Do Terror Attacks Affect the Dollar-Pound Exchange Rate? A Nonparametric Causality-in-Quantiles Analysis[♣]

Mehmet Balcilar[*], Rangan Gupta[**], Christian Pierdzioch[***] and Mark E. Wohar[****]

Highlights

- We apply a non-parametric causality-in-quantiles test.
- We study if terror attacks affect dollar pound exchange-rate returns and volatility.
- We find that terror attacks mainly affect the lower and upper quantiles.
- Attacks also affect most quantiles of the distribution of exchange-rate volatility.

Abstract

While much significant research has been done to study the effects of terror attacks on stock markets, less is known about the response of exchange rates to terror attacks. We suggest a non-parametric causality-in-quantiles test to study whether (relative) terror attacks affect exchange-rate returns and volatility. Using data on the dollar-pound exchange rate to illustrate the test, we show that terror attacks mainly affect the lower and upper quantiles of the conditional distribution of exchange-rate returns, while misspecified (due to nonlinearity and structural breaks) linear Granger causality test show no evidence of predictability. Terror attacks also affect almost all quantiles of the conditional distribution of exchange-rate volatility (except the extreme upper-end), with the significance of the effect being particularly strong for the lower quantiles. The importance of terror attacks is shown to hold also under an alternative measure of volatility and for an important emerging-market currency as well.

JEL classification: C22; C53; F31

Keywords: Exchange rate; returns; volatility; nonparametric causality-in-quantiles test; terror attacks

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1. Introduction

Against the background of geopolitical uncertainty and political disruptions in many parts of the world much significant empirical research has been done to trace out how terror attacks affect financial markets. The majority of studies contributing to this research shed light on the effect of terror attacks on stock markets (see, for example, Karolyi and Martell 2010, Chen and Siems 2004, Arin et al. 2008; for a brief literature review, see Balcilar et al. 2016b). Less is known about how terror attacks affect exchange rates - something we aim to address in this paper, especially given that the foreign exchange market is the largest and most liquid financial market in the world. As reported in the Triennial Survey of Global Foreign Exchange Market Volumes of the Bank for International Settlements (BIS) (2016), the average daily turnover was 5.1 trillion of U.S. dollars 2016. In principle, terror attacks can affect exchange rates through their direct effect on macroeconomic fundamentals and by changing market participants' expectations.

As for the effect of terror attacks on macroeconomic fundamentals, Eckstein and Tsiddon (2004) use a Blanchard-Yaari overlapping-generations model to argue that terror attacks increase the risk of death and, thereby, inflate households' subjective discount rate. Their model predicts that a higher discount rate results in less savings such that in the steady state investment, consumption, and output are lower than in a world without terror. Eckstein and Tsiddon (2004) report empirical evidence for Israel that supports this prediction of their model. They also argue that a government, by increasing defense spending, can try to counter the negative macroeconomic effects of terror attacks because spending resources on the production of security increases households' life expectancy and personal safety. One would expect, thus, that terror attacks trigger an increase in government spending.

Evidence documented by Blomberg et al. (2004) is consistent with this view. They report that terrorism, in addition to deteriorating growth prospects (see also Gaibulloev and Sandler 2008, who also differentiate between domestic and transnational terrorism), triggers a reallocation of resources because it crowds out investment while it crowds in government spending. Viewed through the lens of a simple textbook Mundell-Fleming open-economy model, higher government spending should result in an appreciation of the exchange rate. At the same time, if terror attacks have an adverse effect on output and consumption, the monetary model of exchange-rate determination predicts that terror attacks should trigger a depreciation of the exchange rate.

The exchange-rate effect of terror attacks that operate through their impact on output growth may depend on the type of attacks and the political system of a country hit by an attack. Tavares

(2004) finds that, while terror attacks seem to have a moderate negative effect on output growth, terror attacks on civilians by known terrorist organizations tend to have a comparatively larger effect on output growth than attacks on, for example, political targets. Moreover, the costs of terror attacks as measured in terms of losses in output growth tend to be smaller the more democratic is a country hit by an attack.

Another macroeconomic channel through which terror attacks may affect exchange rates is via the effect on international trade flows. Eckstein and Tsiddon (2004) find for Isreal that terrorism has an adverse effect on exports. Nitsch and Schumacher (2004) find for a panel of more than 200 countries that terror attacks reduce trade. The negative effect of terror attacks on international trade may reflect an increase in frictional trading costs due to, for example, tighter security regulations and higher insurance costs (see the detailed analysis by Walkenhorst and Dihel 2002). Indirect evidence of increases in frictional trading costs brought about by terror attacks has been reported by Bensassi and Martínez-Zarzoso (2012), who estimate gravity models and find that harmful pirate attacks (hijackings) have a significant adverse impact on international maritime trade (for further evidence, see also the recent study by Burlando et al. 2015).

At higher data frequencies, the immediate implications of terror attacks for the formation of market participants' expectations are likely to be more important for exchange-rate movements than their direct effects on macroeconomic fundamentals. While in a baseline reduced-form macroeconomic rational-expectations model of exchange-rate determination, the former simply reflect the present-discounted value of the future path of fundamentals, for our empirical research it is useful to develop a broader view that accounts for market participants' risk reassessments, portfolio-reshuffling effects, contagion, and international volatility transmission.

If terror attacks alter market participants' expectations and trigger reassessments of risks, terror attacks may trigger exchange-rate movements because such attacks cause changes in international capital flows (Enders and Sandler 1996, Enders et al. 2006). In the model developed by Abadie and Gardeazabal (2008), terror attacks trigger large international capital flows if attacks alter expected returns on investments. In their model, the nexus between terror attacks and international capital flows rests on the result that investors with a low level of risk aversion will change abruptly their international investment plans in response to a reassessment of expected returns on their investments in a terror-hit country. The resulting international reallocation of capital tends to be larger the more countries are integrated into international capital markets because, in a world of globalized finance, investors can easily diversify risk without investing funds in countries with a high relative risk of terror attacks. Abadie and Gardeazabal (2008) present empirical evidence that supports the predictions of their model. In particular, estimates of cross-country regressions show that terror risk reduces net foreign investment positions.

Because the "world portfolio" becomes essentially a riskless investment if the number of countries integrated into international financial markets is large, international investments become more sensitive to country-specific news and, even more, the incentives of investors to incur the costs of collecting and verifying country-specific information diminish. As a result, contagion in international financial markets can be the result of portfolio diversification of optimizing investors (Calvo and Mendoza 2000). Terror-driven contagion and transmission of volatility in international financial markets, thus, can arise if terror attacks reveal country-specific "news" or if terror attacks give rise to, for example, media speculation about the stability of a countries' political system. If terror attacks trigger contagion effects in international financial markets, in turn, such effects are likely to bring about sharp and abrupt exchange-rate movements, warranting a detailed inspection of the effects of terror attacks on the tails of the conditional distribution of exchange rate returns and volatility.

Evidence of terror-induced contagion in international financial markets has been reported by Hon et al. (2004). They show that, after accounting for heteroskedasticity in their data, the terror attacks of September 11 in the United States resulted in a stronger international correlation of stock markets. Hon et al. (2004) argue that their findings lend support to the view that market participants interpreted these terror attacks as a global shock. Concerning the transmission of volatility in international financial markets, Chuliá et al. (2009) find evidence of bidirectional volatility transmission between the U.S. and European stock markets. Moreover, they find that the terror attack of 11 September 2001 transmitted onto the volatility of European markets, while the terror attacks that hit London on 11 March 2004 and Madrid on 7 July 2005 did not affect the volatility of the U.S. market.

In sum, both economic theory and earlier empirical research suggest that terror attacks may have a substantial effect on exchange rates. It is, therefore, not surprising that Eldor and Melnick (2004) find evidence that Palestinian terror attacks on Israel trigger a significant devaluation of the exchange rate. As for the terror attacks of September 11, 2001 in the United States, the International Monetary Fund (2001) concludes that the attacks had a substantial albeit short-lived effect on exchange-rate expectations. Specifically, the IMF reports that risk-neutral probability densities as extracted from option prices (risk reversals) indicate that "...the likelihood of a sharp dollar depreciation was greater than that of an equally sharp appreciation over the following three months." (page 28), a result that indicates that it is interesting to have a closer look at the effects of terror attacks on the lower and upper quantiles of exchange-rate movements.

Notwithstanding, empirical evidence on the impact of terror attacks on exchange rates is remarkably scarce. Our first contribution to the research on the effects of terror attacks on financial markets is that we present further systematic evidence of how terror attacks affect exchange rates by studying the effect of terror attacks on the US dollar-UK pound exchange rate, based on daily data covering the period of 21st February, 1968 to 30th December, 2009. The choice of this exchange rate is natural given the global importance of these two currencies historically, as well as, the frequency of terror attacks in these two major economies over time. Because the exchange rate is a relative price, we construct a relative terror index that reflects terror attacks on the United States and the United Kingdom simultaneously on the same date.

Our second contribution is methodological in nature: we show that a novel nonparametric causality-in-quantiles test recently developed by Balcilar et al. (2016a) yields interesting new insights into the effects of terror attacks on exchange rates. The test renders it possible to account for quantile-specific effects of terror attacks on the conditional distribution of exchange-rate dynamics. Studying such quantile-specific effects is interesting because recent research by Gupta et al. (2017) demonstrates that terror attacks have predictive value for the lower and especially for the upper quantiles of the conditional distribution of gold returns. If quantile-specific effects of terror attacks can be recovered in the case of gold returns similar effects may be present in exchange-rate dynamics.

The nonparametric causality-in-quantiles test brings together elements of the test for nonlinear causality of k-th order developed by Nishiyama et al. (2011) with the causality-in-quantiles test recently developed by Jeong et al. (2012). The nonparametric causality-in-quantiles test is robust to misspecification errors because it accounts for the dependence structure between the time series under scrutiny. This robustness is particularly important because there is ample evidence that exchange-rate returns and volatility are subject to structural breaks (regime changes) and that they display nonlinear dynamics (Rapach and Wohar, 2006; Rapach and Strauss, 2008). Moreover, the test can be used to study both causality-in-mean and causality in higher-order moments. Studying causality in higher-order moments is particularly important because earlier researchers have stressed that terror attacks may not only affect the returns but also the volatility of asset prices (Balcilar et al., 2016b).

It must be noted that one could have also used nonlinear causality tests (for example, Heimstra and Jones 1994 and Diks and Panchenko 2005, 2006) and GARCH-type models to analyze the impact of terror attacks on returns and volatility of the US dollar-UK pound exchange rate. However, these approaches rely on conditional-mean based estimation, and hence fail to capture the entire conditional distribution of returns and volatility – something we can do with our approach. Also, standard GARCH models specify linear relationships between returns and volatility with a predictor being studied. In this respect, our test is a more general procedure to detect causality in both returns and volatility simultaneously at each quantile of their respective conditional distributions. Hence, we are able to capture existence or non-existence of causality at various market states, i.e., a bear (lower quantiles), a normal (median) and a bull (upper quantiles) currency market. To that end, being a more general test, our method is more likely to pick up causality when conditional mean-based tests might fail to do so. Finally, since the test does not require the determination of the number of regimes as in a Markov-switching model, and can test for causality at each point of the conditional distribution characterizing specific regimes, our test also does not suffer from any misspecification in terms of specifying and testing for the optimal number of regimes.

We document two main results: First, we show that terror attacks mainly affect the lower and upper quantiles of the conditional distribution of the returns of the dollar-pound exchange rate. Second, while terror attacks affect the majority of quantiles of the conditional distribution of exchange-rate volatility the significance of this effect is particularly strong for the lower quantiles. We also supplement our two main results in that we show that the importance of terror attacks holds under an alternative measure of volatility and for an important emerging-market currency as well. In order to derive our results, we structure the remainder of this paper as follows. In Section 2, we briefly describe the logic underlying the nonparametric causality-in-quantiles test. Our description is compact because the details of the test have been laid out in recent contributions by Balcilar et al. (2016a, b). In Section 3, we describe our data and we summarize our results. In Section 4, we offer some concluding remarks.

2. Testing for Causality-in-Quantiles

This section provides a compact description of the quantile-based methodology that we use to detect nonlinear causality via a hybrid approach developed by Balcilar et al. (2016a), based on the frameworks of Nishiyama et al. (2011) and Jeong et al. (2012). As mentioned earlier, this approach is robust to extreme values in the data and captures general nonlinear dynamic dependencies. Let y_t denote exchange rate returns and x_t denote the predictor variable, in our case the relative terror attacks index (as described in detail in the Data segment of the paper).

Formally, let $Y_{t-1} \equiv (y_{t-1},\ldots,y_{t-p})$, $X_{t-1} \equiv (x_{t-1},\ldots,x_{t-p})$, $Z_t = (X_t, Y_t)$ and $F_{y_t|Z_{t-1}}(y_t, Z_{t-1})$ and $F_{y_t|Y_{t-1}}(y_t, Y_{t-1})$ denote the conditional distribution functions of y_t given Z_{t-1} and Y_{t-1}, respectively. If we denote $Q_\theta(Z_{t-1}) \equiv Q_\theta(y_t \mid Z_{t-1})$ and $Q_\theta(Y_{t-1}) \equiv Q_\theta(y_t \mid Y_{t-1})$, we have $F_{y_t|Z_{t-1}}\{Q_\theta(Z_{t-1}) \mid Z_{t-1}\} = \theta$ with probability one. Consequently, the (non)causality in the θ-th quantile hypotheses to be tested can be specified as:

$$H_0: \quad P\{F_{y_t|Z_{t-1}}\{Q_\theta(Y_{t-1}) \mid Z_{t-1}\} = \theta\} = 1, \tag{1}$$

$$H_1: \quad P\{F_{y_t|Z_{t-1}}\{Q_\theta(Y_{t-1}) \mid Z_{t-1}\} = \theta\} < 1. \tag{2}$$

Jeong *et al.* (2012) employ the distance measure $J = \{\varepsilon_t E(\varepsilon_t \mid Z_{t-1}) f_z(Z_{t-1})\}$, where ε_t is the regression error term and $f_z(Z_{t-1})$ is the marginal density function of Z_{t-1}. The regression error ε_t emerges based on the null hypothesis in (1), which can only be true if and only if $E[1\{y_t \le Q_\theta(Y_{t-1}) \mid Z_{t-1}\}] = \theta$ or, equivalently, $1\{y_t \le Q_\theta(Y_{t-1})\} = \theta + \varepsilon_t$, where $\mathbf{1}\{\cdot\}$ is an indicator function. Jeong *et al.* (2012) show that the feasible kernel-based sample analogue of J has the following form:

$$\hat{J}_T = \frac{1}{T(T-1)h^{2p}} \sum_{t=p+1}^{T} \sum_{s=p+1, s\neq t}^{T} K\left(\frac{Z_{t-1} - Z_{s-1}}{h}\right) \hat{\varepsilon}_t \hat{\varepsilon}_s. \tag{3}$$

where $K(\cdot)$ is the kernel function with bandwidth h, T is the sample size, p is the lag order, and $\hat{\varepsilon}_t$ is the estimate of the unknown regression error, which is estimated as follows:

$$\hat{\varepsilon}_t = 1\{y_t \le \hat{Q}_\theta(Y_{t-1})\} - \theta. \tag{4}$$

$\hat{Q}_\theta(Y_{t-1})$ is an estimate of the θ^{th} conditional quantile of y_t given Y_{t-1}, and we estimate $\hat{Q}_\theta(Y_{t-1})$ using the nonparametric kernel method as

$$\hat{Q}_\theta(Y_{t-1}) = \hat{F}^{-1}_{y_t|Y_{t-1}}(\theta \mid Y_{t-1}), \tag{5}$$

where $\hat{F}_{y_t|Y_{t-1}}(y_t \mid Y_{t-1})$ is the *Nadarya-Watson* kernel estimator given by

$$\hat{F}_{y_t|Y_{t-1}}(y_t \mid Y_{t-1}) = \frac{\sum_{s=p+1, s\neq t}^{T} L\left((Y_{t-1} - Y_{s-1})/h\right) 1(y_s \le y_t)}{\sum_{s=p+1, s\neq t}^{T} L\left((Y_{t-1} - Y_{s-1})/h\right)}, \tag{6}$$

with $L(\cdot)$ denoting the kernel function and h the bandwidth.

In an extension of Jeong *et al.* (2012)'s framework, we also develop a test for the *second* moment. In particular, we want to test the causality running from the relative terror attacks index to volatility of exchange rate returns. Adopting the approach in Nishiyama *et al.* (2011), higher order quantile causality can be specified as:

$$H_0: \quad P\{F_{y_t^k|Z_{t-1}}\{Q_q(Y_{t-1})\,|\,Z_{t-1}\}=q\}=1 \qquad \text{for } k=1,2,\ldots,K \tag{7}$$

$$H_1: \quad P\{F_{y_t^k|Z_{t-1}}\{Q_q(Y_{t-1})\,|\,Z_{t-1}\}=q\}<1 \qquad \text{for } k=1,2,\ldots,K \tag{8}$$

Integrating the entire framework, we define that x_t *Granger causes* y_t *in quantile* θ *up to the* k^{th} *moment* using Eq. (7) to construct the test statistic of Eq. (6) for each k. The causality-in-variance test is then calculated by replacing y_t in Eqs. (3) and (4) with y_t^2. However, it can be shown that it is not easy to combine the different statistics for each $k=1,2,\ldots,K$ into one statistic for the joint null, because the statistics are mutually correlated (Nishiyama *et al.*, 2011).To efficiently address this issue, we include a sequential-testing method as described by Nishiyama *et al.* (2011). First, we test for the nonparametric Granger causality in the *first* moment $(i.e.\, k=1)$. Nevertheless, failure to reject the null for $k=1$ does not automatically lead to no-causality in the *second* moment. Thus, we can still construct the tests for $k=2$.

The empirical implementation of causality testing via quantiles entails specifying three important choices: the bandwidth h, the lag order p, and the kernel type for $K(\cdot)$ and $L(\cdot)$ respectively. In this study, we make use of lag order based on the Schwarz Information Criterion (SIC). Note that, when it comes to choosing lags, the SIC is considered to be parsimonious compared to other lag-length selection criteria. The SIC helps overcome the issue of over-parameterization usually arising with nonparametric frameworks.[1] The bandwidth value is chosen by employing the least squares cross-validation techniques.[2] Finally, for $K(\cdot)$ and $L(\cdot)$ Gaussian-type kernels was employed.

3. Results

3.1. Data and empirical results

Our analysis is based on two daily variables: the returns of the U.S. dollar relative to the UK pound exchange rate and a terror attack index that accounts for terror attacks on both the U.S.

[1] Hurvich and Tsai (1989) examine the Akaike Information Criterion (AIC) and show that it is biased towards selecting an over-parameterized model, while the SIC is asymptotically consistent.

[2] For each quantile, we determine the bandwidth h using the leave-one-out least-squares cross validation method of Racine and Li (2004) and Li and Racine (2004).

and the UK. Exchange-rate returns are measured in terms of the first-differenced of the natural log of the dollar-pound exchange rate, with the data obtained from the Global financial Database. Using exchange-rate returns ensures that the dependent variable is stationary, a requirement for our causality analysis.[3] The terror index is stationary by design. Like Eckstein and Tsiddon (2004) and Arin et al., (2008), we define the daily terror index of a specific country (U.S. or UK) as the natural logarithm of (*e+number of human casualties+number of people injured+number of terrorist attacks*), where *e* denotes the exponential function, that occurred each day. Like Arin et al., (2008), we sum up terror attacks which occurred during a weekend to the previous Friday's figure. Data on the terror attacks were collected from the RAND Database of Worldwide Terrorism Incidents (RDWTI).[4] The RDWTI database integrates data from many important terrorism resources. Our data covers the period of 21st February, 1968 to 30th December, 2009, with the start and end-date being purely driven by availability of data on terror attacks (i.e., a total of 10,503 observations).

Because the exchange rate is the relative price of two currencies (dollar and pound), we further transform the terror index as follows. In order to create a *relative* terror index, we subtract the terror index of the UK from that of the U.S. because intuitively terror attacks on the U.S. (with the UK not attacked) should depreciate the value of the dollar (i.e., increase the dollar-pound exchange rate). Conversely, terror attacks on the UK (with the U.S. not attacked) should appreciate the value of the dollar (i.e., reduce the dollar-pound exchange rate).

Figures 1a-1d display the data on exchange-rate returns, squared-returns (i.e., a model-free estimate of volatility), a GARCH-based estimate of volatility, and the relative terror attacks index. Table 1 shows some summary statistics of returns, squared returns, and the relative terror attacks index. As can be seen from the Jarque-Bera test statistic, exchange-rate returns (and volatility) and the relative terror attacks index are non-normal with heavy left-tail (right-tail) for the exchange-rate returns (volatility) and the relative terror attacks index, which in turn, provides some preliminary justification for using the causality-in-quantiles test.

[3] Details of the unit-root tests are available upon request from the authors.
[4] Available freely for download from: http://www.rand.org/nsrd/projects/terrorism-incidents.html.

Figure 1a. US Dollar to UK Pound Exchange Rate Returns

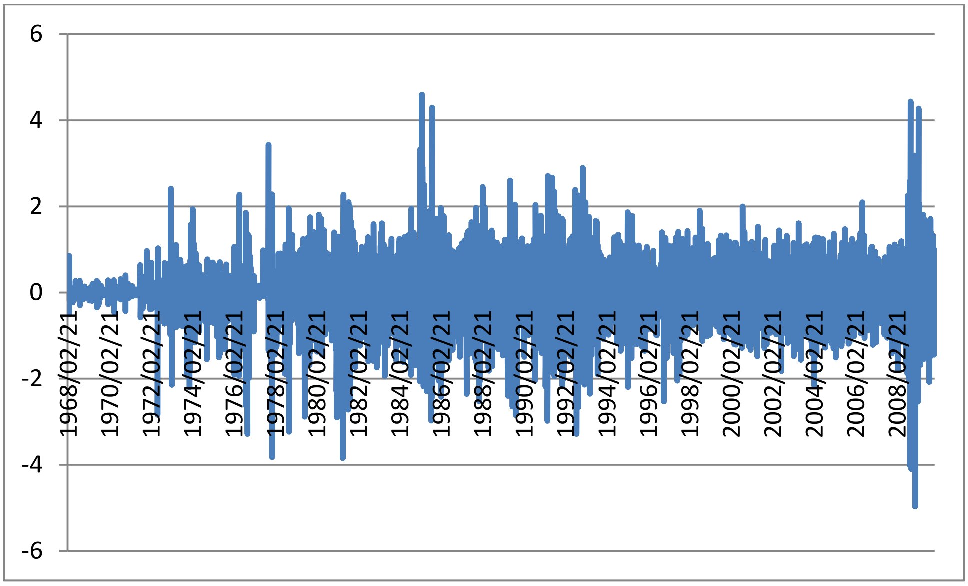


Figure 1b. US Dollar to UK Pound Squared Exchange Rate Returns (Volatility)

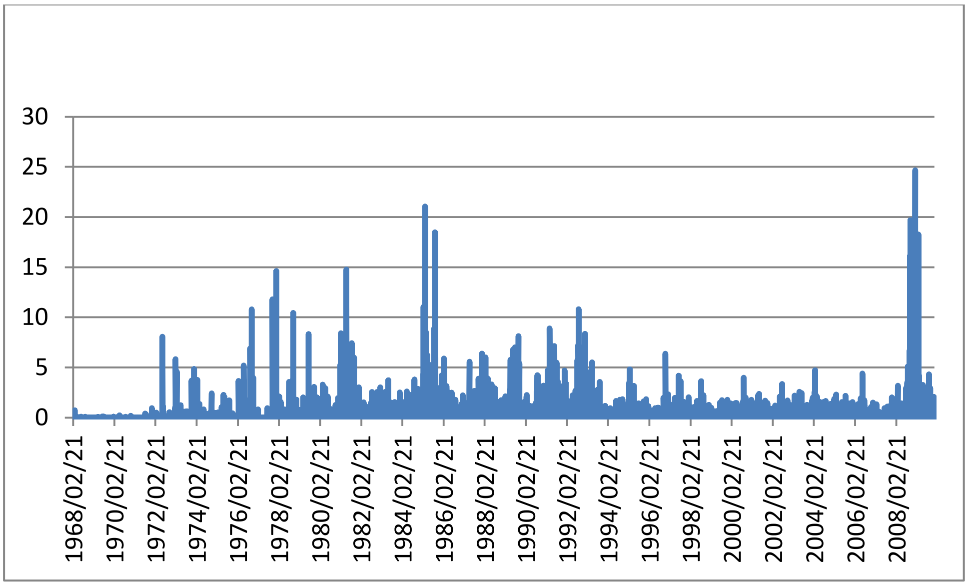


Figure 1c. US Dollar to UK Pound Exchange Rate Returns Volatility (GARCH Model)

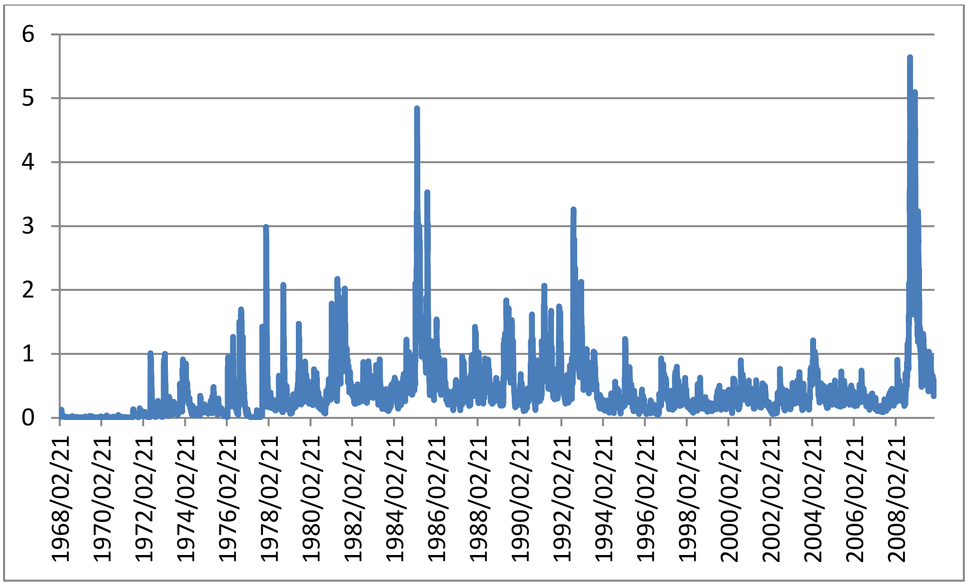


Figure 1d. Terror Index of the US Relative to the UK

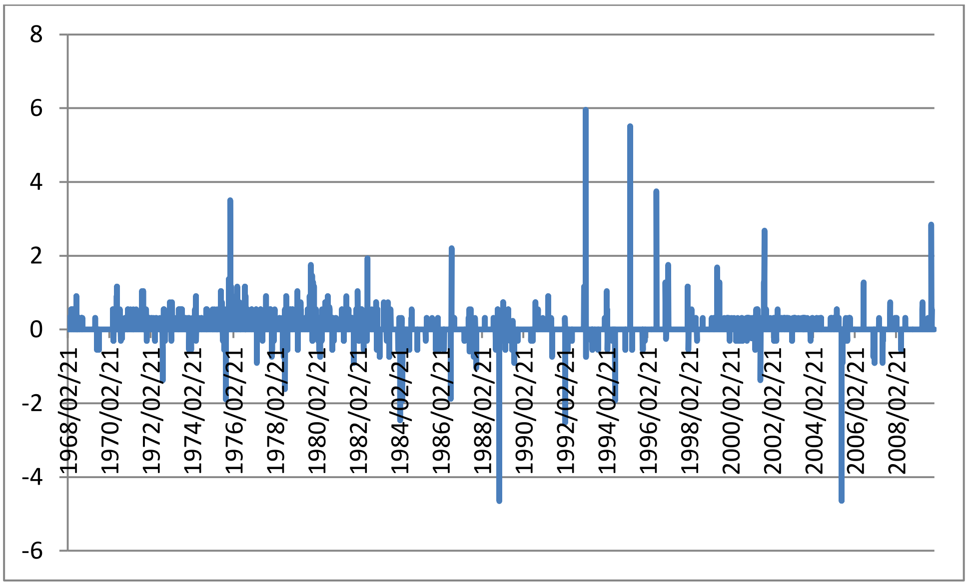


Table 1. Summary Statistics

Statistic	Dollar-Pound Exchange-rate returns	Squared Exchange-rate returns (Volatility)	Relative Terror Index
Mean	-0.0039	0.3419	0.0000
Median	0.0000	0.0678	-0.0617
Maximum	4.5885	24.6636	40.4341
Minimum	-4.9663	0.0000	-44.6378
Std. Dev.	0.5848	0.9382	1.4033
Skewness	-0.2134	9.9256	-2.2015
Kurtosis	8.5225	162.4659	373.2341
Jarque-Bera	13426.5200	11300984.0000	59995194.0000
Probability	0.0000	0.0000	0.0000
Observations	10503	10503	10503

Note: Std. Dev. symbolizes the Standard Deviation; *p*-value corresponds to the test of normality based on the Jarque-Bera test.

Although our objective is to analyze the causality-in-quantiles running from the relative terror attacks index to the returns (and the volatility) of the dollar-pound exchange rate, for the sake of completeness, we also conduct the standard linear test for Granger noncausality based on a VAR(1) model. The results produce a $\chi^2(1)$ statistic of 0.8261 with a *p*-value of 0.3634. In other words, the null hypothesis that (relative) terror attacks do not Granger cause the dollar-pound exchange-rate returns cannot be rejected.

Next, in order to motivate the use of the nonparametric quantile-in-causality test, we investigate the possibility of nonlinearity in the relationship between the exchange-rate returns and (relative) terror attacks. To this end, we apply the Brock et al., (1996, BDS) test on the residuals of an AR(1) model for exchange-rate returns, and the exchange-rate returns equation in the VAR(1) model involving (relative) terror attacks. As can be seen by inspecting the results summarized in Table 2, the null of *i.i.d.* residuals at various embedding dimensions (*m*) is rejected strongly at the highest level of significance. These results provide strong evidence of nonlinearity in not only the exchange-rate returns (as in Rapach and Wohar, 2006), but also in their relationship with terror attacks. In other words, the results of the linear test for Granger noncauslity cannot be deemed robust and reliable.

Table 2. BDS Test

m	*z*-statistic of Residuals of the AR(1) Model of Exchange-rate returns	*p*-value	*z*-statistic of Residuals of Exchange-rate returns Equation of the VAR (1) Model	*p*-value
2	21.4276	0.0000	21.4087	0.0000
3	27.5973	0.0000	27.5779	0.0000
4	32.2313	0.0000	32.2132	0.0000
5	37.0593	0.0000	37.0433	0.0000
6	42.7635	0.0000	42.7469	0.0000

Note: *m* stands for the number of (embedded) dimension which embed the time series into *m*-dimensional vectors, by taking each m successive points in the series. Value in cell represents BDS *z*-statistic corresponding to the null of *i.i.d.* residuals.

Next, we turn to the Bai and Perron (2003) test of multiple structural breaks, applied again to the AR(1) model for exchange-rate returns and the exchange-rate returns equation of the VAR(1) model involving (relative) terror attacks. Based on the sequential and repartition tests, three break dates at 29th September, 1976, 18th March, 1985 and 27th April, 1993 are detected for the AR(1) model of exchange-rate returns, and 18th March, 1985 and 27th April, 1993 are detected as two break dates in the exchange rate equation of the VAR(1) model including terror attacks. As a result, and in line with the BDS test which detects nonlinearity, existence of structural breaks in the exchange-rate returns and in its relationship with terror attacks imply that the Granger noncausality test based on a linear framework is likely to suffer from misspecification. Given the strong evidence of both nonlinearity and regime changes in the exchange-rate equations (AR(1) and VAR(1) models), we now turn to the causality-in-quantiles test.

In Figure 2a and Figure 2b, we present the results obtained from the causality-in-quantiles test for the dollar-pound exchange-rate returns and volatility. As for exchange-rate returns, the results of the causality-in-quantiles test are insignificant near the median, but become significant at the lower and higher quantiles. The insignificance of the test results near the median of the conditional distribution of exchange-rate returns is in line with the results of the linear test for

Granger noncausality, which does not find any evidence that (relative) terror attacks predict exchange-rate returns. Our results, however, clearly show that nonrejection of the null hypothesis of noncausality within a linear test framework does not imply that (relative) terror attacks do not cause exchange-rate returns and volatility. In fact, the results of the causality-in-quantiles test show that relative terror attacks mainly affect the lower and upper quantiles of the conditional distribution of exchange-rate returns. Furthermore, terror attacks also affect the conditional distribution of exchange-rate volatility at most quantiles, with the highest quantile being an exception. The significance of the effect of terror attacks on the conditional distribution of exchange-rate volatility is particularly strong for the lower quantiles at around 0.3.

Figure 2a. Quantile Causality Results for US Dollar to UK Pound Exchange-rate returns

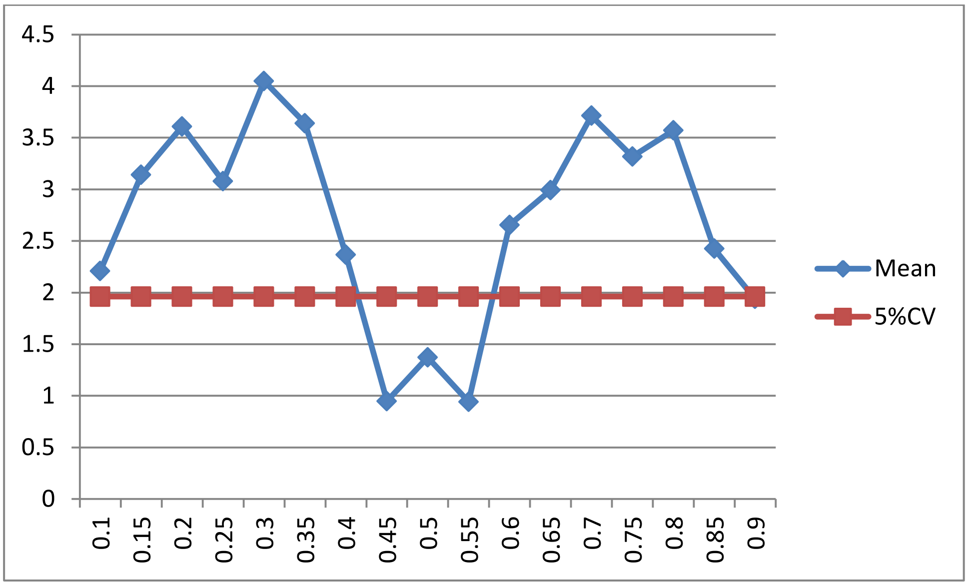


Figure 2b. Quantile Causality Results for US Dollar to UK Pound Exchange Rate Volatility (Squared Returns)

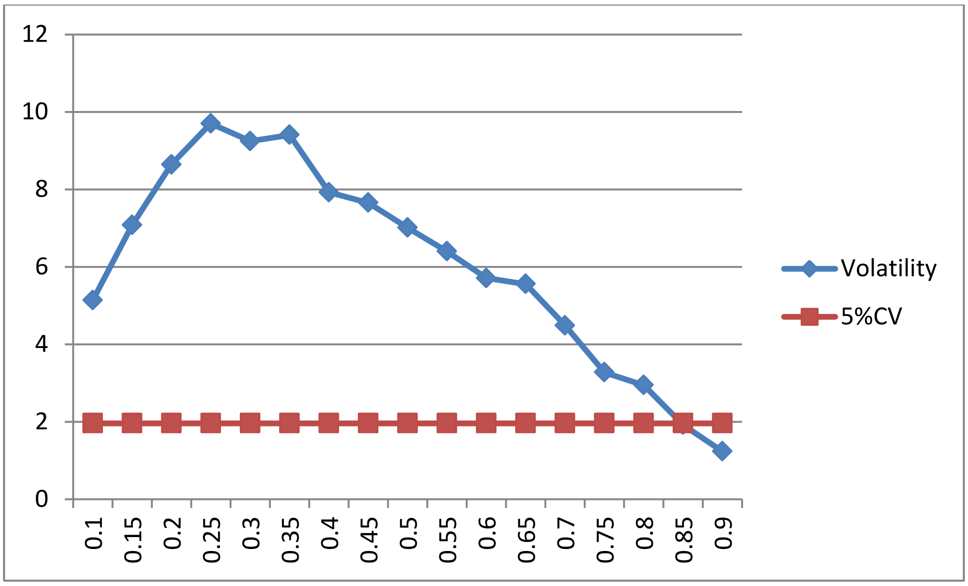
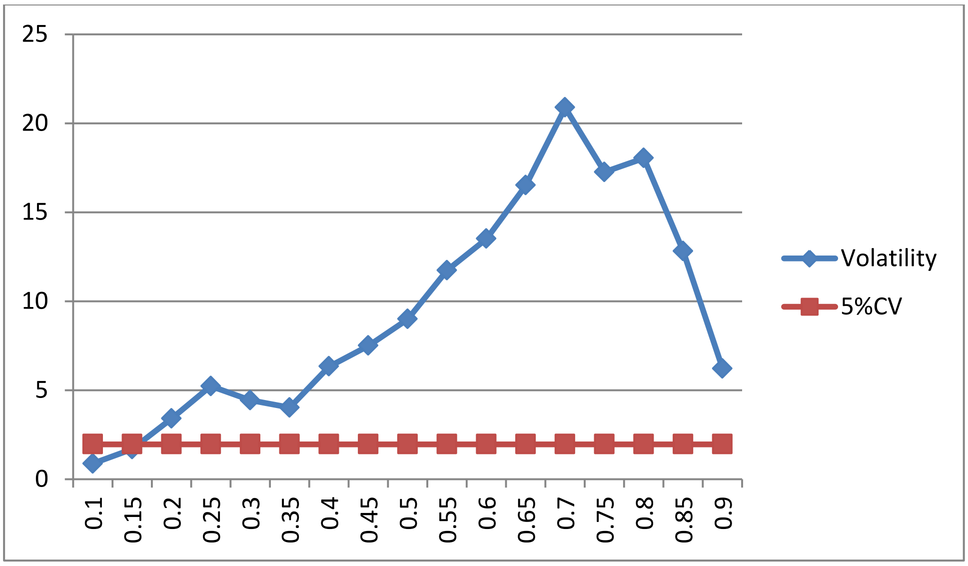


Figure 2c. Quantile Causality Results for US Dollar to UK Pound Exchange Rate Volatility (GARCH Model)



Our results have important implications not only for academic research but also for investors. Our results highlight that in any study of the impact of terror attacks on exchange rates it is important to consider a nonlinear model and to study the entire conditional distribution not only of returns but also of volatility. If inferences were drawn exclusively from a linear model, which in fact is misspecified, then one would mistakenly conclude that terror attacks do not play any role for the dynamics of the dollar-pound exchange rate. In contrast, we show that, when a nonparametric approach is used, terror attacks do move exchange-rate returns at the lower and upper quantiles of their conditional distribution, but not around the median. This result implies that, in turbulent times, investors should condition, as far as exchange-rate returns and thus potential appreciation gains (or losses) of cross-border investments are concerned, their investment positions at least in part on available information on terror attacks. Moreover, our results show that risk-averse investors, who are not only interested in predicting returns but also in predicting volatility, can make predictions of future volatility using information on past volatility only when exchange-rate volatility (as measured by squared returns) is high. In such a market state, uncertainty is already at its extreme-high. When volatility is at its lower-end, however, then risk-averse investors should utilize information on terror attacks to analyze where future volatility is likely to be heading towards. The significant effects at the lower quantiles of the conditional distribution of exchange-rate volatility make sense intuitively since a terror attack is likely to affect uncertainty more in these regions than at the upper end of the volatility spectrum, as such news have greater probability of affecting the risk profile of the currency market when volatility has space to rise.

In addition, exchange-rate predictions are of interest not only for investors, but also for exporters and importers - retailers and consumers, who take decisions based on the value of the domestic currency (Balcilar et al., 2016c). Further, accurate prediction of exchange-rate volatility is important to multinational firms, financial institutions, and traders aiming to hedge currency risks (Pilbeam and Langeland, 2015). Traders of foreign-currency options look to make profits by buying (selling) options if they expect volatility to rise above (fall below) of what is implied in option premiums. In addition, a large body of research has linked exchange-rate volatility to trade and welfare (Clark et al., 2004; Rapach and Strauss, 2008), and other commodity markets (Balcilar et al., 2016d). Policymakers are concerned with exchange-rate pass-through - a major mechanism by which exchange-rate movements affect domestic economic aggregates. Clearly then, accurate prediction of exchange-rate returns and volatility is of paramount importance for various economic agents. In this regard, our results demonstrate that if economic agents would rely on a linear model they would wrongly mistaken the pound relative to the dollar to be a "hedge" against terror attacks. In addition, if agents would rely on a nonlinear model, but only for the first moment (i.e., returns), they would conclude that terror attacks do not affect exchange-rate dynamics at the median of the conditional distribution of returns. However, as we show, while this is indeed the case for returns, terror attacks significantly affect the volatility over its entire conditional distribution barring its extreme upper-end. Therefore, terror attacks will always have some form of impact on the dynamics of the dollar-pound exchange rate.

3.2. Robustness Analyses

Next, we conduct two robustness analyses:

(a) We estimate a univariate GARCH model to obtain an alternative measure of the conditional volatility of the dollar-pound exchange rate returns. We use the GARCH-based volatility instead of the squared returns as a measure of volatility in our causality-in-quantiles test. As can be seen in Figure 2(c), we observe evidence of causality over the entire conditional distribution of exchange-rate volatility, barring the extreme lower quantiles, with strongly significant effects being observed towards the upper-end of the conditional distribution. Hence, we find strong evidence that relative terror attacks impact the volatility of the pound-dollar exchange rate over the majority of the quantiles of its conditional distribution, even though the pattern of causality might be contingent on the underlying measure of volatility being used. As indicated in Balcilar et al. (2016b), since squared returns as a measure of volatility follow directly from the k-th order test of quantile-causality, and as squared returns are independent of a model-based estimate of volatility (which could vary depending on what model one chooses), the use of squared returns is more appropriate in our context as a measure of volatility. Hence, a causality-in-quantiles test based on squared returns is our preferred model. In addition, as indicated earlier, intuitively the overall pattern of causality tends to make more sense when we use squared returns rather than the GARCH-based measure since, when volatility is at its lower-end, then investors would want to utilize information on terror attacks to analyze where future volatility would be heading towards.

(b) In order to analyze the similarities and differences that terror attacks might have on an emerging-economy currency when compared to the British pound, we present results for the Indian rupee. There are primarily three reasons behind choosing India: (i) We have a long-span of data covering the period of 3rd January, 1973 to 30th December, 2009 (i.e., 9281 observations). (2) India has witnessed terror attacks on a regular basis. (3) While there are many emerging economies which have witnessed more terror attacks than India, unlike India these economies are not that important for global investors. Figures A1-A3 plot the returns and squared returns of the rupee-dollar exchange rate, and the relative terror index for India (relative to the U.S.). Figures 3(a) and 3(b) plot the causality-in-quantiles results for the returns and volatility (squared returns) of the rupee-dollar exchange rate.[5] As can be seen, the impact is exceptionally large in

[5] Standard linear Granger causality test again failed to show any evidence of predictability from the relative terror attack index on the rupee-dollar exchange rate. This result, however, was not surprising given evidence of nonlinearity and structural breaks detected by the BDS and the Bai and Perron (2003) tests. In other words, the

Figure 3a. Quantile Causality Results for Indian Rupee to US Dollar Exchange-rate returns

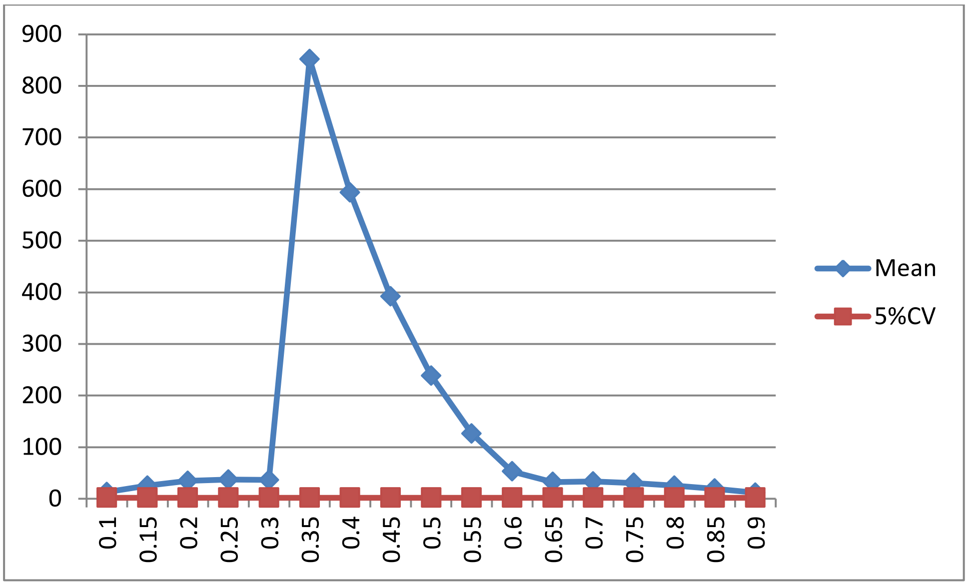
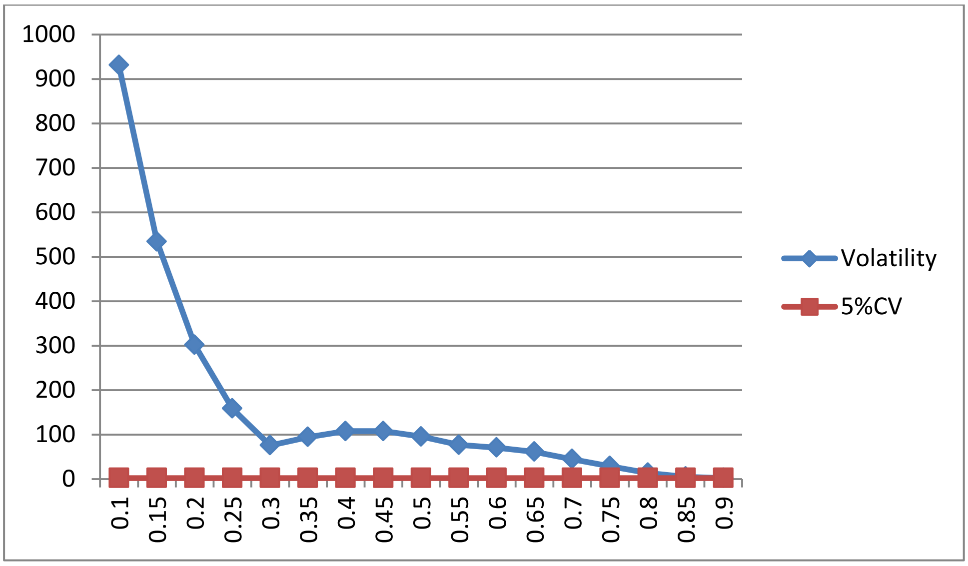


Figure 3b. Quantile Causality Results for Indian Rupee to US Dollar Exchange Rate Volatility (Squared Returns)



terms of significance and peaks at the quantile of 0.35 (quantile of 0.05) for returns (volatility), with causality observed over the entire conditional distribution of returns (volatility). When compared to the results for the dollar-pound exchange rate, there are both similarities and

linear model is again found to be misspecified as in the case of the dollar-pound exchange rate. Details of these results are available upon request from the authors.

differences. A similarity is in the fact that terror attacks do affect both returns and volatility, where the impact on returns and volatility tends to be strong in terms of significance at the lower quantiles. A major difference is that, in case of the rupee, the entire conditional distributions of returns and volatility are affected by terror attacks while, in the case of the pound, there was no evidence of causality around the median for returns and at the upper end of the conditional distribution of volatility (measured by squared returns). Taken together, the results for the rupee-dollar exchange rate are in line with economic intuition as one would expect that (relative) terror attacks exert a stronger impact on an emerging-market currency than on the currency of a developed market economy. This suggests that investments in emerging-market currencies are in general not "hedges" against terror attacks. The significant impact of (relative) terror attacks on exchange-rate volatility at the lower-end of the conditional distribution again corroborates our line of reasoning that at high-levels of uncertainty in the currency market information on terror attacks is comparatively less relevant for predicting the future dynamics of exchange-rate volatility.

4. Concluding remarks

While much significant research has been done to recover the effects of terror attacks on the returns and the volatility of stock-market prices, much less is known about how terror attacks affect exchange rates. We have laid out a methodological framework that helps to close this research gap. The nonparametric causality-in-quantiles test that we have applied in this research is robust to misspecification errors caused by nonlinearities in the data-generating processes and structural breaks, and it renders it possible to test for causality in higher-order moments.

We have applied the nonparametric causality-in-quantiles to study how terror attacks affect the dollar-pound exchange rate. To this end, we have created a relative terror attack index, since the exchange rate is a relative price. Our results show that (relative) terror attacks do affect exchange-rate returns and volatility at many quantiles of the conditional distribution of exchange-rate returns and volatiltiy. Importantly, we have found that (relative) terror attacks do not exert any causal effects on exchange-rate returns in the vicinity of the median of the conditional distribution of exchange-rate returns. While this finding is in line with the results of a linear test for Granger noncausality, we also find that (relative) terror attacks have a significant effect on exchange-rate returns at many quantiles below and above the median of the conditional distribution of exchange-rate returns. While there are subtle differences, our results suggest that even under an alternative model-based (GARCH) measure of volatility, and for returns and volatility of an important emerging market (India) currency, there is ample evidence that terror attacks exert a significant causal effect on the returns and volatility of exchange rates.

In future research, the methodological framework we have outlined in this research lends itself to study other exchange rates than the ones we have considered in our research. In addition, given that in-sample predictability of the exchange rate does not guarantee the same over an out-of-sample (Rossi, 2013), it would be interesting to see whether the relative terror attacks index can forecast exchange rate returns and volatility.

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APPENDIX:

Figure A1. Indian Rupee to US Dollar Exchange Rate Returns

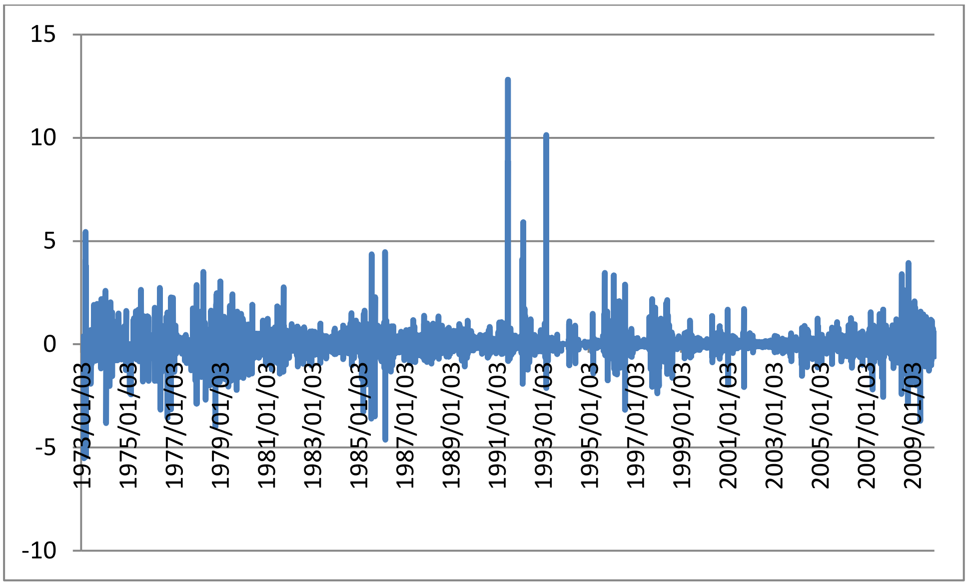

Figure A2. Indian Rupee to US Dollar Squared Exchange Rate Returns (Volatility)

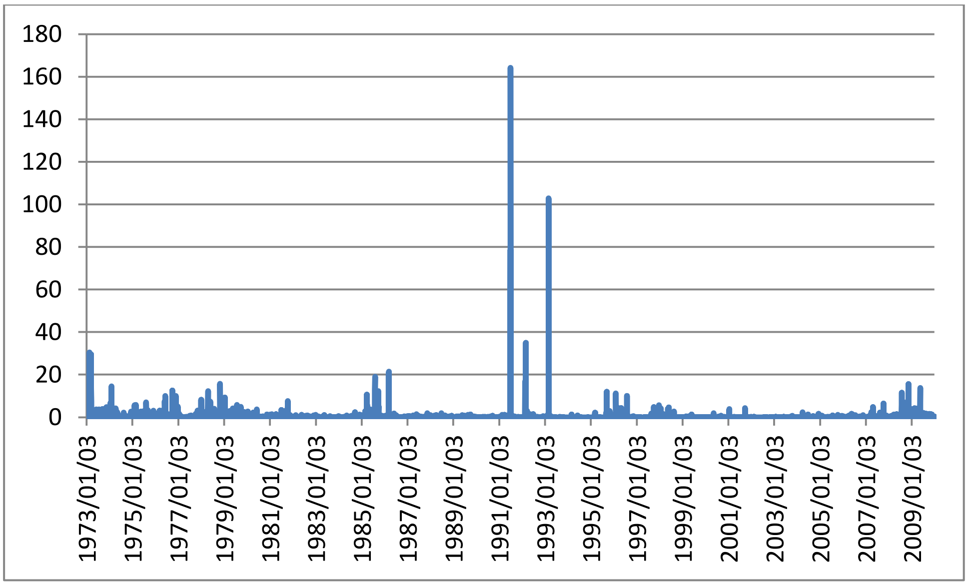

Figure A3. Terror Index of India Relative to the US