# Monetary Policy Uncertainty and Volatility Jumps in Advanced Equity Markets

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## Abstract

We analyze the role of monetary policy uncertainty in predicting volatility jumps in nine advanced equity markets. The standard linear Granger causality test detects weak evidence of monetary policy uncertainty causing volatility jumps. But given the strong evidence of nonlinearity between jumps and monetary policy uncertainty, we next use a nonparametric causality-in-quantiles test, since the linear model is misspecified. Using this data-driven robust approach we find strong evidence of the role of monetary policy uncertainty in predicting volatility jumps, especially towards the lower end of the conditional distribution.

**Keywords:** Stock Market Volatility Jumps, Monetary Policy Uncertainty**.**

**JEL Codes:** C22, G10.

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## 1. Introduction

In a recent paper, Kaminska and Roberts-Sklar (2018) point out that there should be a strong link between monetary policy rate uncertainty and equity return volatility,[1] given that the monetary policy (i.e., short-term risk-free) rate is a key factor for pricing many securities and derivatives. The authors go on to empirically show that monetary policy rate uncertainty has important predictive power for equity return volatility over the last two decades for the Euro Area, the United Kingdom (UK) and the United States (US).[2]

Financial market volatility is important for investment decisions, option pricing and financial market regulation (Poon and Granger, 2003), and given this, market agents care not only about the nature of volatility, but also of its level, with all traders making distinctions between good and bad volatilities (Giot et al., 2010). Good volatility is directional, persistent and relatively easy to anticipate, but bad volatility is jumpy and relatively difficult to foresee (Caporin et al., 2016). Thus, good volatility is associated with the continuous and persistent part of equity market variance, while bad volatility captures the discontinuous and jump components of the same. In this context, it has been stressed that incorporating jumps into volatility models can improve their overall performance, given their dominance in the volatility process (Todorov and Tauchen, 2011).

Against this backdrop, given the observations made by Kaminska and Roberts-Sklar (2018), the objective of our paper is to empirically check whether monetary policy uncertainty predicts volatility jumps, and in the process provides a channel through which overall market volatility is impacted. For our predictability analysis, we rely on the nonparametric causality-in-quantiles test of Jeong et al. (2012), which allows us to test for predictability over the entire conditional distribution of volatility jumps by controlling for misspecification due to uncaptured nonlinearity. To the best of our knowledge, this is the first paper that evaluates the predictive power of monetary policy uncertainty for nine advanced stock markets

[1] In this regard note that Pástor and Veronesi (2012) also theoretically relate stock price movements with general government policy uncertainty.
[2] This empirical finding is confirmed by Gupta and Wohar (forthcoming) for the UK, based on more than 150 years of historical data.

(Canada, France, Germany, Italy, Japan, Spain, Sweden, the UK, and the US) based on a quantiles-based nonparametric framework. The remainder of the paper is organized as follows: Section 2 lays out the basics of the econometric methodologies involving volatility jumps and the causality-in-quantiles approach; Section 3 presents the data and results, with Section 4 concluding the paper.

## 2. Econometric Methodologies

### 2.1. Volatility Jumps

In this sub-section, we briefly present the methodology for the computation of volatility jumps (hereafter *JUMPS*). We employ daily log-returns to estimate a monthly point estimate of realized volatility. The monthly volatility is constructed by the realized variance $(RV)$, which is a benchmark and a widely used realized volatility measure. In each month $t$, $RV_t$ is given by:

$$RV_t = \sum_{i=1}^{T} R_{t,i}^2 \tag{1}$$

where $R_{t,i}$ stands for the daily log-return for month $i$ and $i = 1, \dots T$ where $T$ represents the total number of daily log-returns within a month.

The monthly jump component from volatility is detected by the following criterion:

$$JUMPS_t = \left(\log(RV_t) - \log(RBV_t)\right) \mathbf{1}\{U_t > \Phi_a\} \tag{2}$$

where the $RBV$ is the standardized realized bipower variation, which allows for a non-parametric distinction between the continuous component and the jump component of the volatility. Following Barndorff-Nielse and Shepherd (2004), the $RBV_t$ is given by:

$$RBV_t = \mu_1^{-2} \sum_{i=2}^{T} \left|R_{t,i-1}\right|\left|R_{t,i}\right| \tag{3}$$

where $\mu_1$ is equal to $\sqrt{2/\pi}$ obtained from the mean of a standard random variable $Z$ in absolute values. Furthermore, $U$ denotes the jump statistic to detect the discontinuous jump variation. Following Andersen et al. (2007), $U_t$ is given by:

$$U_t = \sqrt{T}\ \frac{\left(\log(RV_t) - \log(RBV_t)\right)}{[(\mu_1^{-4} + 2\mu_1^{-2} - 5)RTQ_t(RBV)_t^{-2}]^{\frac{1}{2}}} \to N(0,1) \quad (4)$$

where $RTQ$ denotes the realized tripower quarticity, which converges in probability to integrated quarticity. The $RTQ_t$ can be estimated as follows:

$$RTQ_t = T\mu_{4/3}^{-3} \sum_{i=3}^{T} \left|R_{t,i-2}\right|^{4/3} \left|R_{t,i-1}\right|^{4/3} \left|R_{t,i}\right|^{4/3} \quad (5)$$

where $\mu_{4/3} = E\left(|Z|^{4/3}\right)$, while $E\left(|Z|^{4/3}\right) = 2^{2/3} \cdot \Gamma(7/6) \cdot \Gamma(1/2)^{-1}$. A jump is significant when the $U_t$ exceeds the appropriate critical value of the standardized Gaussian distribution ($\Phi_a$), at a 10% significance level.

### 2.2. Causality-in-Quantiles

In this sub-section, we briefly present the methodology for testing nonlinear causality as developed by Jeong et al. (2012). Let $y_t$ denote stock market $JUMPS_t$ and $x_t$ the monetary policy uncertainty variable, with details on the latter provided in the next section. Further, 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 $F_{y_t|\cdot}(y_t| \bullet)$ denote the conditional distribution of $y_t$ given $\bullet$. Defining $Q_\theta(Z_{t-1}) \equiv Q_\theta(y_t|Z_{t-1})$ and $Q_\theta(Y_{t-1}) \equiv Q_\theta(y_t|Y_{t-1})$, we have $F_{y_t|Z_{t-1}}\{Q_\theta(Z_{t-1})|Z_{t-1}\} = \theta$ with probability 1. The (non) causality in the $\theta$-th quantile hypotheses to be tested are:

$$H_0\text{:}\ \ P\left\{F_{y_t|Z_{t-1}}\{Q_\theta(Y_{t-1})|Z_{t-1}\} = \theta\right\} = 1 \quad (6)$$

$$H_1\text{:}\ \ P\left\{F_{y_t|Z_{t-1}}\{Q_\theta(Y_{t-1})|Z_{t-1}\} = \theta\right\} < 1 \quad (7)$$

Jeong et al. (2012) show that the feasible kernel-based test statistics has the following formulation:

$$\hat{J}_T = \frac{1}{T(T-1)h^{2p}} \sum_{t=p+1}^{T} \sum_{s=p+1, s\neq t}^{T} K\left(\frac{Z_{t-1} - Z_{s-1}}{h}\right) \hat{\varepsilon}_t \hat{\varepsilon}_s \quad (8)$$

where $K(\bullet)$ is the kernel function with bandwidth $h$, $T$ is the sample size, $p$ is the lag order, and $\hat{\varepsilon}_t = \mathbf{1}\{y_t \leq \hat{Q}_\theta(Y_{t-1})\} - \theta$ is the regression error, where $\hat{Q}_\theta(Y_{t-1})$ is an estimate of the $\theta$-th conditional quantile and $\mathbf{1}\{\bullet\}$ is the indicator function. The *Nadarya-Watson* kernel estimator of $\hat{Q}_\theta(Y_{t-1})$ is given by:

$$\hat{Q}_\theta(Y_{t-1}) = \frac{\sum_{s=p+1,s\neq t}^{T} L\left(\frac{Y_{t-1} - Y_{s-1}}{h}\right) \mathbf{1}\{y_s \leq y_t\}}{\sum_{s=p+1,s\neq t}^{T} L\left(\frac{Y_{t-1} - Y_{s-1}}{h}\right)} \quad (9)$$

with $L(\bullet)$ denoting the kernel function.

The empirical implementation of causality testing via quantiles entails specifying three key parameters: the bandwidth ($h$), the lag order ($p$), and the kernel types for $K(\cdot)$ and $L(\cdot)$. We use a lag order of one based on the Schwarz Information Criterion (SIC). We determine $h$ by leave-one-out least-squares cross validation. Finally, for $K(\cdot)$ and $L(\cdot)$, we use Gaussian kernels.

**3. Data and Results**

Our analysis involves two variables, the measures of volatility jumps and monetary policy uncertainty. We use the monthly interest rate uncertainty measures of Istrefi and Mouabbi (2018), which are, in turn, based on forecasts of short- (3 month) and long-term (10 year) interest rates, 3- and 12-months-ahead, stemming from Consensus Economics surveys. The measures account for two components, disagreement among forecasters and the perceived variability of future aggregate shocks. The data on the four measures of monetary policy uncertainty, i.e., 3m3m, 10y3m, 3m12m, and 10y12m corresponding to 3 month and 10 year government bond yields at 3- and 12-months-ahead horizons respectively, are available for Canada, France, Germany, Italy, Japan, Spain, Sweden, the UK and the US.[3] Understandably, the availability of data on the measures of monetary policy uncertainty for these countries determine our sample economies, as well as the length of the time series. We also use daily log-returns of the MSCI equity indices of the nine countries, derived from the Datastream database of Thomson Reuters, to arrive at the monthly volatility jump values. The data is

[3] The data is available for download from: https://sites.google.com/site/istrefiklodiana/interest-rate-uncertainty?authuser=0.

summarized in Table A1, and as can be seen from this table, the *JUMP* variables for each country are positively skewed and have excess kurtosis, resulting in non-normal distributions, as indicated by the overwhelming rejection (at 1 percent level of significance) of the null of normality under the Jarque-Bera test. The heavy-tail of the unconditional distribution of volatility jumps provides a preliminary justification for the causality-in-quantiles test used in the empirical analysis.

Before we present the findings of the causality-in-quantiles test, for the sake of completeness and comparability, we first conduct the standard linear Granger causality test. The resulting $\chi^2(1)$ statistics are presented in Table 1, and as can be seen from the table, the null of no-Granger causality from the monetary policy uncertainty measures to volatility jumps is rejected in only 12 of the possible 36 cases. Strong evidence (3 cases each) of predictability is observed for *JUMPS* in the Italian and Spanish equity markets, followed by Germany and the UK (2 cases each), with relatively weaker evidence detected for Canada and Sweden (one case each). But in general, based on the standard linear test, one would conclude there is weak prediction of volatility jumps due to monetary policy uncertainties.

**[INSERT TABLE 1 ABOUT HERE]**

Given the insignificant results in 67% of the cases obtained from linear causality tests, we statistically examine the presence of nonlinearity in the relationship *JUMPS* and 3m3m, 10y3m, 3m12m, and 10y2m. For this purpose, we apply the Brock et al. (1996, BDS) test to the residuals from the jump equation involving one lag of *JUMPS* and the four alternative measures of monetary policy uncertainty, considered by turn. Table A2 in the Appendix presents the results of the BDS test of nonlinearity. As shown in this table, we find strong evidence for the rejection of the null of *i.i.d.* residuals at various embedded dimensions (*m*), which in turn, is indicative of nonlinearity in the relationship *JUMPS* and 3m3m, 10y3m, 3m12m, and 10y2m. This finding indicates that the results based on the linear Granger causality test cannot be deemed robust and reliable.

**[INSERT TABLE 2 ABOUT HERE]**

Given the strong evidence of nonlinearity in the relationship between volatility jumps and monetary policy uncertainties, we now turn our attention to the causality-in-quantiles test, which is robust to linear misspecification due to its nonparametric (i.e., data-driven) approach, besides providing evidence of predictability (if any) over the entire conditional distribution of the *JUMPS* variable. As can be seen from Table 2, for the cases of Canada, France, Spain, the UK and the US, predictability due to monetary policy uncertainty is generally restricted towards the lower end of the conditional distribution of volatility jumps. However, predictability is quite strong in the remaining four cases of Germany, Italy, Japan and Sweden, barring the upper end of the conditional distribution of *JUMPS*.[4] But consistently across all these countries, the strongest evidence of causality (in terms of the size of the test statistic), is observed at the lowest control. More importantly, unlike the linear Granger causality test, where evidence of predictability is restricted to five of the nine countries, and that too not necessarily for all the four alternative measures of monetary policy uncertainty, we find evidence of predictability for at least four quantiles of *JUMPS* for all nine countries, and across 3m3m, 10y3m, 3m12m, and 10y12m. Recalling that Kaminska and Roberts-Sklar (2018) suggest that monetary policy uncertainty drives volatility, based on our results we can now say that a channel[5] through which this happens is that monetary policy-related uncertainties affect jumps, and hence, bad volatilities.

## 4. Conclusion

Recent evidence tends to suggest that monetary policy uncertainty can affect equity market volatility. Given that the volatility-related literature also stresses the dominance of jumps in variance of stock prices, we, in this paper, analyze the role of monetary policy uncertainty in predicting volatility jumps of nine advanced stock markets (Canada, France, Germany, Italy, Japan, Spain, Sweden, the UK and the US). For our predictability analysis, we rely on a nonparametric causality-in-quantiles test, which is robust to not only misspecification due to nonlinearity being a data-driven procedure, but also provides evidence of causality over the entire conditional distribution of volatility jump. Our results indicate that monetary policy

[4] Alternative measures of monetary policy uncertainty, based on newspaper articles, have been developed by Baker et al. (2016) and Husted et al. (2017) for the US, and by Arbatli et al. (2017) for Japan. The data is available for download from: http://policyuncertainty.com/monetary.html. As a robustness check, when we use these indices, and re-conduct our analysis of predictability for *JUMPS*, we obtain similar results to those reported in Table 2 (with the Proximity: 10 Word (Fed) index of Husted et al. (2017) showing strong predictability for the US *JUMPS* over its entire conditional distribution). These results are presented in Table A3 in the Appendix.

[5] Note that, since, according to basic present value models, the variance of equity prices is linked to the conditional variances of future discount rates, which are in turn the explicit functions of expected risk-free interest rates and risk premia, we have a direct channel through which monetary policy uncertainties are likely to affect volatility.

uncertainty does indeed predict volatility jumps of all countries at the lower end of the conditional distribution, with relatively stronger effects observed for Germany, Italy, Japan, and Sweden. In summary, our analysis shows that uncertainty related to monetary policy decisions can affect stock market variance via volatility jumps.

Given that appropriate prediction of the process of volatility has ample implications for portfolio selection, the pricing of derivative securities and risk management, our results imply that investors and policymakers can use the information contained in monetary policy uncertainty to predict volatility jumps, and hence volatility. As part of future analysis, contingent on data availability, our paper can be extended to analysing the role of monetary policy uncertainty in predicting stock market volatility jumps of emerging economies.

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**Table 1:** Granger Causality Test Results

| Country | Independent variable | $\chi^2(1)$-statistic | *p*-value |
|---|---|---|---|
| Canada | 3m3m | 0.0036 | 0.9520 |
| | 10y3m | 0.0933 | 0.7603 |
| | 3m12m | 0.0341 | 0.8537 |
| | 10y12m | 5.8623 | 0.0162** |
| France | 3m3m | 2.6455 | 0.1054 |
| | 10y3m | 2.2522 | 0.1346 |
| | 3m12m | 8.0E-05 | 0.9929 |
| | 10y12m | 0.0060 | 0.9382 |
| Germany | 3m3m | 18.944 | 0.0000*** |
| | 10y3m | 0.7703 | 0.3809 |
| | 3m12m | 7.3125 | 0.0075** |
| | 10y12m | 1.4209 | 0.2344 |
| Italy | 3m3m | 23.350 | 0.0000*** |
| | 10y3m | 31.955 | 0.0000*** |
| | 3m12m | 6.4359 | 0.0120** |
| | 10y12m | 2.0142 | 0.1571 |
| Japan | 3m3m | 0.6599 | 0.4173 |
| | 10y3m | 0.7873 | 0.3757 |
| | 3m12m | 0.0120 | 0.9128 |
| | 10y12m | 1.0679 | 0.3024 |
| Spain | 3m3m | 45.940 | 0.0000*** |
| | 10y3m | 4.9557 | 0.0269** |
| | 3m12m | 17.948 | 0.0000*** |
| | 10y12m | 0.1414 | 0.7073 |
| Sweden | 3m3m | 4.1738 | 0.0421** |
| | 10y3m | 0.0095 | 0.9226 |
| | 3m12m | 1.9945 | 0.1592 |
| | 10y12m | 0.4672 | 0.4950 |
| UK | 3m3m | 23.785 | 0.0000*** |
| | 10y3m | 13.501 | 0.0003*** |
| | 3m12m | 3.5249 | 0.0616* |
| | 10y12m | 1.5098 | 0.2203 |
| US | 3m3m | 0.5844 | 0.4452 |
| | 10y3m | 2.4763 | 0.1167 |
| | 3m12m | 0.0012 | 0.9719 |
| | 10y12m | 1.4042 | 0.2371 |

**Note:** ***, **, * respectively represent rejection of the null of no-causality at 1%, 5%, and 10% levels of significance respectively.

**Table 2.** Nonparametric Causality-in-Quantiles Results

| Country | Independent variable | Quantile | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **0.1** | **0.2** | **0.3** | **0.4** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** |
| Canada | 3m3m | 43.089*** | 13.377*** | 2.521** | 0.279 | 0.171 | 0.146 | 0.095 | 0.101 | 0.132 |
| | 10y3m | 39.014*** | 11.398*** | 1.807* | 0.352 | 0.319 | 0.300 | 0.176 | 0.113 | 0.086 |
| | 3m12m | 39.994*** | 12.235*** | 2.331** | 0.337 | 0.449 | 0.779 | 0.547 | 0.366 | 0.232 |
| | 10y12m | 38.006*** | 11.095*** | 1.669* | 0.150 | 0.800 | 0.967 | 0.580 | 0.590 | 0.321 |
| France | 3m3m | 42.163*** | 15.093*** | 4.385*** | 0.739 | 0.461 | 0.439 | 0.413 | 0.470 | 0.208 |
| | 10y3m | 52.492*** | 18.046*** | 4.685*** | 0.751 | 0.375 | 0.728 | 0.542 | 0.228 | 0.255 |
| | 3m12m | 36.507*** | 13.162*** | 3.971*** | 0.779 | 0.386 | 0.578 | 0.371 | 0.417 | 0.196 |
| | 10y12m | 42.819*** | 14.158*** | 3.292*** | 0.350 | 0.319 | 0.332 | 0.276 | 0.267 | 0.164 |
| Germany | 3m3m | 9.949*** | 6.273*** | 5.025*** | 4.939*** | 4.991*** | 4.954*** | 4.694*** | 3.946*** | 3.018*** |
| | 10y3m | 13.713*** | 6.750*** | 4.270*** | 3.613*** | 3.600*** | 3.518*** | 3.473*** | 3.051*** | 2.101** |
| | 3m12m | 12.018*** | 6.050*** | 3.873*** | 3.342*** | 3.036*** | 3.049*** | 2.793*** | 2.570*** | 1.629 |
| | 10y12m | 13.344*** | 6.394*** | 3.935*** | 3.448*** | 3.260*** | 2.742*** | 2.852*** | 2.321** | 1.989** |
| Italy | 3m3m | 15.756*** | 6.934*** | 3.504*** | 2.254** | 2.046** | 1.951* | 1.959* | 2.065** | 1.442 |
| | 10y3m | 23.502*** | 9.920*** | 4.524*** | 2.350** | 3.111*** | 3.466*** | 3.228*** | 2.502** | 1.661* |
| | 3m12m | 11.972*** | 6.535*** | 4.406*** | 3.583*** | 4.330*** | 3.769*** | 3.388*** | 3.235*** | 1.978** |
| | 10y12m | 30.184*** | 11.569*** | 4.141*** | 1.311 | 1.334 | 1.189 | 1.701* | 1.441 | 0.839 |
| Japan | 3m3m | 19.064*** | 8.218*** | 4.024*** | 2.531** | 2.517** | 2.322** | 2.072** | 1.614 | 1.354 |
| | 10y3m | 17.916*** | 7.829*** | 3.925*** | 2.493** | 3.193*** | 3.009*** | 2.370** | 2.102** | 1.575 |
| | 3m12m | 17.426*** | 7.361*** | 3.506*** | 2.184** | 2.066** | 1.897* | 1.921* | 1.316 | 1.250 |
| | 10y12m | 21.264*** | 9.914*** | 5.425*** | 3.597*** | 3.488*** | 2.938*** | 2.785*** | 2.612*** | 1.404 |
| Spain | 3m3m | 43.596*** | 15.777*** | 4.630*** | 0.464 | 0.493 | 0.856 | 0.828 | 0.747 | 0.406 |
| | 10y3m | 63.025*** | 24.203*** | 7.917*** | 1.092 | 0.292 | 0.500 | 0.735 | 1.133 | 0.305 |
| | 3m12m | 23.741*** | 9.017*** | 3.320*** | 1.271 | 1.115 | 1.111 | 1.536 | 0.930 | 0.892 |
| | 10y12m | 34.665*** | 12.641*** | 3.969*** | 0.723 | 0.570 | 0.423 | 0.553 | 0.693 | 0.358 |
| Sweden | 3m3m | 21.287*** | 9.174*** | 4.505*** | 2.783*** | 2.284** | 1.981** | 1.785* | 1.737* | 1.996** |
| | 10y3m | 15.907*** | 6.779*** | 3.485*** | 2.610*** | 2.582*** | 2.735*** | 1.719* | 2.211** | 1.198 |
| | 3m12m | 15.158*** | 6.061*** | 2.775*** | 1.903* | 2.056** | 1.952* | 1.714* | 1.611 | 1.105 |
| | 10y12m | 17.355*** | 7.089*** | 3.199*** | 1.907* | 1.641 | 1.488 | 1.613 | 1.527 | 1.174 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| UK | 3m3m | 38.241*** | 14.158*** | 4.782*** | 1.317 | 0.967 | 0.952 | 0.656 | 0.603 | 0.499 |
| | 10y3m | 33.731*** | 12.411*** | 4.264*** | 1.440 | 1.566 | 1.347 | 1.358 | 0.976 | 0.528 |
| | 3m12m | 32.030*** | 12.006*** | 4.378*** | 1.730* | 1.361 | 1.185 | 0.757 | 0.675 | 0.483 |
| | 10y12m | 31.821*** | 12.277*** | 4.703*** | 1.891* | 1.722* | 1.460 | 1.485 | 1.167 | 0.948 |
| US | 3m3m | 17.572*** | 2.658*** | 0.383 | 0.576 | 0.521 | 0.282 | 0.645 | 0.421 | 0.192 |
| | 10y3m | 19.621*** | 3.364*** | 0.412 | 0.295 | 0.290 | 0.174 | 0.270 | 0.362 | 0.389 |
| | 3m12m | 15.468*** | 2.467*** | 0.464 | 0.323 | 0.356 | 0.135 | 0.302 | 0.193 | 0.221 |
| | 10y12m | 16.956*** | 3.244*** | 1.042 | 0.672 | 0.272 | 0.149 | 0.475 | 0.415 | 0.320 |

**Note:** ***, **, * respectively represent rejection of the null of no-causality for a specific quantile at 1%, 5%, and 10% levels of significance respectively.

**APPENDIX:**

**Table A1.** Summary Statistics

| Country | Independent variable | Mean | Median | Maximum | Minimum | Std. Dev | Skewness | Kurtosis | Jarque-Bera | *p*-value | observation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Canada | Jumps | 0.0005 | 0.0001 | 0.0063 | 0.0000 | 0.0009 | 3.7566 | 19.8290 | 3778.7 | 0.0000 | 5/1/1993 to 7/1/2015 (N=267) |
| | 3m3m | 0.1576 | 0.1501 | 0.4641 | 0.0217 | 0.0810 | 0.8386 | 4.0334 | 43.174 | 0.0000 | 5/1/1993 to 7/1/2015 (N=267) |
| | 10y3m | 0.2846 | 0.2407 | 1.2462 | 0.0226 | 0.1889 | 1.5197 | 6.3304 | 226.163 | 0.0000 | 5/1/1993 to 7/1/2015 (N=267) |
| | 3m12m | 0.3388 | 0.3200 | 1.2160 | 0.0844 | 0.1597 | 1.3055 | 6.6445 | 216.071 | 0.0000 | 5/1/1993 to 10/1/2014 (N=258) |
| | 10y12m | 0.3123 | 0.2761 | 0.7356 | 0.1620 | 0.1102 | 1.2560 | 4.3687 | 87.967 | 0.0000 | 5/1/1993 to 10/1/2014 (N=258) |
| France | Jumps | 0.0006 | 0.0002 | 0.0156 | 0.0000 | 0.0013 | 6.4486 | 61.1576 | 41548 | 0.0000 | 5/1/1993 to 9/1/2016 (N=281) |
| | 3m3m | 0.0847 | 0.0776 | 0.4165 | 0.0112 | 0.0547 | 2.1408 | 11.8947 | 864.84 | 0.0000 | 1/1/1999 to 9/1/2016 (N=213) |
| | 10y3m | 0.1860 | 0.1739 | 0.4520 | 0.1024 | 0.0501 | 2.1875 | 9.6718 | 745.27 | 0.0000 | 5/1/1993 to 9/1/2016 (N=281) |
| | 3m12m | 0.2568 | 0.2159 | 1.2078 | 0.0085 | 0.1897 | 1.8646 | 8.0569 | 312.54 | 0.0000 | 1/1/1999 to 10/1/2014 (N=190) |
| | 10y12m | 0.2528 | 0.2426 | 0.5453 | 0.1019 | 0.0676 | 1.1803 | 5.2286 | 113.29 | 0.0000 | 5/1/1993 to 10/1/2014 (N=258) |
| Germany | Jumps | 0.0006 | 0.0002 | 0.0139 | 0.0000 | 0.0014 | 5.4457 | 41.8553 | 19065 | 0.0000 | 5/31/1993 to 9/30/2016 (N=281) |
| | 3m3m | 0.0801 | 0.0696 | 0.4127 | 0.0075 | 0.0630 | 2.3380 | 11.7734 | 877.19 | 0.0000 | 1/29/1999 to 9/30/2016 (N=213) |
| | 10y3m | 0.2259 | 0.1995 | 0.7577 | 0.0171 | 0.1402 | 0.8797 | 3.4089 | 38.199 | 0.0000 | 5/31/1993 to 9/30/2016 (N=281) |
| | 3m12m | 0.1871 | 0.1759 | 0.5946 | 0.0251 | 0.0826 | 1.6635 | 8.0666 | 290.85 | 0.0000 | 1/29/1999 to 10/1/2014 (N=190) |
| | 10y12m | 0.2212 | 0.2171 | 0.4871 | 0.1244 | 0.0476 | 1.7659 | 9.4422 | 580.24 | 0.0000 | 5/31/1993 to 10/1/2014 (N=258) |
| Italy | Jumps | 0.0006 | 0.0001 | 0.0143 | 0.0000 | 0.0014 | 5.1504 | 39.8305 | 17124 | 0.0000 | 5/1/1993 to 9/1/2016 (N=281) |
| | 3m3m | 0.0816 | 0.0757 | 0.3599 | 0.0075 | 0.0507 | 1.7098 | 9.5965 | 489.96 | 0.0000 | 1/1/1999 to 9/1/2016 (N=213) |
| | 10y3m | 0.2778 | 0.2311 | 1.0285 | 0.0859 | 0.1448 | 2.0776 | 8.8743 | 606.16 | 0.0000 | 5/1/1993 to 9/1/2016 (N=281) |
| | 3m12m | 0.2025 | 0.1984 | 0.4045 | 0.0735 | 0.0605 | 0.3883 | 3.3879 | 5.96 | 0.0506 | 1/1/1999 to 10/1/2014 (N=190) |
| | 10y12m | 0.3264 | 0.2729 | 2.2043 | 0.1461 | 0.1958 | 4.6304 | 37.8204 | 13955 | 0.0000 | 5/1/1993 to 10/1/2014 (N=258) |
| Japan | Jumps | 0.0006 | 0.0002 | 0.0168 | 0.0000 | 0.0014 | 7.2774 | 74.2346 | 58809 | 0.0000 | 5/31/1993 to 7/31/2015 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | (N=267) |
| | 3m3m | 0.0501 | 0.0384 | 0.1709 | 0.0063 | 0.0357 | 1.1539 | 3.8286 | 66.88 | 0.0000 | 5/31/1993 to 7/31/2015 (N=267) |
| | 10y3m | 0.1265 | 0.1103 | 0.3346 | 0.0359 | 0.0613 | 1.0097 | 3.7157 | 50.87 | 0.0000 | 5/31/1993 to 7/31/2015 (N=267) |
| | 3m12m | 0.0866 | 0.0674 | 0.3872 | 0.0060 | 0.0719 | 1.5377 | 5.4457 | 165.97 | 0.0000 | 5/31/1993 to 10/1/2014 (N=258) |
| | 10y12m | 0.1714 | 0.1537 | 0.4862 | 0.0454 | 0.0842 | 1.2295 | 4.4456 | 87.12 | 0.0000 | 5/31/1993 to 10/1/2014 (N=258) |
| Spain | Jumps | 0.0007 | 0.0001 | 0.0149 | 0.0000 | 0.0016 | 5.0268 | 35.3927 | 12510 | 0.0000 | 1/1/1995 to 9/1/2016 (N=261) |
| | 3m3m | 0.0814 | 0.0760 | 0.5813 | 0.0149 | 0.0625 | 4.3562 | 32.8316 | 8571 | 0.0000 | 1/1/1995 to 9/1/2016 (N=213) |
| | 10y3m | 0.2511 | 0.2125 | 1.6744 | 0.1331 | 0.1322 | 5.7020 | 55.0517 | 30878 | 0.0000 | 1/1/1999 to 9/1/2016 (N=261) |
| | 3m12m | 0.2091 | 0.1970 | 0.7015 | 0.0465 | 0.0943 | 1.3583 | 7.1120 | 192.27 | 0.0000 | 1/1/1999 to 10/1/2014 (N=190) |
| | 10y12m | 0.3026 | 0.2662 | 1.2168 | 0.1449 | 0.1340 | 2.5412 | 13.3571 | 1319 | 0.0000 | 1/1/1995 to 10/1/2014 (N=238) |
| Sweden | Jumps | 0.0008 | 0.0002 | 0.0156 | 0.0000 | 0.0018 | 4.5083 | 28.8177 | 7696 | 0.0000 | 1/1/1995 to 7/1/2015 (N=247) |
| | 3m3m | 0.1248 | 0.1140 | 0.4106 | 0.0634 | 0.0474 | 2.5239 | 12.6819 | 1226 | 0.0000 | 1/1/1995 to 7/1/2015 (N=247) |
| | 10y3m | 0.2859 | 0.2416 | 1.0810 | 0.0251 | 0.1975 | 1.3701 | 5.3343 | 133.35 | 0.0000 | 1/1/1995 to 7/1/2015 (N=247) |
| | 3m12m | 0.3296 | 0.2656 | 1.4869 | 0.0353 | 0.2322 | 1.7804 | 7.8147 | 355.61 | 0.0000 | 1/1/1995 to 10/1/2014 (N=238) |
| | 10y12m | 0.3033 | 0.2741 | 0.7765 | 0.1770 | 0.1052 | 1.9320 | 7.3742 | 337.80 | 0.0000 | 1/1/1995 to 10/1/2014 (N=238) |
| UK | Jumps | 0.0003 | 0.0001 | 0.0076 | 0.0000 | 0.0008 | 6.1914 | 49.7185 | 25987 | 0.0000 | 5/1/1993 to 7/1/2015 (N=267) |
| | 3m3m | 0.1410 | 0.1306 | 0.8514 | 0.0284 | 0.0798 | 3.6792 | 29.2373 | 8260 | 0.0000 | 5/1/1993 to 7/1/2015 (N=267) |
| | 10y3m | 0.2822 | 0.2316 | 1.1634 | 0.0383 | 0.1873 | 1.2680 | 5.0522 | 118.40 | 0.0000 | 5/1/1993 to 7/1/2015 (N=267) |
| | 3m12m | 0.3612 | 0.3158 | 1.1073 | 0.0453 | 0.1943 | 1.3677 | 4.6970 | 111.39 | 0.0000 | 5/1/1993 to 10/1/2014 (N=258) |
| | 10y12m | 0.3807 | 0.3516 | 1.3537 | 0.0843 | 0.2028 | 1.1009 | 4.9475 | 92.88 | 0.0000 | 5/1/1993 to 10/1/2014 (N=258) |
| US | Jumps | 0.0005 | 0.0002 | 0.0205 | 0.0000 | 0.0014 | 11.7503 | 170.038 | 333151 | 0.0000 | 5/1/1993 to 9/1/2016 (N=281) |
| | 3m3m | 0.1119 | 0.1049 | 0.4968 | 0.0124 | 0.0682 | 1.5430 | 8.4188 | 455.29 | 0.0000 | 5/1/1993 to 9/1/2016 (N=281) |
| | 10y3m | 0.2306 | 0.2237 | 0.4726 | 0.1703 | 0.0407 | 1.8886 | 9.3511 | 639.31 | 0.0000 | 5/1/1993 to 9/1/2016 (N=281) |
| | 3m12m | 0.2890 | 0.2800 | 0.7900 | 0.0185 | 0.1475 | 0.3818 | 2.9644 | 6.2813 | 0.0433 | 5/1/1993 to 10/1/2014 (N=258) |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10y12m | 0.3397 | 0.3316 | 0.6460 | 0.1936 | 0.0820 | 0.6663 | 3.3819 | 20.65 | 0.0000 | 5/1/1993 to 10/1/2014 (N=258) |

**Note:** Std. Dev: stands for standard deviation; *p*-value corresponds to the Jarque-Bera test with the null of normality.

**Table A2.** Brock et al. (1996, BDS) Test of Nonlinearity

| Independent variable | Dimension | | | | |
|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 |
| Canada | | | | | |
| 3m3m | 4.471*** | 5.306*** | 5.644*** | 5.670*** | 5.999*** |
| 10y3m | 4.533*** | 5.352*** | 5.704*** | 5.748*** | 6.085*** |
| 3m12m | 4.321*** | 5.163*** | 5.497*** | 5.595*** | 5.787*** |
| 10y12m | 4.308*** | 5.079*** | 5.283*** | 5.206*** | 5.191*** |
| France | | | | | |
| 3m3m | 7.079*** | 7.577*** | 7.922*** | 8.065*** | 8.288*** |
| 10y3m | 7.913*** | 8.275*** | 8.662*** | 8.900*** | 9.162*** |
| 3m12m | 7.049*** | 8.125*** | 8.790*** | 9.259*** | 9.753*** |
| 10y12m | 7.514*** | 8.532*** | 9.282*** | 9.853*** | 10.543*** |
| Germany | | | | | |
| 3m3m | 7.880*** | 8.040*** | 8.615*** | 8.942*** | 9.072*** |
| 10y3m | 8.808*** | 9.049*** | 9.352*** | 9.465*** | 9.672*** |
| 3m12m | 8.077*** | 8.344*** | 8.943*** | 9.238*** | 9.483*** |
| 10y12m | 8.427*** | 9.238*** | 9.732*** | 10.084*** | 10.533*** |
| Italy | | | | | |
| 3m3m | 4.578*** | 4.656*** | 5.109*** | 5.729*** | 6.523*** |
| 10y3m | 2.839** | 3.612*** | 3.590*** | 3.975*** | 4.458*** |
| 3m12m | 3.536*** | 4.749*** | 5.358*** | 5.661*** | 6.100*** |
| 10y12m | 3.883*** | 4.906*** | 5.399*** | 5.712*** | 6.032*** |
| Japan | | | | | |
| 3m3m | 3.881*** | 3.727*** | 3.457** | 3.156** | 3.108** |
| 10y3m | 3.867*** | 3.711*** | 3.403** | 3.031** | 2.963** |
| 3m12m | 3.742*** | 3.552*** | 3.295** | 3.166** | 3.033** |
| 10y12m | 4.079*** | 3.937*** | 3.655*** | 3.403** | 3.145** |
| Spain | | | | | |
| 3m3m | 2.852** | 4.683*** | 5.544*** | 5.866*** | 6.541*** |
| 10y3m | 3.526*** | 4.445*** | 5.175*** | 5.219*** | 5.546*** |
| 3m12m | 2.586** | 4.337*** | 4.934*** | 5.203*** | 5.680*** |
| 10y12m | 4.449*** | 5.756*** | 6.610*** | 7.022*** | 7.274*** |
| Sweden | | | | | |
| 3m3m | 5.627*** | 5.801*** | 6.368*** | 6.726*** | 7.116*** |
| 10y3m | 6.039*** | 6.376*** | 6.948*** | 7.309*** | 7.798*** |
| 3m12m | 5.523*** | 6.404*** | 7.051*** | 7.434*** | 7.969*** |
| 10y12m | 6.064*** | 7.003*** | 7.429*** | 7.728*** | 8.142*** |
| UK | | | | | |
| 3m3m | 1.615 | 2.502** | 2.749** | 3.182** | 3.226** |
| 10y3m | 2.977** | 3.096** | 2.918** | 3.075** | 2.927** |
| 3m12m | -0.193 | 2.218** | 2.687** | 2.758** | 3.501** |
| 10y12m | -0.193 | 2.218** | 2.687** | 2.758** | 3.501** |
| US | | | | | |
| 3m3m | 5.960*** | 5.838*** | 5.986*** | 6.005*** | 6.062*** |
| 10y3m | 5.062*** | 5.192*** | 5.531*** | 5.531*** | 5.682*** |
| 3m12m | 5.194*** | 5.206*** | 5.461*** | 5.571*** | 5.684*** |
| 10y12m | 4.997*** | 5.140*** | 5.598*** | 5.827*** | 5.919*** |

**Note:** Entries correspond to the *z*-statistic of the BDS test with the null of *i.i.d.* residuals, with the test applied to the residuals recovered from the jump equation with one lag each of the *JUMP* and monetary policy uncertainty variables; ***, * indicate rejection of the null hypothesis at 1% and 5% levels of significance respectively.

**Table A3.** Additional Nonparametric Causality-in-Quantiles Results for Japan and the US

| **Country** | **Independent variable** | **Quantile** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **0.1** | **0.2** | **0.3** | **0.4** | **0.5** | **0.6** | **0.7** | **0.8** | **0.9** |
| Japan | MPU | 15.033*** | 9.546*** | 7.426*** | 6.693*** | 6.867*** | 6.714*** | 6.232*** | 5.440*** | 4.023*** |
| US | MPU | 17.350*** | 0.922 | 0.061 | 0.081 | 0.102 | 0.087 | 0.022 | 0.005 | 0.016 |
| | 3 Word (Fed) | 15.019*** | 0.652 | 0.023 | 0.033 | 0.054 | 0.026 | 0.026 | 0.014 | 0.010 |
| | Proximity: 10 Word (Fed) | 2.125** | 2.011** | 2.813*** | 3.102*** | 3.419*** | 3.234*** | 3.181*** | 2.516** | 1.924* |

**Note:** MPU stands for the monetary policy uncertainty index developed by Baker et al. (2016) for the US and Arbatli et al. (2017) for Japan; 3 Word (Fed) and Proximity: 10 Word (Fed) are indices of monetary policy uncertainty developed by Husted et al. (2017); ***, **, * respectively represent rejection of the null of no-causality for a specific quantile at 1%, 5%, and 10% levels of significance respectively.