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Intra-day response of foreign exchange markets after the Tohoku-Oki earthquake

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HIGHLIGHTS

- The USD/JPY market reacted the Tohoku-Oki earthquake within 2 minutes.
- The reaction was evaluated by recurrence plots and binomial tests.
- The market could be efficient in the time scale of minutes.

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ABSTRACT

Although an economy is influenced by a natural disaster, the market response to the disaster during the first 24 hours is not clearly understood. Here we show that an earthquake quickly causes temporal changes in a foreign exchange market by examining the case of the Tohoku-Oki earthquake. Recurrence plots and statistical change point detection independently show that the United States dollar–Japanese yen market responded to the earthquake activity without delay and with the delay of about 2 minutes, respectively. These findings support that the efficient market hypothesis nearly holds now in the time scale of minutes.

1. Introduction

Advancements in measurement techniques enable us to record many big data in fine precision. For example, earthquake activities are being recorded with the precision of 10 ms or less. The trades of foreign exchange markets are being recorded in the precision of 100 ms; however, the influence of earthquake effects on the foreign exchange markets with respect to time is not well understood, while the efficient market hypothesis [1,2] assumes that the markets react immediately after an event happens.

Some studies discussed the relationship between earthquake activity and foreign exchange markets [3–6]. Lee et al. [3], Asongu [4], and Wewel [5] showed by analyzing daily time series that a large earthquake triggers a contagion in the related markets. In addition, Neely [6] discussed the effect of March 18, 2011 intervention announcement by the G-7 after the Tohoku-Oki earthquake of $M9.0$ on March 11, 2011 [7–9]. However, none of Refs. [3–6] investigated the short-term reaction of foreign exchange markets to earthquakes within the time scale of less than a day. The reaction within a 24-hour time frame is the subject of this current investigation.

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Close attention is required to investigate the effects of earthquakes on foreign exchange markets with respect to a specific time frame, because earthquake activity and foreign exchange market trades are both recorded as marked point processes: a series of discrete events that accompany some values such as magnitudes, longitudes, latitudes, and depths in the case of earthquakes, and prices and volumes in the case of foreign exchange markets.

We have developed methods to analyze marked point processes [10,11]. The core factor with respect to these methods is to use a distance for marked point processes [10,12]. Previously, we showed a possibility that a series of United States dollar/Japanese yen market is of deterministic chaos [11]. Therefore, we use the same framework as outlined in Refs. [10,11] to analyze the interaction of two marked point processes using recurrence plots [13,14].

2. Datasets

The dataset for foreign exchange markets was purchased from EBS Service Company Limited. The dataset for earthquake activity was provided by the Japan Meteorological Agency. We used the series of earthquake activity around Japan and the series of trades between the United States dollar (USD) and the Japanese yen (JPY) in the foreign exchange market to investigate the interaction between them. The precision of the records for the USD/JPY market is 100 ms. The trades in foreign exchange market were recorded according to Greenwich Mean Time (GMT). We converted the times of earthquake occurrence, which are originally recorded in Japanese Standard Time, to GMT. For both datasets, we used the period between 0:00 am GMT on March 10 and 0:00 am GMT on March 12, 2011. We selected earthquakes with magnitudes greater than or equal to 1, with the longitudes and latitudes of the epicenters between 125°E and 148°E and between 25°N and 45°N, respectively. With respect to the USD/JPY market, we selected the actual transactions that occurred during that period.

3. Methods

3.1. Overview

A recurrence plot [13,14] is a two-dimensional plot originally proposed for the visualization of time series. Both axes show the identical time axis. If the metric for a pair of two time windows is close, then we plot a point at the corresponding place. Otherwise, no point is plotted there. This simple plot provides substantial information [14]. We used the distance proposed in Ref. [10] as the metric to define recurrence plots for earthquakes and trade series for the USD/JPY market. Then, we use their joint recurrence plot [15] and joint parallel plot to quantify their interactions.

3.2. Distance for marked point processes

The distance [10] is an edit distance proposed for marked point processes. For a pair of time windows for marked point processes, we define a distance as the total minimum cost for converting one of them to the other. Allowed operations include deletion, insertion, and shift of events. For deletion or insertion, we assign a cost of one. For shift, we assign a cost which is proportional to the amounts of time and values shifted.

Following previous work [11], we used time windows of 10 min and sampled the time windows every 10 min if not mentioned. We used $N = 288$ time windows. Between each pair of time windows, we calculated the distance of marked point processes [10] for the series of earthquakes and the series of USD/JPY trades by formulating each problem as a minimum cost perfect matching on a bipartite graph. We used the times, magnitudes, longitudes, latitudes, and depths of earthquakes to calculate the distances for the earthquake series, whereas we used the times and prices of trades for the distances for the USD/JPY series. We normalized the magnitudes, longitudes, latitudes, and depths of earthquakes so that their means were 0 and their standard deviations were the same as that for the inter-earthquake intervals. We also normalized the prices of USD/JPY trades so that the standard deviation was the same as that for the inter-trade intervals.

3.3. Recurrence plots

A recurrence plot [13,14] shows the similarity between two time windows. Let $w_e(i)$ be the ith time window for the earthquake activity, d_e be a function for the distance, and ε_e be the threshold for the distances. Then, a recurrence plot R_e for the earthquake activity is defined as

$$R_e(i,j) = \begin{cases} 1, & \text{if } d_e\left(w_e\left(i\right), w_e\left(j\right)\right) \leq \varepsilon_e, \\ 0, & \text{otherwise.} \end{cases}$$

If $R_e\left(i,j\right) = 1$, then we plot a point at (i,j). If $R_e\left(i,j\right) = 0$, we do not plot a point at (i,j). Similarly, letting $w_f(i)$, d_f, and ε_f be the ith time window, a distance function for the time windows for the USD/JPY market, and the threshold for the distances, respectively, a recurrence plot R_f for the USD/JPY market can be defined as

$$R_f(i,j) = \begin{cases} 1, & \text{if } d_f\left(w_f\left(i\right), w_f\left(j\right)\right) \leq \varepsilon_f, \\ 0, & \text{otherwise.} \end{cases}$$

We set ε_e and ϵ_f so that approximately 20% of the places, excluding the central diagonal line, have points.