**
A 8 (= 58 days of abnormal return)	Mean	0,04%	-0,05%	0,03%	0,03%	0,00%	0,10%	0,02%	0,04%	0,21%	-0,05%	-0,04%	-0,09%	-0,01%	0,02%	-0,03%
	Var	1,15E-04	2,10E-04	4,21E-04	1,27E-04	7,83E-05	3,05E-04	9,51E-05	9,09E-05	2,15E-04	8,24E-05	1,53E-04	4,38E-04	9,69E-05	1,13E-04	1,19E-04
	Min	-3,36%	-5,92%	-5,27%	-3,55%	-2,58%	-4,51%	-3,72%	-3,19%	-5,33%	-3,26%	-3,86%	-5,86%	-2,92%	-3,43%	-2,65%
	Max	3,20%	5,10%	6,53%	3,24%	2,30%	6,68%	3,07%	2,32%	4,26%	2,26%	2,62%	4,68%	2,64%	2,67%	2,86%
	N° obs	**117**	**117**	**117**	**117**	**117**	**117**	**117**	**117**	**117**	**117**	**117**	**117**	**117**	**117**	**117**
A 9 (= 31 days of abnormal return)	Mean	0,00%	0,09%	0,07%	-0,06%	0,06%	-0,03%	0,07%	-0,04%	0,57%	0,03%	-0,11%	-0,04%	-0,03%	-0,02%	0,11%
	Var	2,10E-04	1,18E-04	4,47E-04	2,54E-04	1,46E-04	1,99E-04	3,74E-04	1,62E-04	3,88E-04	9,56E-05	1,44E-04	1,66E-04	2,29E-04	1,38E-04	1,52E-04
	Min	-4,23%	-3,54%	-11,21%	-4,04%	-2,76%	-3,50%	-4,67%	-3,91%	-5,25%	-2,64%	-3,48%	-3,53%	-4,10%	-3,52%	-3,18%
	Max	3,81%	3,43%	3,27%	4,88%	4,47%	2,72%	4,59%	3,43%	5,33%	2,55%	2,72%	2,35%	3,50%	2,27%	2,69%
	N° obs	**63**	**63**	**63**	**63**	**63**	**63**	**63**	**63**	**63**	**63**	**63**	**63**	**63**	**63**	**63**
All sample (mean for variance)	Mean	0,05%	0,07%	0,00%	0,03%	0,03%	0,06%	0,02%	0,04%	0,08%	0,01%	-0,04%	-0,08%	0,03%	0,03%	0,12%
	Var	2,01E-04	2,42E-04	2,49E-04	2,21E-04	7,33E-05	3,66E-04	2,16E-04	1,76E-04	8,38E-04	8,53E-05	1,87E-04	3,49E-04	1,25E-04	2,04E-04	3,14E-04
	Min	-9,84%	-7,74%	-11,21%	-7,14%	-4,15%	-9,71%	-7,57%	-9,15%	-16,39%	-4,35%	-9,85%	-12,38%	-5,72%	-9,85%	-9,86%
	Max	6,69%	7,32%	6,53%	5,91%	4,47%	12,90%	8,62%	5,93%	33,46%	5,34%	6,38%	13,61%	5,05%	6,39%	11,09%
	N° obs	**1083**	**1083**	**1083**	**1083**	**1083**	**1083**	**1083**	**1083**	**1083**	**1083**	**1083**	**1083**	**1083**	**1083**	**1083**

Table 2: Summary statistics. Data: Yahoo finance and KSE website 2014.

	Index	NASDAQ	N BANK	N INDUS	N INSUR	N TRANSP
A 1 (= 11 days of abnormal return)	Mean	0,11%	0,01%	0,14%	0,06%	0,02%
	Var	7,66E-05	3,98193E-06	1,2753E-05	2,7965E-05	4,0349E-05
	Min	-1,88%	-0,57%	-0,70%	-0,75%	-0,95%
	Max	1,47%	0,29%	0,66%	1,76%	1,52%
	N° obs	23	23	23	23	23
A 2 (= 233 days of abnormal return)	Mean	0,12%	0,08%	0,07%	0,09%	0,05%
	Var	1,75E-04	1,84173E-05	5,031E-05	3,304E-05	6,2882E-05
	Min	-4,98%	-1,77%	-3,51%	-2,01%	-2,60%
	Max	4,92%	1,35%	1,99%	2,13%	3,45%
	N° obs	467	467	467	467	467
A 3 (= 104 days of abnormal return)	Mean	0,28%	-0,07%	0,02%	-0,01%	-0,08%
	Var	4,43E-04	1,45E-04	2,21E-04	1,63E-04	1,97E-04
	Min	-9,86%	-3,99%	-7,26%	-4,35%	-4,72%
	Max	6,72%	5,29%	4,28%	3,91%	4,26%
	N° obs	209	209	209	209	209
A 4 (= 61 days of abnormal return)	Mean	-0,04%	0,03%	-0,04%	0,00%	0,05%
	Var	9,27E-04	1,21E-04	4,09E-04	9,88E-05	3,41E-04
	Min	-8,70%	-5,72%	-6,05%	-3,47%	-8,51%
	Max	11,09%	2,95%	6,68%	3,38%	4,36%
	N° obs	123	123	123	123	123
A 5 (= 8 days of abnormal return)	Mean	1,15%	0,42%	0,86%	0,37%	0,86%
	Var	1,09E-03	1,78E-04	3,74E-04	2,50E-04	1,88E-04
	Min	-3,20%	-1,70%	-1,87%	-1,92%	-1,27%
	Max	7,14%	2,79%	4,12%	3,63%	3,12%
	N° obs	17	17	17	17	17
A 6 (= 28 days of abnormal return)	Mean	-0,05%	-0,07%	0,04%	0,04%	0,09%
	Var	1,31E-04	5,22E-05	1,19E-04	4,82E-05	1,18E-04
	Min	-2,51%	-2,72%	-2,61%	-2,08%	-2,50%
	Max	3,02%	1,33%	2,51%	1,58%	2,44%
	N° obs	57	57	57	57	57
A 7 (= 3 days of abnormal	Mean	-0,06%	0,23%	0,31%	0,23%	0,34%
	Var	4,20E-05	7,18802E-06	6,5698E-05	2,5774E-05	8,3398E-05
	Min	-1,03%	-0,24%	-1,04%	-0,63%	-0,82%

return)	Max	0,84%	0,61%	1,63%	0,99%	2,15%
	N° obs	7	7	7	7	7
A 8 (= 58 days of abnormal return)	Mean	-0,03%	0,02%	-0,04%	0,05%	-0,05%
	Var	1,19E-04	6,33E-05	1,09E-04	5,22E-05	2,90E-04
	Min	-2,65%	-1,88%	-2,55%	-1,46%	-5,31%
	Max	2,86%	2,24%	2,99%	1,98%	4,54%
	N° obs	117	117	117	117	117
A 9 (= 31 days of abnormal return)	Mean	0,11%	-0,05%	0,02%	-0,03%	0,01%
	Var	1,52E-04	2,44E-04	1,38E-04	2,24E-04	2,10E-04
	Min	-3,18%	-3,01%	-2,33%	-3,53%	-3,51%
	Max	2,69%	7,66%	3,12%	6,05%	4,18%
	N° obs	63	63	63	63	63
All sample (mean for variance)	Mean	0,12%	0,03%	0,05%	0,05%	0,03%
	Var	3,14E-04	7,63E-05	1,43E-04	8,28E-05	1,58E-04
	Min	-9,86%	-5,72%	-7,26%	-4,35%	-8,51%
	Max	11,09%	7,66%	6,68%	6,05%	4,54%
	N° obs	1083	1083	1083	1083	1083

Table 3: Summary statistics for sectoral data. Data: Yahoo finance, KSE website

All statistics have one point in common: huge differences in terms of distribution of the data (basically the variances, means and even skewness and kurtosis are expected to be different for each subsample). This inter-subsamples analysis is not the core of the analysis here, the goal being to catch the disturbances created intra-subsamples. These differences are however a sign of completeness of our sample taking into account a lot of diverse subsambles.

III. RESULTS

A. RESULTS IN TERMS OF HETEROSKEDASTICITY

Risks are commonly defined by the return's variances. In our model, terrorist attacks influence the variance and covariance of our indexes' returns. The variance is directly or indirectly a component of the main tools to measure risk. That is the reason why the first estimator computed is a heteroskedasticity-based estimator. The results are obtained by applying the equation p13 to our set of values. The result can be compared to a classical β-premium for market risk assessment. The benchmark is the NASDAQ100 index. All obtained results for so called $\widehat{ds}$ are not absolute but must be compared with the denominator (basically the change in the variance of the NASDAQ index). That is the reason why denominators' values are also reported to understand the real impact of the attacks. The n-root of the 1+percentage change is also reported to be able to compare the impact for daily return. Results can be seen in Table 4. Cells are colored regarding to the impact of the corresponding attack on the corresponding index (increasing or decreasing). These results illustrate the spill-over effect among markets and countermovements. A careful interpretation helps to understand investing behaviors in periods of stress.

Table 5 presents results for NASDAQ-sectoral indexes.

	Period	dAMS	dATH	dBSE	dCAC40	dASX	dIPC	dSING	dSSMI	dSSE	dTSX	dNIKKEI	dKSE	dFOOT	dDAX	Num val	n-th root
Attack 1	11	-3,174	-3,400	-1,340	-5,975	-1,823	1,853	-1,566	-0,079	1,488	-0,568	3,569	1,341	-4,936	-4,053	0,02%	0,0021%
t-value		*(-3,54)***	*(-3,12)***	*(-1,36)*	*(-4,36)***	*(-2.42)***	*(0.25)*	*(-2.44)***	*(-0.86)*	*(0.17)*	*(-2,92)***	*(0,94)*	*(0,28)*	*(-4,62)***	*(-3,06)***	*(2,01)***	
Attack 2	233	0,045	0,090	-0,145	-0,098	-0,129	0,218	0,099	0,022	0,048	-0,003	-0,009	-0,057	0,094	-0,006	3,84%	0,0162%
t-value		*(-1,75)**	*(-1,25)*	*(-1,36)*	*(-1,26)*	*(-1.98)***	*(-0.53)*	*(-1.41)*	*(-1.64)**	*(-0.31)*	*(-2.31)***	*(-1.14)*	*(-1.13)*	*(-1,42)*	*(-1,67)**	*(2,05)***	
Attack 3	104	0,292	0,355	0,119	0,211	0,078	0,235	0,201	0,276	0,094	0,372	0,233	-0,160	0,157	0,301	4,97%	0,0466%
t-value		*(-0,69)*	*(-0,55)*	*(-0,91)*	*(-0.87)*	*(-2.00)***	*(-0.67)*	*(-0.72)*	*(-0.75)*	*(-1.48)*	*(-0.97)*	*(-1.05)*	*(-0.77)*	*(-1,29)*	*(-0,73)*	*(1,66)**	
Attack 4	61	0,008	0,024	0,637	-0,182	0,201	-0,268	0,101	-0,209	0,327	-0,586	0,030	-0,156	0,088	-0,198	2,77%	0,0447%
t-value		*(-1,49)*	*(-1,54)*	*(-0,76)*	*(-1.78)**	*(-2.58)***	*(-2.93)***	*(-1.63)*	*(-2.32)***	*(-1.11)*	*(-4.27)***	*(-1.98)***	*(-2.08)***	*(-1,94)**	*(-1,78)**	*(21,09)***	
Attack 5	8	-16,609	-1,115	-3,896	-16,246	7,552	-8,727	-9,323	-14,202	-4,206	-0,144	-6,738	16,757	-8,470	-20,293	-0,03%	-0,0039 %
t-value		*(-19,94)***	*(-4,01)***	*(-11,10)***	*(-14.74)***	*(27.69)***	*(-21.67)***	*(-18.51)***	*(-16.96)***	*(-20.86)***	*(-2.41)***	*(-9.45)***	*(25,72)***	*(-12,75)***	*(-16,61)***	*(-0,14)*	
Attack 6	28	0,369	-0,290	0,799	0,520	0,091	-0,392	-0,184	0,840	0,495	0,451	-0,543	0,598	0,897	1,552	0,12%	0,0041%
t-value		*(-0,69)*	*(-1,42)*	*(-0,14)*	*(-0.70)*	*(-2.56)***	*(-1.78)**	*(-1.77)**	*(-0.26)*	*(-0.56)*	*(-0.85)*	*(-1.46)*	*(-0,55)*	*(-0.19)*	*(0,54)*	*(4,32)***	
Attack 7	3	1,004	-0,330	-1,220	1,063	-0,525	-1,052	0,457	1,245	-1,808	0,718	1,552	-0,534	0,187	1,223	-6,27E-07	-8,56E-03
t-value		*0,00*	*(-1,40)*	*(-2,10)***	*(0.031)*	*(-2.78)***	*(-1.41)*	*(-0.45)*	*(0.08)*	*(-0.61)*	*(-0.35)*	*(0,20)*	*(-0.35)*	*(-0,47)*	*(0,13)*	*(-0,81)*	
Attack 8	58	-0,960	-1,764	-0,053	-1,099	1,515	0,095	0,284	-0,343	0,951	-0,339	1,031	-0,110	0,987	-0,497	-0,17%	-0,0030 %

t-value		*(-2,05)***	*(-2,29)***	*(-0,56)*	*(-2.11)***	*(0.59)*	*(-0.57)*	*(-0.81)*	*(-1.58)*	*(-0.04)*	*(-1.67)*	*(0.03)*	*(-0.62)*	*(-0,01)*	*(-1,57)*	*(-7,01)***	
Attack 9	31	0,247	-0,121	0,446	0,174	0,191	0,328	0,206	0,253	0,372	0,180	0,241	-0,865	0,398	0,279	-0,28%	-0,0091 %
t-value		*(-0,61)*	*(-1,40)*	*(-0,49)*	*(-0,60)*	*(-0.79)*	*(-0.57)*	*(-0.49)*	*(-0.64)*	*(-0,36)*	*(-1.13)*	*(-0.67)*	*(-1.67)*	*(-0,49)*	*(-0,73)*	*(-10,58)***	

Table 4: $\widehat{d}$ results for cross markets comparison. Data: Yahoo Finance and KSE website

- In brackets the t-value for the test $\widehat{d}$ =1; ** : 95% confidence level; *90% confidence level.

Sectoral	Period	dBANK	dIND	dINS	dTRANS	Numerator value	nth root
Attack 1	11	-0,606	-0,072	-0,361	-0,856	0,02%	0,0021%
t-value		*(-5,97)***	*(-1,87)**	*(-2,11)***	*(-2,30)***	*(2,01)***	
Attack 2	233	0,035	0,399	0,080	0,221	3,84%	0,0162%
t-value		*(-2,92)***	*(-1,13)*	*(-2,08)***	*(-1,38)*	*(2,05)***	
Attack 3	104	0,486	0,590	0,459	0,421	4,97%	0,0466%
t-value		*(-0,91)*	*(-0,55)*	*(-0,89)*	*(-0,89)*	*(1,66)*	
Attack 4	61	0,301	0,798	0,293	0,705	2,77%	0,0447%
t-value		*(-2,03)***	*(-0,32)*	*(-2,44)***	*(-0,60)*	*(21,09)***	
Attack 5	8	-6,611	-1,350	-16,409	-5,752	-0,03%	-0,0039%
t-value		*(-19,71)***	*(-4,11)***	*(-22,84)***	*(-14,87)***	*(-0,14)*	
Attack 6	28	0,332	0,591	0,732	0,127	0,12%	0,0041%
t-value		*(-1,11)*	*(-0,43)*	*(-0,45)*	*(-0,95)*	*(4,32)***	
Attack 7	3	-0,155	-0,222	-0,108	-0,867	-6,27E-07	-8,56E-03
t-value		*(-2,25)***	*(-0,61)*	*(-0,76)*	*(-0,91)*	*(-0,81)*	
Attack 8	58	0,447	0,792	-0,024	-0,435	-0,17%	-0,0030%
t-value		*(-0,72)*	*(-0,21)*	*(-1,47)*	*(-0,93)*	*(-7,01)***	
Attack 9	31	0,098	0,581	0,608	0,370	-0,28%	-0,0091%
t-value		*(-0,71)*	*(-0,47)*	*(-0,35)*	*(-0,58)*	*(-10,58)***	

Table 5: $\hat{d}$ results for cross-sectors comparison. Data: Yahoo Finance and KSE website.

- In brackets the t-value for the test $\hat{d}$ =1; ** : 95% confidence level; *90% confidence level.

The heteroskedasticity based-estimator gives an understanding of the movements on markets in times of stress. An analysis of the market risks' measurement tools helps to determine the effect of this revealed heteroskedasticity. However it should be noticed that the observed difference for a cross-index analysis is not similar to the test conducted on the sample of sectoral data. Decorrelation is an almost permanent phenomenon for cross-index comparison whereas it is not really puzzling at a sector level. It can be explained by the macro-impact of terrorist attacks. Even though some sectors could be more impacted by the attacks (such as airplane or insurance companies for example), this over-exposure to risk does not lead to a significant impact in term of sectors decorrelation. This observation is in any case a good proof of the perception of terrorism. This perception should be modelized by a national perspective as it is mostly perceived as a “national threat”. Consequently the differences in reactions across sectors are quite hard to analyze and conceptualize.

B. Effects on measurement tools

The second series of results is obtained by the computation of diverse risk indicators for the pre-stress period and the stress period. These computations are the first step to build a reliable data set of risk indicators to lead an ANOVA analysis. As a consequence the data set is composed of 252 VaR computations (126 for stress periods and 126 for pre-stress periods), 252 ES computations and 252 EVT computations following the same structure for the cross-index analysis. For a cross-sector analysis the set is more restrained and contains 72 values for each indicator (so 36 for pre-stress periods and 36 for stress periods). Some basic percentage changes are also calculated to identify some trends or to stress the attacks with the biggest impacts.

For each type of indicator, the historical method is used. Basically the distribution‘s characteristics of each sample are used to compute the indicator.

The VaR indicators represent the lower bound of the 95% confidence interval for the expected return. The same confidence level is used for ES (that is the reason why the two computations are not comparable; 95%VaR being closer to 97,5%ES). For the EVT computation it was decided to choose the lower bound of 2-days expected return with 95%. This indicator is much more precise for fat-tails distribution but also less robust offering huge differences from distribution to distribution. The stability of this indicator also gives some hints of the effect of geopolitical disruptions on risk measures. However it should be noticed that in some cases (the cases with a very small number of days of abnormal returns) these indexes are very volatile and it leads to an insignificant ANOVA analysis. Moreover, this analysis is only as good as its assumptions and in the case of terrorist attacks some heteroskedasticity has been revealed. As a consequence, heteroskedasticity tests are also conducted in order to ensure the validity of the results. All theses results are presented in the following tables.

C. ANOVA analysis

An ANOVA analysis helps to determine some global trends framing the "terrorism premium" or discount among markets. The difference in the mean between the pre-stress period sub-sample and the stress period sub-sample helps to determine a "terrorism premium". Whereas the assumption of normal distribution of the risk measures is accepted, the hypothesis on the homoskedasticity is tested for each sample. Leading to perturbations in risk measuring, terrorist attacks can have an impact also on the variance among the measures. This analysis is also a two-step analysis: beginning with a cross-country analysis and finishing with a cross-sector analysis.

i. Cross-country analysis

VaR			
	Coeff	p-value	Adj R^2
Equation 1	**1,85E-03**	7,93%	41,80%
Equation Ams	-2,78E-04	95,60%	23,91%
Equation Ath	**6,51E-03**	5,48%	72,92%
Equation Bse	6,14E-03	11,00%	56,00%
Equation CAC	4,52E-03	27,73%	38,85%
Equation Dax	2,09E-04	95,93%	39,23%
Equation Footsie	-9,86E-04	72,22%	48,88%
Equation Ipc	2,88E-03	43,78%	59,21%
Equation Kse	3,87E-03	11,97%	11,97%
Equation Nasdaq	-2,22E-03	41,49%	82,77%
Equation Nikkei	-1,16E-03	71,36%	27,38%
Equation Sing	4,16E-04	85,63%	72,92%
Equation SSE	**7,79E-03**	3,67%	68,44%
Equation SSMI	-4,33E-05	99,25%	18,72%
Equation TSX	-1,77E-03	50,38%	41,05%
Breusch-Pagan[3]	6,83%		

Table 6: ANOVA Analysis of the impact of terrorist attacks on VaR indicators. Data: Yahoo Finance and KSE website.

3 Breusch Pagan test p-value for equation 1

ES			
	Coeff	p-value	Adj R²
Equation 1	3,53E-04	79,31%	45,74%
Equation Ams	-1,95E-03	75,02%	32,56%
Equation Ath	3,79E-03	25,25%	84,42%
Equation Bse	3,52E-03	36,23%	70,03%
Equation CAC	3,31E-03	47,38%	48,55%
Equation Dax	-2,16E-03	63,16%	52,92%
Equation Footsie	-1,78E-03	56,13%	63,28%
Equation Ipc	3,08E-03	53,43%	58,18%
Equation Kse	-9,61E-04	87,24%	50,23%
Equation Nasdaq	-5,06E-03	24,93%	72,82%
Equation Nikkei	-8,36E-04	84,91%	14,88%
Equation Sing	1,22E-03	72,24%	69,83%
Equation SSE	7,38E-03	10,99%	76,84%
Equation SSMI	-1,68E-03	80,70%	13,72%
Equation TSX	-2,96E-03	28,80%	64,80%
Breusch-Pagan [4]	2,38%		

Table 7: ANOVA Analysis of the impact of terrorist attacks on ES indicators. Data: Yahoo Finance and KSE website.

EVT			
	Coeff	p-value	Adj R²
Equation 1	1,13E-03	23,25%	8,83%
Equation Ams	5,22E-03	15,00%	35,43%
Equation Ath	2,60E-03	16,89%	2,19%
Equation Bse	**3,24E-03**	0,45%	81,81%
Equation CAC	3,12E-04	91,35%	46,24%
Equation Dax	1,32E-03	62,03%	84,84%
Equation Footsie	**2,31E-03**	2,30%	89,91%

[4] Breusch Pagan test p-value for equation 1

Equation Ipc	**2,75E-03**	0,37%	87,37%
Equation Kse	1,98E-03	29,80%	55,93%
Equation Nasdaq	-6,26E-04	78,29%	30,54%
Equation Nikkei	3,18E-04	81,60%	57,34%
Equation Sing	-4,56E-05	96,47%	77,61%
Equation SSE	4,94E-04	86,18%	22,00%
Equation SSMI	2,64E-03	36,10%	38,92%
Equation TSX	-6,69E-03	43,43%	48,42%
Breusch-Pagan[5]	11,55%		

Table 8: ANOVA Analysis of the impact of terrorist attacks on EVT indicators Data: Yahoo Finance and KSE website.

ii. Sectoral analysis

VaR			
	Coeff	p-value	Adj R²
Equation 1	**-2,43E-03**	4,19%	62,60%
Equation Bank	-2,21E-03	28,99%	62,66%
Equation Ins	-1,70E-03	45,36%	43,89%
Equation Ind	-2,05E-03	43,93%	69,01%
Equation Trans	-3,74E-03	13,62%	71,44%
Breusch-Pagan[6]	14,64%		

Table 9: ANOVA Analysis of the impact of terrorist attacks on VaR indicators (sectoral analysis). Data: Yahoo Finance and KSE website.

5 Breusch Pagan test p-value for equation 1

6 Breusch Pagan test p value for equation 1

ES			
	Coeff	p-value	Adj R²
Equation 1	**-3,89E-03**	1,36%	64,38%
Equation Bank	2,90E-03	30,57%	62,04%
Equation Ins	-1,94E-03	53,91%	43,12%
Equation Ind	-3,93E-03	25,63%	66,89%
Equation Trans	**-6,79E-03**	8,66%	67,55%
Breusch-Pagan[7]		8,10%	

Table 10: ANOVA Analysis of the impact of terrorist attacks on ES indicators (sectoral analysis). Data: Yahoo Finance and KSE website.

EVT			
	Coeff	p-value	Adj R²
Equation 1	-1,59E-04	77,76%	46,40%
Equation Bank	-7,38E-04	56,99%	36,82%
Equation Ins	-4,41E-04	58,95%	79,80%
Equation Ind	3,54E-04	78,86%	44,10%
Equation Trans	1,89E-04	83,64%	33,34%
Breusch-Pagan[8]		0,01%	

Table 11: ANOVA Analysis of the impact of terrorist attacks on EVT indicators (sectoral analysis). Data: Yahoo Finance and KSE website.

[7] Breusch Pagan test p value for equation 1

[8] Breusch Pagan test p value for equation 1

IV. DISCUSSION OF RESULTS

After studying the impact of terrorism on market risk assessment, it is important to connect these numbers with the facts and consequently to conduct more qualitative approach. The discussion of results will also follows the structure of the "results" section. At first a study of the heteroskedasticity-based estimator helps to determine the existence of an impact on risk measures after terrorist attacks. Secondly, the ANOVA analysis frames this possible impact and gives some insights on numeric values. Thirdly a lack of convergence in the results can be completed by more qualitative and geopolitical analysis.

A. REVEALED HETEROSKEDASTICITY

i. OVERALL RESULTS

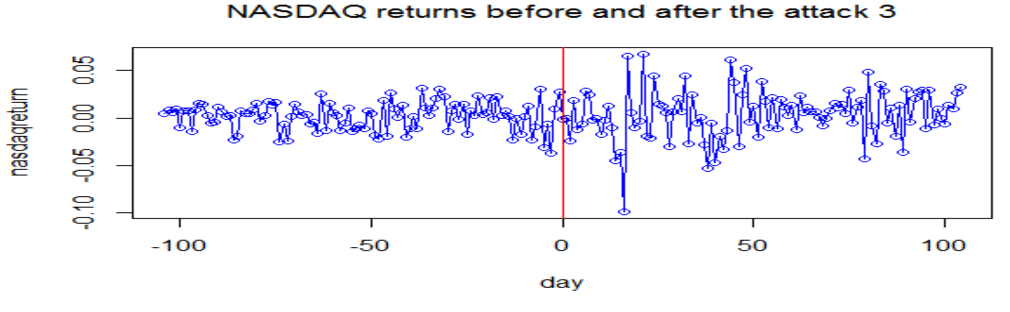

Figure 1: NASDAQ returns before and after the attack 3. Data: Yahoo Mail

Table 4 already gives some insights concerning a possible "terrorism risk premium". The NASDAQ is a benchmark in our study as it is the leading indicator and the US has a meaningful experience with terrorism. A significant difference between the pre-stress period and the stress period for the NASDAQ is present in 7 out of 9 attacks. This significant difference between pre-stress period and stress period consists in either an increase of the NASDAQ variance (see Figure 1) or a decrease of the NASDAQ variance (see Figure 2).

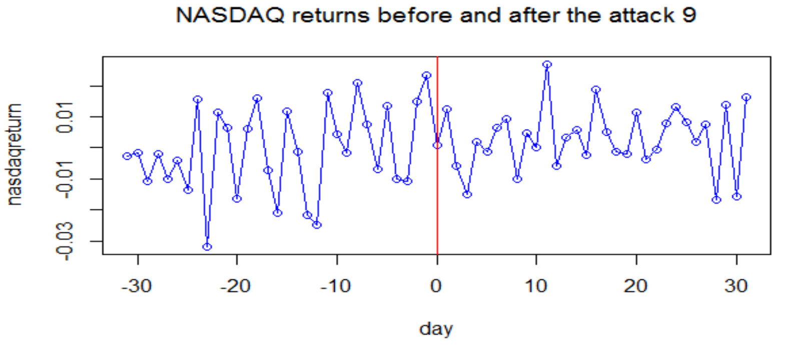

Figure 2: NASDAQ reaction before and after the attack 9. Data: Yahoo Finance

One of the basic interpretations of the results is that there exists no simple rule defining the impact of terrorism on market risk.

The 2 attacks leading to an insignificant change in the variance of the NASDAQ are attack 5 (in Moscow, Russia) and attack 7 (in Beslan, Russia).

Out of the 7 significant differences in the variances observed, 5 attacks (attack 1 in Tokyo, Japan; attack 2 in Oklahoma, US; attack 3 in Nairobi, Kenya; attack 4 in New York City, US and attack 6 in Madrid, Spain) lead to an increase of the variance and 2 to a decrease of the variance of the NASDAQ's returns (attack 8 in Mumbai, India and attack 9 in Sinjar, Iraq). The correlation between the attacks, their target and the market reaction of the NASDAQ may be intuitively understood. When a major partner or the US is concerned the variance of the NASDAQ increases.

It is even more accurate when an American target is under attack of a foreign group (like the attack of the American embassies in Africa in year 1998 or the World Trade Center in year 2001). These attacks produced the biggest differences of the variances in the sample. A behavioral approach explains that these new terrorist modus operandi impacted investors' behavior way more than an already known danger. The attack of the American embassies and the 9/11 represents both awereness of an unexpected danger and quite unknown threat (because it is coming from abroad). That might be the reason why the Oklahoma attack had a smaller impact in terms of change on the NASDAQ variance. The Oklahoma attack was conducted by a national terrorist belonging to the Militia Movement (an already known actor in the American internal geopolitical frame).

The attacks impacting developing countries (attack 8 in India and 9 in Iraq) produced the inverse effect. The variance of the NASDAQ decreased. It is probably explained by slightly higher returns due to the rebalancing of portfolios from ermerging countries to safer-looking places (as shown on Figure 2). This trend is smooth, coming from day to day rebalancing (after the information releases for example) and does not create any disruption on the index movements. Moreover, for an investor in American stocks it is really hard to consider the linkage between US markets and safety in developing and emerging countries.

There are furthermore only 2 attacks having an insignificant impact on the change in variance, both targeted Russia. A possible way to interpret this fact is that American and Russian markets are not interconnected and/or that Russia is seen as a country that can not be compared with the US (notably in term of macroeconomic aggregates). Furthermore, a distinction in terms of investment behavior might be created between investors in the US and investors in Russia. The two countries are not facing the same growth path, the same political linkages and the same market structures. As a consequence, attacks in Russia will not create a rebalancing from Russia to US markets.

Additionnaly, this proven heteroskedasticity can be also explained sector by sector (cf Table 5). Out of 36 cases, 13 show a significant difference in the sector movements with respect to the NASDAQ. The bank sector is the one having the biggest difference in the variance. In 5 cases out of 9 the banking sector has a $\widehat{d}$ significantly different from 1. It enlights the particularity of the banking sector. It is also linked with the insurance sector (having a significant difference in terms of variance for 4 cases out of 9). Sectors of the real economy (Industry and Transport in the study) are less likely to experience these distortions after terrorist attacks. All these disruptions on an indexes or a sectoral level are worth to study attack by attack to understand the dynamic of each of them. These observations could reinforce the importance of the psychological dimension of terrorist attacks' impact. Traditional sectors are not expecting any material destruction, so their indices are following the NASDAQ one. Banks and Insurance are nevertheless more impacted by markets behaviors.

ii. *ATTACK BY ATTACK APPROACH.*

As seen in Table 4, a simple positive or negative premium is really impossible to define but several factors could explain the different factors, index particularities and attacks particularities. The heteroskedasticity of the NASDAQ is the benchmark for all measures.

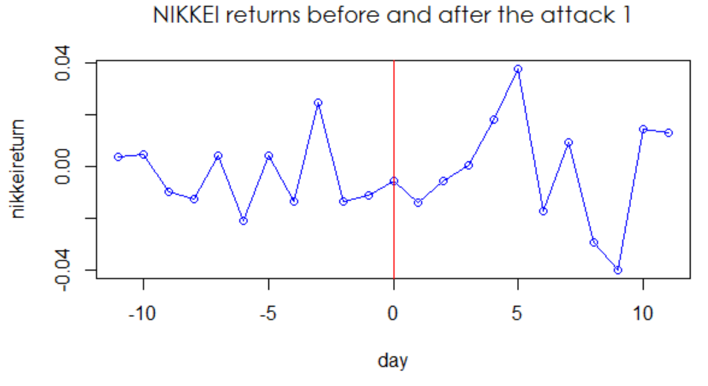

Figure 3: Nikkei reaction before and after the attack 1. Data: Yahoo Finance

The abnormal returns period of the first attack (Tokyo's one, as observed on Figure 3) is only of 11 days. None of the market has been clearly impacted by this attack (even if the NIKKEI is a part of the sample). The NIKKEI has the higher $\hat{d}$ but it is insignificant as the disturbances created on the covariance (NIKKEI ; NASDAQ) are very volatile. The observed heteroskedasticity for all Asian markets except for Bombay Stock Exchange index (Karachi Stock Exchange, Shanghai Stock Exchange) is positive as for the NASDAQ. The estimator for the IPC index (MEXBOL) is also positive. All these positive estimators are insignificant. As a consequence; the high level of non-consistent movements and high variance in the estimator lead to the insignificancy of the increase for these estimators. Therefore this set of value appears as following the same change terms of variance than the NASDAQ. A pure spill-over effect can be explained consequently.

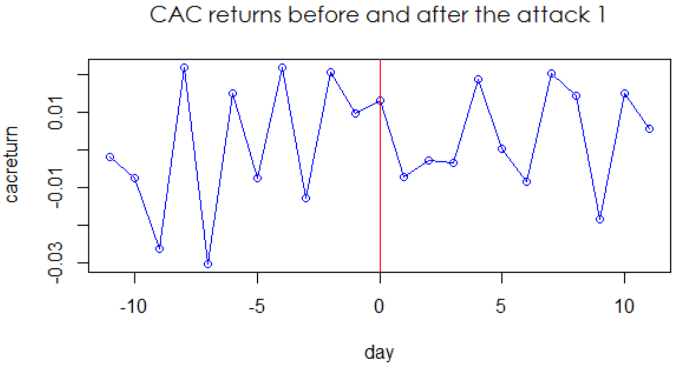

Figure 4: CAC reaction before and after the attack 1. Data: Yahoo Finance

On the contrary, the other observed movements on the markets variances are negative. For the rest of the indexes a significant negative $\hat{d}$ is observed (for all European Indexes, the Australian Stock Exchange Index, the Singapore Stock Exchange Index and the Toronto Stock Exchange Index as it can be seen on Figure 4). The rebalancement of portfolios following the attack may generate the negative estimator for those indicators (countermoverment between the directly impacted indexes and the indexes representing a solution for portfolios rebalancement). This lower variance might be also a consequence of a new awareness of the real risk factors for western or unconcerned countries. Alternatively this lowering can also come from poor linkage among countries.

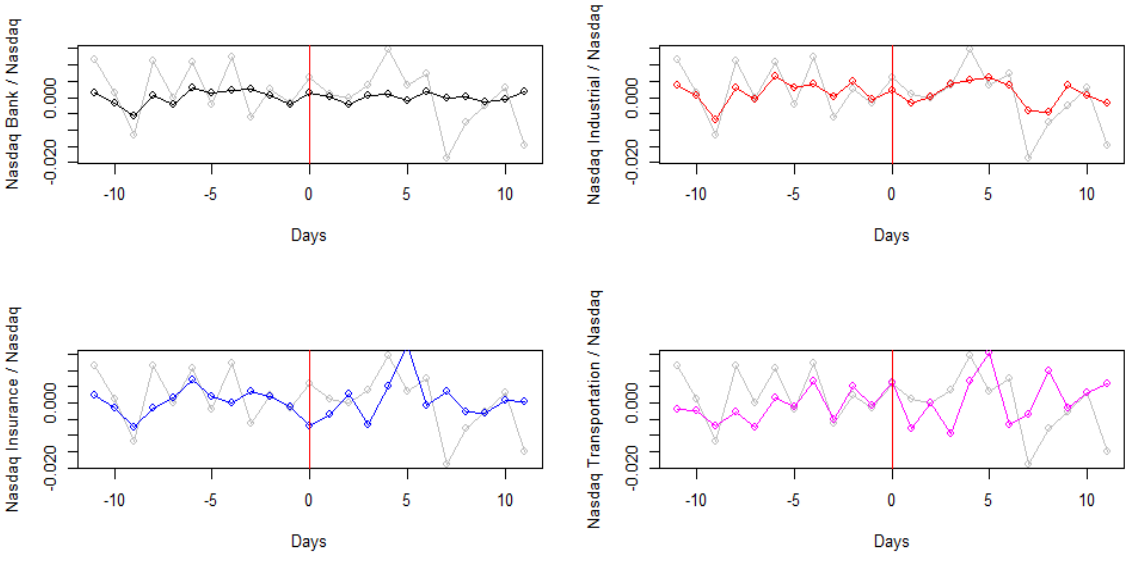

Figure 5: Sectoral indices evolution before and after the attack 1. Data: Yahoo Finance

A sectoral comparison shows that the NASDAQ reaction is not equal among sectors. All studied sectors have a significantly negative $\hat{d}$. The attack also creates internal disruptions on the intra-index variance-covariance matrix. The $\widehat{ds}$ diminishe for the sectoral indices but the variance increases for the whole index. As a consequence, the variance for the remaining sectors (with unavailable data such as IT sector which is highly connected with the Japanese market and/or the commodity indice) may have increased a lot more than the observed change at the index level.

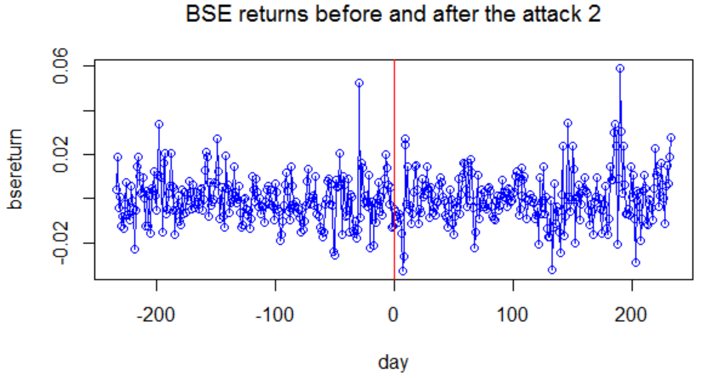

Figure 6: Bombay Stock Exchange reaction before and after the attack 2. Data: Yahoo Finance

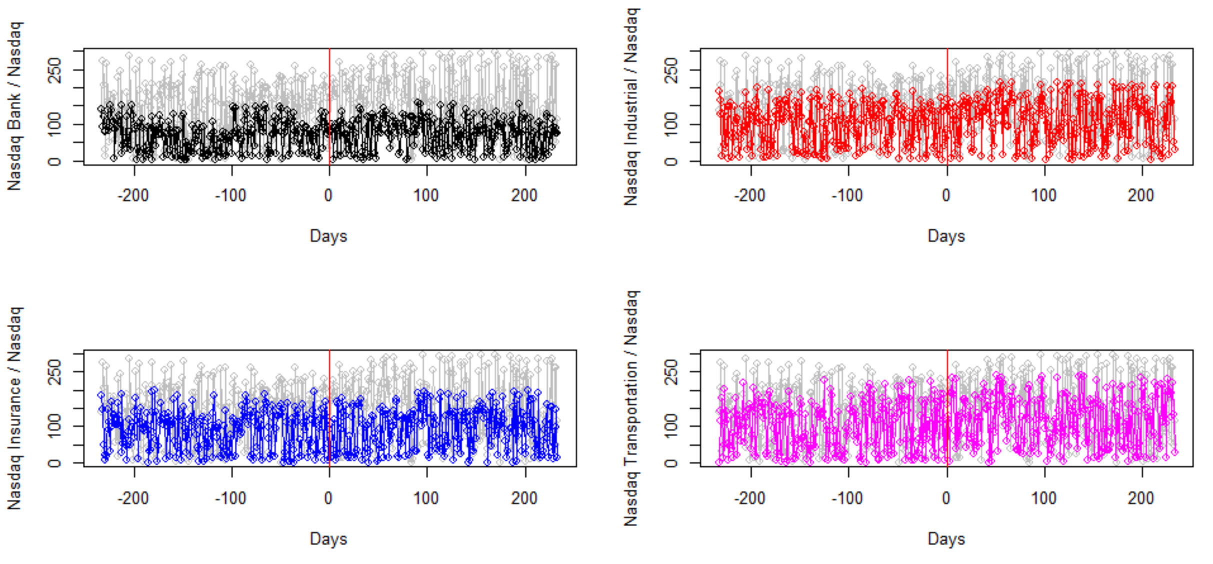

Figure 7: Sectoral reactions differences before and after the attack. Data: Yahoo Finance

Attack 2 is an attack on the rail network of Mumbai, India. Bombay Stock Exchange is surprisingly almost not impacted by this attack (see Figure 6, where negative returns are observed for the first days following the attack). NASDAQ has been the most impacted index by this attack. Out of the 14 indexes of the sample, 9 had a $\hat{d}$ not significantly different from 1 (at a 90% confidence interval). The total spill-over effect can thus be clearly justified for this attack. On the contrary, there exist 5 indexes having a $\hat{d}$ significantly different from 1 (Amsterdam Stock Exchange Index, Australian Stock Exchange Index, Swiss Stock Market Index, Toronto Stock Exchange, and DAX). These 5 indexes have a $\hat{d}$ really close to 0 meaning that their variations are really minor compared to the NASDAQ's one. On a sectoral level, whereas Transportation and Industrial sectors have a $\hat{d}$ belonging to the 90% confidence interval for $d = 1$, Banks and Insurance sectors are significantly different from 1 and very close to 0. Banks and Insurance sectors are thus really resilient to this attack (see Figure 7).

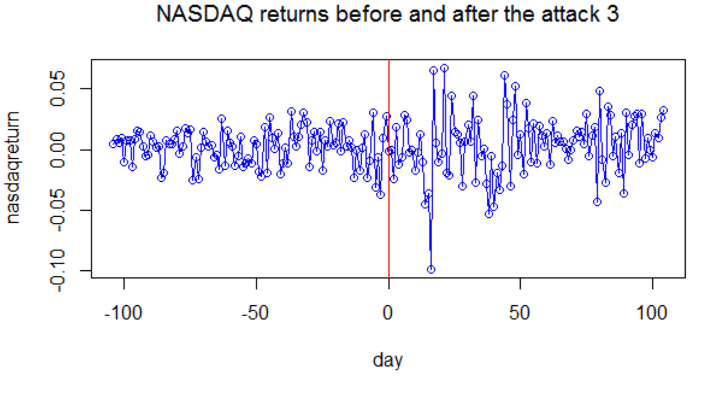

Figure 8: Nasdaq reaction before and after the attack 3. Data: Yahoo Finance

The attack 3 is the so called "American Embassies in Africa Attack". Logically the NASDAQ is the most impacted index in the sample (see Figure 8). 13 indexes out the 14 in the sample have a $\hat{d}$ belonging to the 90% confidence interval for $d = 1$. The increase in the variance of the NASDAQ is then followed by other indexes' movements which can be compared to the NASDAQ's ones (Australian Stock Exchange being the only index with a significant lower $\hat{d}$). In that case, Australian Stock Exchange can be seen as a safe place (with a $\hat{d}$ close to zero showing the lack of influence on Australian Stock valuation). On a sectoral level all estimators belong to the confidence interval for $d = 1$. The results for the attack 3 are totally in line with the total spill-over effect across sectors and indexes.

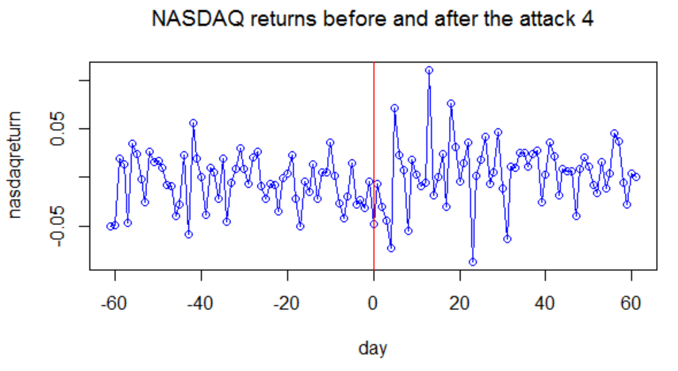

Figure 9: Nasdaq reaction before and after the attack 4. Data: Yahoo Finance

The attack 4 (the 9/11) had a huge impact on the NASDAQ too (see Figure 9). Unlike the attack 2 the spill-over effect is not that puzzling. 9 out of 14 estimators have a $\widehat{d}$ significantly different from 1. However the spill-over effect is confirmed for Amsterdam Stock Exchange Index, Athens Stock Exchange Index, Bombay Stock Exchange Index, Singapore Stock Exchange Index and Shanghai Stock Exchange Index.

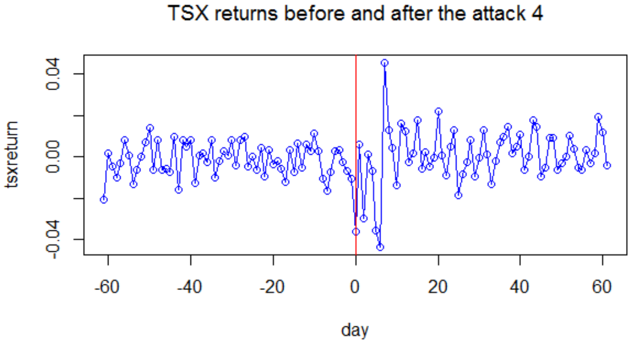

Figure 10: Toronto Stock Exchange reaction before and after the attack 4. Data: Yahoo Finance

For the rest of the sample some of them experience a lower change in terms of variance (Footsie, Nikkei, and Australian Stock Exchange Index) whereas others experience a negative change in terms of covariance (for the CAC40, the IPC (MEXBOL), the Swiss Stock Market Index, the Toronto Stock Exchange Index, the Karachi Stock Exchange Index, and the DAX). It can be a result of rebalancing from an "unsafe" place to a safer environment. Figure 10 shows that the Toronto Stock Exchange appears as having slightly higher returns after the attack than before (after a period of negative returns which can be explained by the closure of the NASDAQ during 6 days).

On the sectoral level there is a significant spill-over effect for Transportation and Industrial indexes whereas Banks and Insurance sectors are less impacted (it was also the case for Attack 2). The impact on the industrial index is easily explainable by the fact that airlines were expecting huge changes with respect to security and regulations of their activities.

The attack 5 produced much more different results than the previous ones. Russia was assaulted by a Chechen commando in a theater, Moscow City. First the impact on the dataset of indexes is quite low (only 8 days of abnormal returns). Our choice of indexes contains mainly indexes from Western Europe, North America and South-East Asia. It may engender this narrow effect (no countries politically or geographically close to Russia included in the dataset). For that case the heteroskedasticity of the NASDAQ is not stastitically significant (see Figure 11). This insignificancy leads to really high estimators for the majority of our indexes. As all $\hat{d}$ have a numerator really close to 0, their values are driven up. They are just significantly higher than the limit of a 90% confidence interval. As a consequence some indexes are quite stable even after the attack but have a high $\hat{d}$ (such as DAX with a $\hat{d}$= -20.293). The results are the same for the sectoral indexes.

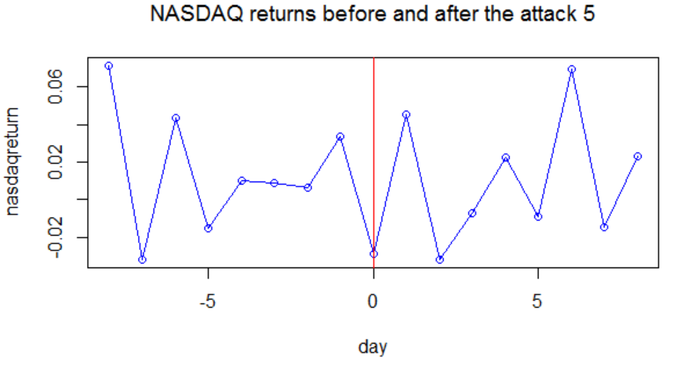

Figure 11: Nasdaq returns before and after the attack 5. Data: Yahoo Finance

The attack 6 is the attack on the rail network in Madrid. The attack had a significant effect on the DAX (as a leading European index, see Figure 12) but also on the NASDAQ. 11 out of the 14 indexes have results that are not significantly different from 1. The spill-over is consequently confirmed for these indexes. On the contrary, the Australian Stock Exchange Index, the IPC (MEXBOL) and the Singapore Stock Exchange Index have $\widehat{d}$ really close to 0. As a consequence these indexes appear as more resilient and less impacted than the rest of the sample. Sectoral indexes have a $\widehat{d}$ no different from 1 in each case.

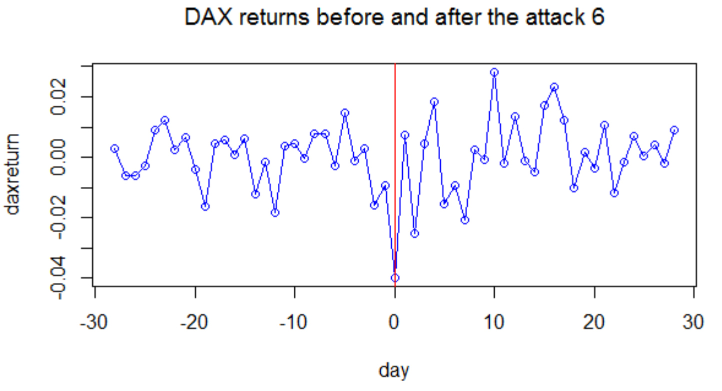

Figure 12: Dax returns before and after the attack 6. Data: Yahoo Finance

The attack 7 also took place in Russia. Firstly, the number of abnormal returns' days has to be noticed: only 3 (what significantly means the poor impact of the attack on the sample). The observed results for NASDAQ are in line with those of the attack 5. If the NASDAQ variance experienced no significant change, the other indexes $\hat{d}\,s$ are not significantly different from 1 (except for Bombay Stock Exchange Index and Australian Stock Exchange Index with significantly negative $\hat{d}\,s$).

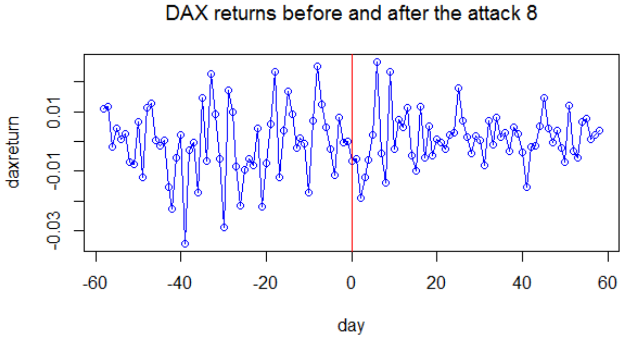

Figure 13: DAX returns before and after the attack 8. Data: Yahoo Finance

The attack 8 has a longer abnormal returns period. This attack concerned the rail network of Mumbai. Surprinsingly this attack did not induce any increase of the variance for the Bombay Stock Exchange as expected in our hypothesis. It represents a surprising resilience of these investors in Mumbai compared to western investors (it could be also explained by the fact that investors of the Bombay Stock Exchange are not domestic investors). It constitutes the first example of a negative difference in the variance for the NASDAQ in the sample. This decrease is followed by 10 indexes (see Figure 13 for an example on the DAX). Several reasons and logics are prone to explain this decrease. The most probable one might be a rebalancing of the portfolios from India to safer places (as NASDAQ and DAX are defined). However this attack also created a $\hat{d}$ significantly different from one for three European indexes (CAC 40, Athens Stock Exchange Index and Amsterdam Stock Exchange Index). Different timings for their rebalancement compared to the DAX or NASDAQ ones might cause this deviation. The covariance change between the NASDAQ and such indexes is consequently positive even if these indexes experience a reduction of the variance (see Figure 14). Consequently, this reduction in terms of variance (when the covariance between the ATH, AMS, CAC and the NASDAQ increase) is explained by NASDAQ movements towards a regular growth path. These movements are even more important for the above-mentionned indexes and lead to a more regular returns path. The strict spill-over effect is respected for all sectors.

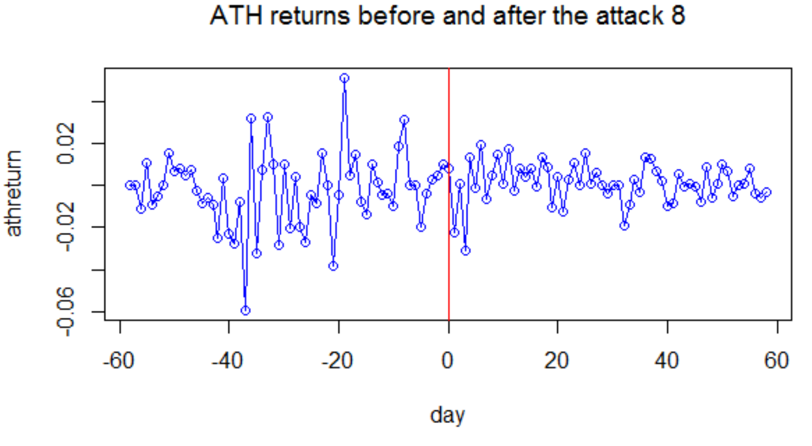

Figure 14: ATH returns before and after the attack 8. Data: Yahoo Finance

The attack 9 (ethnic attack in the region of Sinjar, Iraq) also implied a decrease in the variance for the NASDAQ. This attack implied an increase on the KSE's variance (with a t value close to a 90% significancy level). It is a significative change with respect to the results obtained for the eighth attack, as the Karachi Stock Exchange could be considered as the closest index to the attack in the sample. This time the pure spill-over effect is respected and there exists no $\hat{d}$ different from one. This effect is also confirmed on a sectoral level.

In conclusion, the first sight on the heteroskedasticity observed in the sample leads to different analyses with respects to the particularities of each attack but also of each index (and/or country specificities).

iii. Implications in terms of Beta measurement.

These particularities have some consequences on basic risk measurement of the indexes' βs. The computed $\hat{d}$ is the ratio of the explained difference in covariance between the index and a reference index (here the NASDAQ) on the variance of this reference index. Assuming perfectly correlated markets, a $\hat{d}$ different from 1 means a disruption for the β measurement (which is assumed to be equal to 1 if markets are perfectly correlated). Furthermore to know if the heteroskedasticity created by the attacks induces a disruption in the Beta measurement of the stock index, it is useful to test if $\beta_{hist} = \hat{d}$ (if the normal beta can be induced by the measurement of the $\hat{d}$ which links the covariance of indexes with the referential on the referential variance).

Therefore, we should compare historical betas on a yearly basis with the measurement of $\hat{d}$ we had. This issue is quite hard to tackle as Forbes and Rigobon (2002) noticed, the induced heteroskedasticity makes it quite impossible to compare comovement's estimates during a crisis time and in more normal times. Moreover, this heteroskedasticity is also confirmed in the sample of $\hat{d}$ (quite high standard deviations for numerous observations and an almost constant returns' path in other cases). The heteroskedasticity created for the returns is followed by a heteroskedasticity of the risk measures (such as β or $\hat{d}$ in this study). Further study of other risk measures will deepen this first sight on the issue. As a consequence, terrorist attacks create a really specific subset of data having its own parameters of distribution.

B. ANOVA TEST

i. COUNTRY BY COUNTRY, SPILL-OVER EFFECTS

The first approach is dealing with results regarding "official" measures of risk: VaR and ES. Classical measures of risk do not exhibit any significant changes after terrorist attacks. Moreover the Breusch-Pagan test indicates that the homoskedasticity hypothesis is not rejectable. However Table 6 shows that some risk discount exists if we take into account all the VaR values in the sample. This implies that on average after terrorist attacks the 5th percentile of distribution of the indexes'returns is higher than before the attacks. It can be explained by a catch-up process (to recover the index value before the attacks, markets exhibit higher returns), moreover the losses directly following the attacks are not significant enough to counterbalance this mechanism. The significancy of these results should however be weighted with the low R^2

observed in this case. This phenomenon is nevertheless not observed with the ANOVA analysis of ES. This is explained by the fact that terrorist attacks create extreme losses and extreme movements and countermovements in the decision making-process of investors. The period following the attack is basically a period of uncertainty but the period of abnormal returns as used in the thesis is longer than the one of returns lead by such feelings as it also covers the catch-up process following the period of uncertainty. The extreme losses following the attacks lower nevertheless the expected value of the indexes's return in the 5% worst scenario. The design of a measure such as ES made the counterbalance of the catch up mechanism possible in the risk measurement.

The first subset distribution's parameter that is tested is the mean of several basic risks measures such as VaR, Expected Shortfall and Block Minima expected return for 2 days.

The first check for differences in the means of the two subsamples of the risk estimators leads to a risk discount for VaR and EVT computation at a 10% significancy-level. This positive premium is confirmed for results derived from observations on Athens Stock Exchange Index and Shanghai Stock Exchange Index. With regards to the others estimators computed no inference on a systematic premium is valid. A complementary study conducted with EVT computations shows approximately the same results than the one with ES except for index-specific computations showing that overall BSE, IPC and FOOTSIE have a risk discount on the period following the terrorist attacks. It should however be remembered that even if the R^2 is rather high in the three identified cases, the homoskedasticity assumption is often rejected (see results for p-value of Breusch-Pagan test).

Overall these 3 sets of results offer a remarkable example of the discrepancies existing among risks measures and the impact of an event which creates a statistical redistribution of returns by a really atypical manner. It leads to some interesting policy implications for the use of such measures, which are complementary and should be used by taking into account their definitions and specificities.

On the contrary, the use of ES has no-significant effect for a restricted ANOVA. As a consequence, the change of the VaR is mostly explained by the presence of extreme values in the sample (fat tails not being taken into account in VaR computations). EVT leads to some significant computations and all positive. Two facts can produce this discount:

- The recovery path induced higher growth (i.e after the attacks effects being vanished a recovery path with higher returns is needed to recover the previous level of the stock index – this is also a phenomenon connected with the definition used for abnormal returns).

- This effect could have been multiplied by the choice of the 2 days expected returns lower bound of the confidence interval.

Moreover, it is easily observable that these significant coefficients exist just for few observations. The relationship between terrorism and variance increase (or risk estimators increase) is not stationary (as it can be seen on Figure 17).

ii. Sectoral aspects

The complementary measures on sectoral indexes lead to quite different interpretations. The first one is the absence of risk discount in each case whereas VaR computations exhibit a risk discount for index-wide measures. However the induced heteroskedasticity is more important at sector level than at country level. It means that the changes in terms of risk across sectors can be even more significant than across indexes whereas the decorrelation across indexes is more significant than the one across sectors (remember the conclusions on the heteroskedasticity based estimators). Moreover we observe that using ES computations, there is a huge increase in term of risk for the transportation sector. This is in line with the use of transports as a vector for terrorist attacks and the post-attacks impact on that sector (i.e. airlines after the 9/11). As a consequence, sectoral specificities can lead to important extreme losses which are not translated by all risk measures. The EVT measures on the contrary do not induce any significant changes in term of risk.

This observation of the different results is very interesting from a methodological point of view. Heteroskedasticity-based estimators do not induce a change in term of variance (countermoves appear within the range of the previous variance). It can lead to discrepancies between multivariate and univariate risk measures. Moreover, as the distribution of returns does not strictly follow a normal law, there are some discrepancies remaining among univariate estimators because of fat tails but also maybe of skewness of the returns as it is shown in Figure 15 for skewness and Figure 16 for kurtosis.

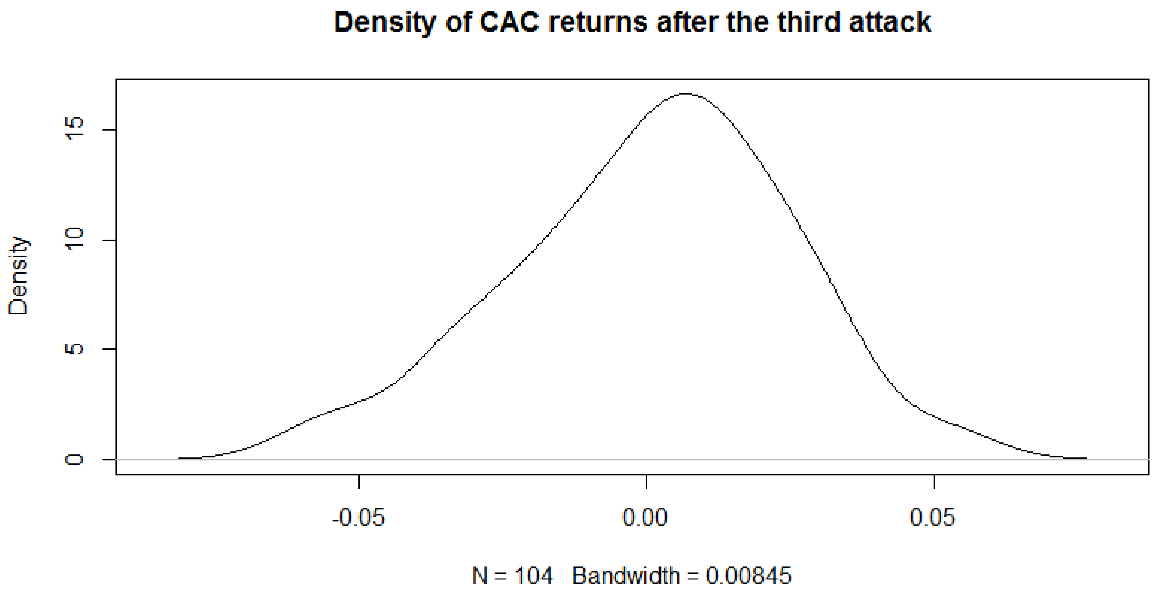

Figure 15: An example of skewness: the distribution of CAC returns after the attack 3. Data: Yahoo Finance

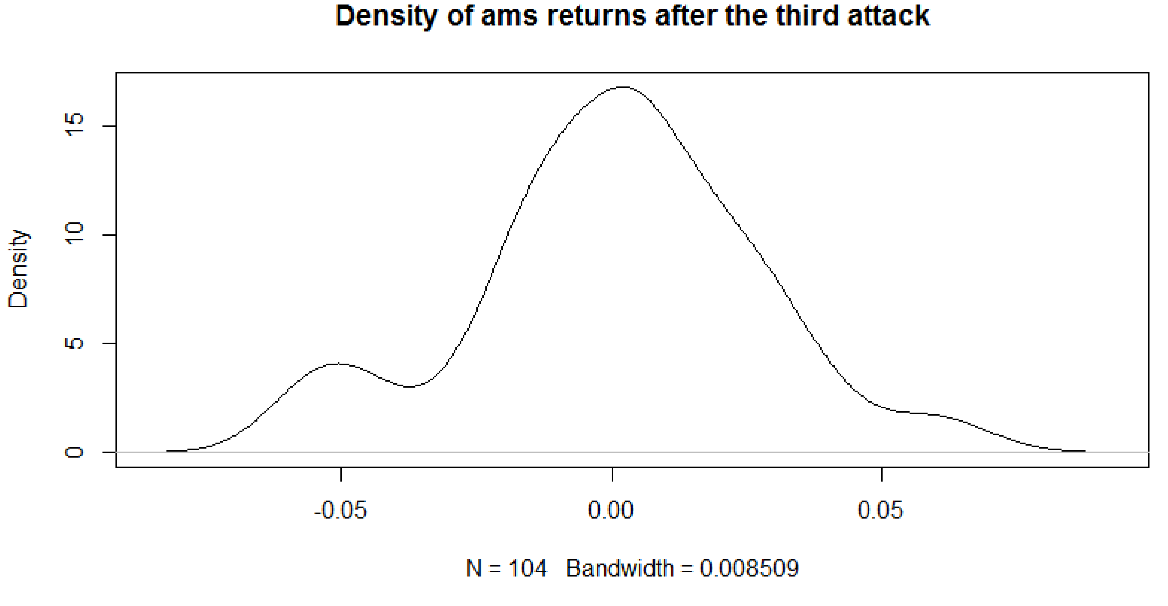

Figure 16: An example of kurtosis: the distribution of AMS returns after the attack 3. Data: Yahoo Finance

iii. TIME EVOLUTION

The ANOVA analysis (to conduct a study dealing with the correlation of risk measures changes and terrorist risk) is quite impossible to lead. The main problem remains the heteroskedasticity among the sub-samples. First of all, each attack has its own particularities, as denoted in the data description part. As a consequence the ANOVA analysis compares the indexes with subsamples having different distribution parameter (and not only in terms of means: in that case it will be determined by the ANOVA, but also in terms of variance). Actually, the terrorist attacks have diverse effects with respect to the concerned index and the particularities of the attack. The time evolution of the risk measure, in average, does not lead to impressive results. However, no linear trends are observed through time and this leads to very volatile characteristics in a time frame.

Moreover, it is really hard to have a balanced sample of observations (it was the main issue in the study). Either the sample remains consistent and homogeneous in terms of results (i.e all experiencing the same impact of the attack on their stock market) or it aims at showing a variousness of effect (i.e some counter-reactions could be observed but it leads to high heteroskedasticiy in the sample).

Furthermore, the heteroskedasticity due to indexes' specificities or even more on the variances of the indexes due to the timing also generates non-robust estimator for a classic OLS regression (high discrepancies due to the factor time could be observed even in non-stress times, see Figure 17). As all values are negative, a positive difference results in a negative premium of risk and negative difference implies a positive premium.

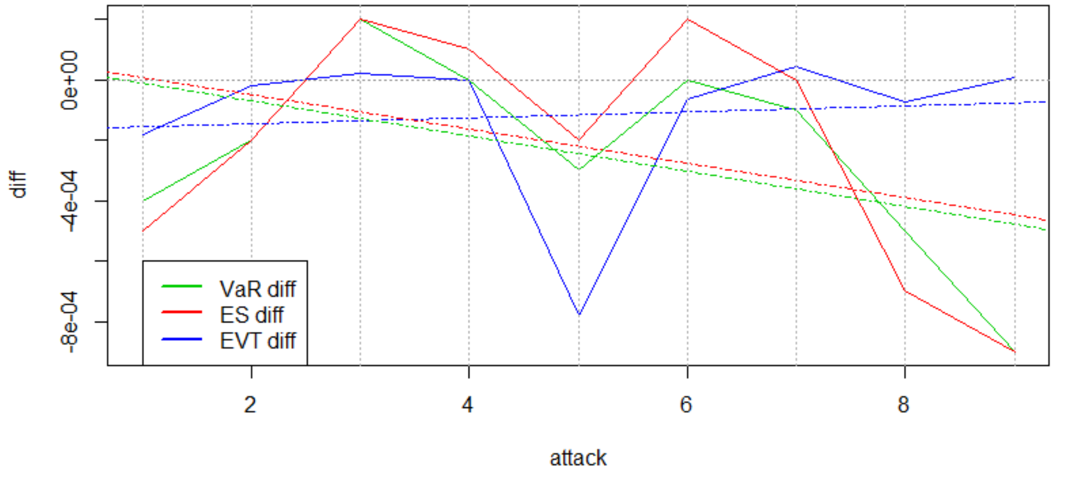

Figure 17: Time Evolution of the mean difference between "normal" period and "stress period". Data: Yahoo Finance and KSE website.

C. THE EFFECT OF AN OVERALL HETEROSKEDASTICITY

Several factors of heteroskedasticity might explain difficulties to understand the relationship between terrorism risk and thus its translation into the risk measures. Additionnaly, risks measures are really volatile depending on business cycles, domestic economic evolutions and changes at firms' level. Hence cautiousness is very important to study the results of studies tackling the issue of the impact of terrorism on risk measures.

i. EXPECTED HETEROSKEDASTICITY IN THE SAMPLE

Because of the factoral nature of the explanatory variables in the sample, basic heteroskedasticitiy tests do not give precise results. However a simple Breusch-Pagan test for the different populations already gives some hint. Even if on a plot representing the whole population of risks measures the heteroskedasticity is not easily detectible (see Figure 18) a more detailed analysis shows some trends specific for each index.

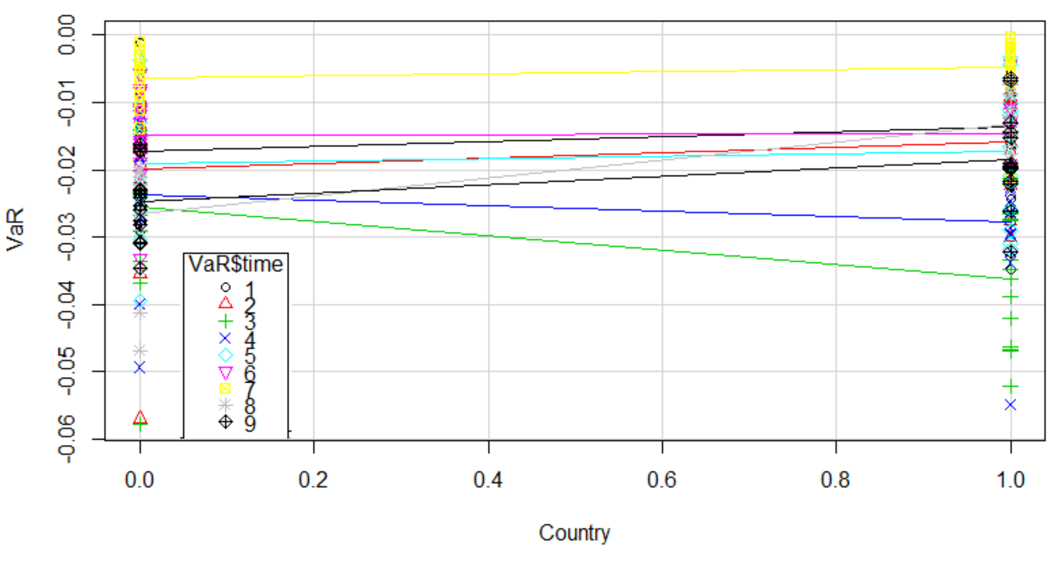

Figure 18: Risk measures heteroskedasticity (pre attack and post attack means comparison per attack). Data: Yahoo Finance and KSE website.

If no obvious heteroskedasticity appears in the cross-country sample it is although observable at a country level (in other terms whereas the risk measures rise in some countries at some times it could decrease in some others at the same time). On the cross-country sample no heteroskedasticity is observed because of this redistribution of values. Nevertheless, inta-sarmple movements and heteroskedasticity exist (see the example of NASDAQ and VaR in Figure 19).

This intra-sample or country-specific heteroskedasticity lead to errors in the measurement at a country level but also creates discrepancies in the measure of attacks' effect on risk measures. In our example we can see that the variance among the measures increases, but for some other indices the contrary can hold (see Figure 20 and the example of the Australian Stock Exchange Index).

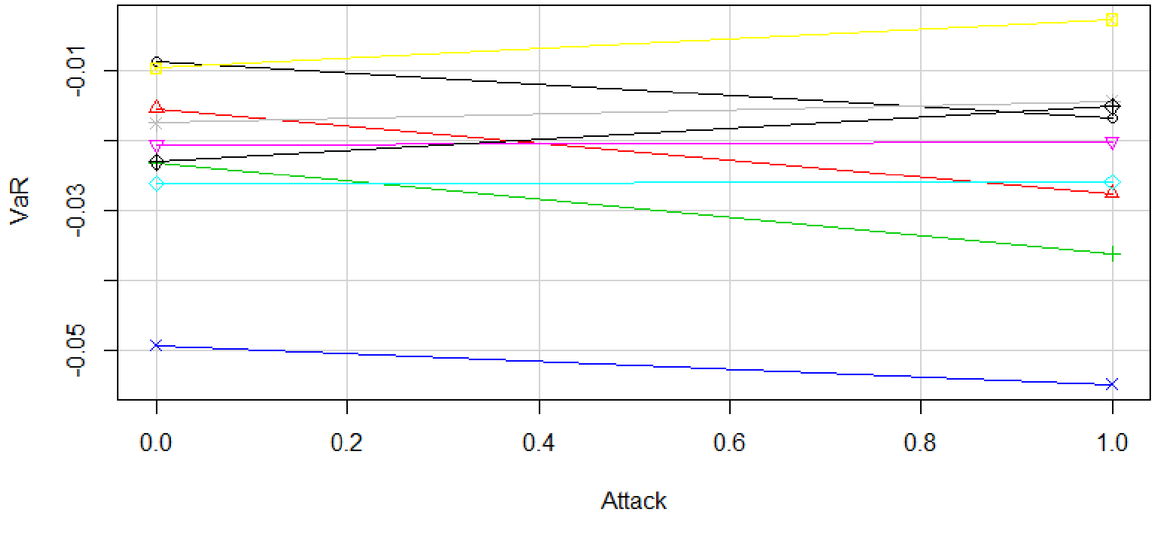

Figure 19: Redistribution of VaR values for the NASDAQ after the attacks. Data: Yahoo Finance

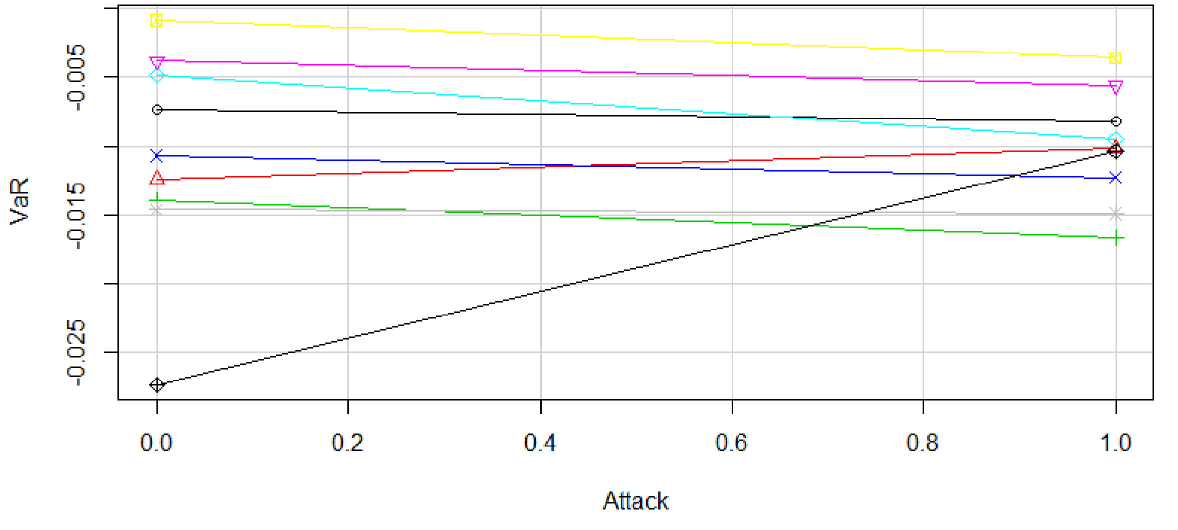

Figure 20: Redistribution of VaR values for the ASX after the attacks. Data: Yahoo Finance.

ii. Perfect framework for a event study technique development

With respect to these previous observations, it is interesting not to test a rule of thumb for the effect of terrorist attacks on risk measures but to observe the evolution at the closest level. Table 12 thus summarizes the movements of risk measures for our indexes after each attack.

For each index, 3 cases are identified:

- Increase of the risk measure
- Decrease of the risk measure
- No movements of the risk measure.

Each attack is then analyzed as belonging to one scenario or another. The number of the attack is finally written on the right column. We can already draw some conclusions. The first one is that results for VaR and for ES are almost in line. The kurtosis which can be observed after some attack does not disturb the distribution of the risk measures more than expected by the VaR. The results from ANOVA analysis are thus explained by a different magnitude of the risk measures' increase/decrease (e.g. VaR measures increase/decrease less than ES following a predetermined attack) and not by opposite changes between ES and VaR. Table 12 does not take into account the intensity of the migration smoothing theses difference between VaR and ES measures.

	VaR				ES			
	Disp*	Increasing VaR	Decreasing VaR	VaR=	Disp*	Increasing ES	Decreasing ES	ES=
AMS	+	2,5,7,8,9	3,4,6	1	+	2,5,7,8,9	3,4,6	1
ATH	=	1,4,5,7,8,9	3,6	2	+	1,5,7,8,9	3,4,6	2
ASX	-	2,9	3,4,5,6,7	1,8	-	2,9	1,3,4,5,6,7,8	
BSE	-	1,3,6,8,9	2,4,7	5	-	1,3,6,8,9	2,4,5,7	
CAC40	+	1,2,5,7,8,9	3,4,6		+	1,2,5,7,8,9	3,4,6	
IPC	=	1,2,5,8	3,7	4,6,9	=	1,2,5,6,8	3,7	4,9
SING	+	1,2,7,8	3,4,5,6,9		+	1,2,7,8,9	3,4,6	5
SSMI	+	1,2,5,7,8,9	3,4,6		+	1,2,5,7,8,9	3,4,6	
SSE	-	1,2,5,6,7,8,9	4	3	-	1,2,3,5,6,7,8,9	4	
TSX	=	2,8,9	1,3,4,5,6,7		+	2,8,9	1,3,4,5,7	6
NIKKEI	=	5,6,8	1,2,3,7,9	4	=	2,6,8	1,3,4,5,7,9	
KSE	-	1,3,6,8,9	4,5,7	2	-	1,2,3,6,8	4,5,7	9
FOOT	+	2,7,8,9	3,4,5,6	1	+	1,2,7,8,9	3,4,5,6	
DAX	+	2,5,7,8,9	3,4,6	1	+	2,7,8,9	3,4,5,6	1
NASDAQ	+	5,7,8,9	1,2,3,4	6	+	7,9	1,2,3,4	5,6,8

Tableau 12: Risk measures movements after the attack. Data: Yahoo Finance and KSE website.

*holds for dispersion of values.

a) Indexes' groups identification

There exist two ways to identify different groups with regards to their reactions after terrorist attacks: the change of variance of the distribution of risk measures (due to terrorist attacks) or the parallel change in the risk measure due to terrorist attack. A complementary measure is the dispersion of the risk measures during the 9 attacks (if after the attacks the risk measures are converging within a certain range or if the range of risk measures' values is increasing after the attacks).

The first group experiences a decrease of the dispersion of risk measures after the attacks (like ASX observed on Figure 20). These indexes are ASX, BSE, SSE, KSE. All of them also experienced almost no change (or a positive change) for attack 1, 8 and 9; whereas they experienced a negative change for the attack 4.

The second group experiences almost no change of the dispersion. These indexes are Athens Stock Exchange, IPC, TSX and NIKKEI. All of them also experienced almost no change (or a positive change) for attack 2, 8 and 9; whereas they experienced a negative change for the attack 3.

The third group experiences an increase of the dispersion. These indexes are AMS, CAC40, SING, SSMI, FOOTSIE, DAX, NASDAQ. All of them also experienced no change (or a positive change) for attacks 2, 7 and 8, whereas they experienced a negative change for attacks 3, 4 and 6.

The identification of these three groups leads to several interpretations. The first group represents far indexes, often seen as a "safe" solution for reinvestment. After terrorist attacks these indexes only take into account standard risk determinants and we witness a convergence in the values (see Figure 20). The second group comprises peripherical indexes, they are known to be correlated with the leading indexes but do not have the fear to be targeted by an attack (except for the NIKKEI with the attack of Tokyo subway but the marginality of the perpetrators did not imply behavioral change). The third group is composed by regional leading indexes (or markets highly exposed to terrorist risk). They experience a higher dispersion of their risk measures after the attacks (some attacks are indeed leading to an increase of the risk whereas some others are reducing it). Notably, only the Tokyo attack leads to no significative changes on this sample.

Some indexes' particularities may explain changes on market risk measures after terrorist attacks. These observations are just some hints and reflect the fact that markets exposure to terrorism can be historically observed through markets' reactions in the aftermath of terrorist attacks.

b) Attacks' impacts observation

The markets reactions are not only the results of markets characteristics but are also the results of attacks' impacts. These impacts should not be assessed just by their intensity (i.e. number of casualties or media coverages), but also by their scales (regional impact or a more worldwide impact). Our sample of attacks is thus not homogeneous and heteroskedasticity is a considerable issue to tackle (see Figure 21).

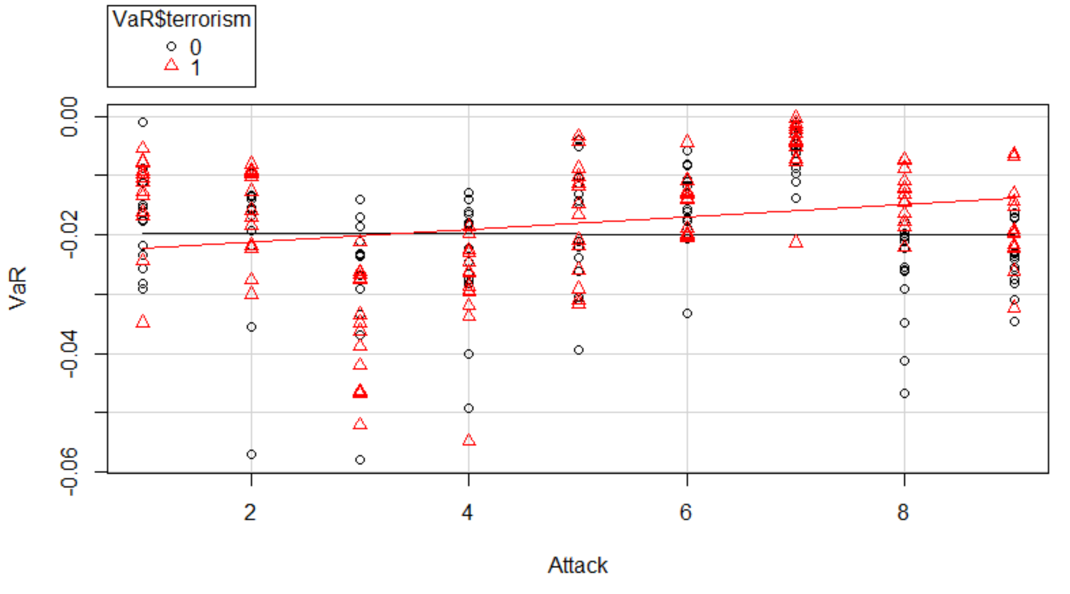

Figure 21: VaR evolution through time. Data: Yahoo Finance and KSE website.

The dispersion of values is first due to specific markets' time-varying determinants (country risk…) which can explain the change in dispersion before the attack (but the mean remains quite constant over-time). The dispersion of pre-attack values is a component of the post-attack dispersion and markets reactions to the attack are the second one. However, the post-attack dispersion is sometimes mainly due to the effects of the attacks (see Attack 3 on Figure 21, where the dispersion of the risk measures is much larger than before the attack).

Despite this heteroskedasticity, global trends after attacks can be observed. Attacks 3, 4 and 6 had the biggest impact on the sample (decrease in VaR for 12 countries out of 15 for the third one and the fourth one and 9 out of 15 for the sixth one). It should be noticed that these attacks targeted twice the US and once Europe, and were perpetrated by Al Qaeda or groups related to them. Attacks 1, 5, 8 and 9 had a smaller impact. These attacks targeted Tokyo, Moscow, Mumbai and Sinjar. Each time it has been perpetrated by national rebels groups. The importance of identification to the victims or to the targets is a main driver of markets movements, this identification might also be reinforced by media coverage (as used in Rigobon and Sack 2005). Being a country financially correlated with the targeted country does not imply an effect of the attack on the domestic index (for example the attack on Sinjar had no effect on Karachi Stock Exchange).

Markets reaction depends on the perception of the terrorist risk. This perception depends on media coverage but also of a time-varying sensitivity of investors (a tense geopolitical atmosphere will amplify markets reactions whereas some habituation processes are another interesting hypothesis). These dimensions might be taken into account for further research.

c) A link between de-correlation and risk assessment?

As heteroskedasticity based estimators have already been used to assess “war risk” (e.g. Rigobon and Sack, 2005), a comparison between these estimators and the change in risk measures has not been conducted yet. Effectively a decorrelation between two classes of assets does not necessarily mean a change in the risk measures for one asset or another (i.e. countermovements for example does not necessarily imply change in the variance). In the sample, the attack 5 is really interesting. The decorrelation is quite important for a majority of indexes but this decorrelation leads to no change in variance for Bombay Stock Exchange for example. The same things happens for the attack 1, which lead to unsignificant changes for the VaR computation for AMS, DAX, FOOTSIE and ASX but the decorrelation was quite important for these indexes. This phenomenon is partially explained by a difference in timing. Markets have different speed and ways to treat information and thus different timings for markets movements. Markets experience different movements due to their reaction to different information or to different treatment of information. These lagged treatments are thus producing counter-movements on the markets.

Heteroskedasticity-based estimators are expected to be quite in line with classic risk measures. It is even clearer with the globalization and the acceleration in the treatment of the information. According to this analysis, through the development of IT tools and a more globalized interpretation of the world’s conflicts, the differences observed in terms of heteroskedasticity will be smoothen over time. That is the reason why the attacks perpetrated by Al Qaida and targeting symbols of the western civilization have bigger impacts than others on all markets (the dominant interpretation was the horror of these attacks and the risk for the western civilization which could lead to a new type of war).

The difference between the observations of heteroskedasticity-based estimators and classic risk measures are finally partly explained by the product of country-specific information treatment.

CONCLUSION

The purpose of this thesis is to assess terrorist risk on the market. In order to assess this risk, the study focuses not on the risk per se (which would have been quite impossible to assess) but on its perception by markets' participants. The main issues to tackle are the propagation of the risk among markets, the explanation of the possible differences observed among markets but also the specificity of the returns' distribution after a terrorist attack.

Therefore, several measurement tools have been used to perform this assessment across different markets in the world. This allows for a comparison of the consequences of terrorist attacks on different markets but also a comparison between the used risk measures. Thus the specificities of returns distribution during the stress period following a terrorist attack are better understood.

As the first conclusion, no rule describes markets movement in the aftermath of a terrorist attack. There is no special effect of terrorist attacks on market risk or market risk measures. However, the characteristics of the attack (mainly geopolitical) and of its coverage (mainly media coverage) shape the market reactions. In that frame, terrorist attacks are just the starting point to test the effect of such variables. Thus terrorism does not have any influence on the market; but terrorism's outcomes (e.g. political, psychological, legal…) may drive the investors' decisions. That is the reason why the management of the post-attacks effect is of primary importance for policy makers. The definition of a concrete premium or discount linked to terrorist activities is consequently impossible to define on the markets (using multivariate or univariate estimators). Moreover, no differences have been observed concerning risks measures. Indeed terrorist attacks mainly have a political meaning. This meaning is often multi-dimensional, thus political actions are very hard to translate into financial effects. The multiple dimensions framing a terrorist attack are the perpetrators, the target (on which the study focused), the number of casualities but also the media coverage and, the resilience of the population (which are very hard to assess) matter on the topic. These variables can be affected by the history of the population but also if it get used to the production of "terror". The effect of terrorism on market risk assessment may raise a question: Would the efficient market analysis stay valid if reasarchers would consider the perception and the analysis of the pieces of information and not only their delivery?

In that frame, this work defines three types of indexes showing three types of reaction. The first one is quite sensitive to terrorist attacks showing a larger dispersion of their risks measures after the attacks than before. Those are leading indexes, directly targeted if the attack took place in a West- (middle or near) East struggle frame whereas they are refuges for investments if other places are targeted (or others geopolitical groups).

The second group is composed by peripherical indexes. In “normal times” they are correlated with the leading indexes but as they are not directly targeted by the attacks, they do not experience significant change. The third group is composed of “safe havens”. These places are considered as safe from terrorist threats and served as safe investments in case of any attacks. This differenciation in term of indexes is completed by some sectoral consequences (notably between financial sectors such as Banks and Insurance and non-financial sectors such as Transportation and Industry).

This fragmentation of the sample shows how volatile the political dimension is. That is the reason why the event –study methodology really fits the needs of such research. This allows scientists to take into account each event particularities and the heteroskedasticity in the sample considered as a whole. In case of terrorist activities these qualitative particularities are at the center of the translation of a political action into financial effects. Annex 1 describing the details of each attack is thus very helpful for the reader to understand the logic underlying each interpretation.

If a typology of countries is defined from the observation on risks measures, it is also the result of the observation on heteroskedasticity based estimators. These estimators rely on the decorrelation among markets on a defined period. In the study this estimator shows that the markets movements induced by terrorist attacks are not identical for each index ($\widehat{d} \neq 1$) but also that these movements are not in line with the normal correlation among markets ($\widehat{d}$ is not in the range of normal values for β in numerous cases). As a consequence, the financial spill-over effect in normal case does not fit the transmission effect in the aftermath of a terrorist attack. From the econometrical point of view, terrorist attacks show a useful example of discrepancies between univariate risk measures and multivariate risk measures. A significative change in multivariate measures is experienced in the majority of cases in the sample whereas no conclusion can be drawn from the majority of regressions with univariate risk measures. Some discrepancies in the results show that the weight given by ES and EVT to extreme losses implies a terrorist attacks neutrality of the indexes in the sample whereas conclusions on VaR implies a risk discount in the period following the attacks (it is also explained by the definition of the abnormal returns period which is based on the length of the catching up process).

The multivariate measures of risk are also practical to assess the impact of terrorist activities on some specific sectors. The results show that in some case specific sectors are more impacted than others due to their sectoral particularities but no hard rules can be drawn from the study. It has been shown that using ES as a risk measure implies a significative loss for the transportation industry after all the attacks (it is logical as transports are vectors of the attacks in a majority of cases). However, no sector-specific patterns have been observed. Some attacks are more harmful for some sectors whereas some others endure severe losses during different episodes of terrorism. This observation is consistent with the hypothesis of a macro-impact of terrorist activities (all markets are impacted by fear which is not necessarily rational and reactions are not build on a specific impact of the attack on a stock or a sector but on the overall impact of the attack on a geopolitical area).

The policy implications are numerous in this study. First of all, the issue can be tackled from a risk perspective. The main finding is the typology of countries with respect to the migration of their risk measures. Building a complete typology can be very useful for building a diversification strategy to hedge terrorist risk. However, this finding is completed by the fact that “on average” no significant change on the risk measures after terrorist attacks exists.

Secondly, from a pure financial perspective, the markets decorrelation can create some lucrative trading opportunities in a case of high-frequency trading. The effect of this decorrelation is thus significant on the markets’ β and should be considered for the β computation of specific period.

The third policy implication relies on the choice of risks measures in extreme cases. Terrorist attacks in our case prove the inadequacy of VaR measures in order to capture the risk if non-normal distribution is proven. As the normal distribution of returns’ assumption in “normal times” can not be validated in numerous cases, extreme events cause its violation almost in each case after the attacks. Thus regulators have high incentives to consider new types of measures because the classical VaR computation does not account of all the dimension of risks.

In conclusion terrorist attacks play on some key feelings of behavioral finance (e.g. identification, solidarity and fear). A variation of these behavioral determinants and of the geopolitical environment leads to market turbulences. These turbulences do not produce a unique outcome observable in each case. That is the reason why a careful geopolitical analysis can be the basis of a hedging strategy of a portfolio from this risk. Moreover, the post-attack period engendering an unclear trading environment produces some opportunities to create significant gains. Furthermore terrorist attacks lead in some cases to extreme losses and create a significative shift in the four first moments of returns' distribution. The inadequacy of classical risk measures in such period enlights the need for a geopolitical analysis to frame the trading activity. Finally, should we consider that a geopolitical analysis is the best solution to account for this translation of political actions into financial outcomes? But how can we efficiently integrate this dimension in financial modelling?

ANNEXES:

Annex 1: Rand description of the attack (Source: Rand website).

Date	City	Country	Perpetrator	Weapon	Injuries	Fatalities	Both	Description
20/03/1995	Tokyo	Japan	Aum Shinri Kyo	Chemical	5000	12	5012	JAPAN. The Tokyo subway system was the target of an attack with nerve gas. Twelve people were killed and over 5000 injured including several foreigners. A Japanese extreme Buddhist sect called Aum Shinri Kyo (Sublime/Supreme Truth), is suspected of releasing the gas. On 7 June 1995, the leader of Aum Shinri Kyo, Shoko Asahara, was indicted for the murder of the people who died in the subway gas attack. Six followers were also indicted on murder charges and nine others on lesser charges.
19/04/1995	Oklahoma City	US	Other	Explosives	500	168	668	UNITED STATES. A massive roadside truck bomb detonated at the Murrah Federal Building in Oklahoma City, killing 168 people and injuring over 500 others. Until 11 September 2001, this was the largest act of terrorism in the United States history.
07/08/1998	Nairobi	Kenya	Al Qaeda	Explosives	5000	213	5213	A suicide car bomb exploded outside the US Embassy in Nairobi, Kenya, killing at least 213 people, including 12 US nationals, and injuring more than 5,000 people. It is unclear how many Americans were injured in the attack. The blast occurred almost at the same time that another suicide car bomb detonated outside the US Embassy in Dar es Salaam, Tanzania. At least ten people were killed in that attack, none of them Americans. The attack has been claimed by Al-Qaeda.

11/09/2001	New York City	US	Al Qaeda	Other	2337	2938	5275	Hijacked American Airlines Flight 11 from Boston bound for Los Angeles, CA crashed into the north tower of the World Trade Center. Fifteen minutes later, hijacked United Airlines Flight 175 from Boston bound for Los Angeles, CA crashed into the south tower of the World Trade Center. Both towers collapsed, causing around 2,823 casualties and hundreds of injuries. The terrorists were said to have used small knives and box cutters to overtake the planes. Al Qaeda is responsible for this and three other hijacked planes on this day that caused over 3,000 total deaths.
24/10/2002	Moscow	Russia	Movsar Barayev Gang	Firearms	650	162	812	Approximately forty-five Chechen terrorists stormed into the Palace of Culture Theater in Moscow during a performance of 'Nord-Ost,' taking 750 to 800 audience member and actors hostage with automatic rifles. The militants, wired with explosives, demanded an end to the war in Chechnya, calling Russia to remove all its troops in Chechnya and requesting a large sum of money. The militants allowed all Chechens, Georgians, and Abkhazians to leave the building that they had wired with explosives. During the raid, Russian forces filled the theater with gas that was intended to incapacitate people inside. Early reports indicated that sixty-seven hostages died during the raid, most of them by the gas (only one hostage was reportedly killed in the crossfire). The death toll of hostages later rose to at least 129, as more died from the effects of the gas. Forty-five to fifty of the hostage-takers were also killed in the raid, but reports indicated that at least forty-one of them died from gunfire, not from the gas.

11/03/2004	Madrid	Spain	Abu Hafs al-Masri Brigade	Explosives	600	191	791	191 people were killed and over 600 others injured when ten bombs detonated in four different locations on Madrid's train line. Three of these bombs detonated in a train that was pulling into the Atocha station, a busy hub for the commuter train line and the metro rail. At first the Spanish government blamed the separatist group, the Basque Fatherland and Freedom (ETA) for the attacks, but later the Abu Hafs al-Masri Brigade claimed responsibility on behalf of Al Qaeda. In response to the attacks, the ruling Spanish party was defeated in elections (which took place four days after the incident) and the new Prime Minister vowed to remove Spanish troops from combat in Iraq.
01/09/2004	Beslan	Russia	Riyad us-Saliheyn Martyrs' Brigade	Firearms	727	331	1058	A group of thirty to thirty-five (sources varied) armed Chechen separatists, including men and women, many wearing suicide bomber belts, seized a school in the Southern Russian town of Belsan taking children, parents, and teachers hostage in the school gym. At least ten of the hostage-takers appeared to be from Arab countries. Most sources originally estimated there were about 400 hostages. However, it was later revealed that there were between 1,000 and 1,500 being held. They said they would kill fifty children for every one killed fighter and twenty for every injured fighter. They also claimed the building had been filled with mines that would be set off if police attempted to storm the building.
11/07/2006	Mumbai	India	Unknown	Explosives	625	190	815	On July 11, a series of seven explosions targeted railroad networks in Mumbai. In all, 190 people were killed and 625 were injured across all the incidents. One of the explosions took place in the first class trains of the Western Railway at Mira-Bayandhar Station.

14/08/2007	Sinjar	Iraq	Unknown	Explosives	1500	500	2000	Four truck bombs hit a poor rural area near the Syrian border. The bombs went off near an area of mud and stone houses. The known casualty toll is an astonishing 500-plus dead and one thousand and five hundred wounded. The Iraqi Red Crescent Society calls this attack the bloodiest coordinated attack since 2003. Even a week after the explosion, emergency workers are still trying to remove bodies from the scenes of the explosion and identifying the wounded. Officials believe that the terrorists were going after Yazidis. Others also believe this attack was retribution for an incident in April, when a Yazidi woman was stoned to death by Yazidis because she married a Sunni. However, the latter detail is far from conclusive.This attack supports the idea that insurgent cells have flowed away from high troop affiliations and have gone to smaller villages instead.

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