

Reply to Referee 1

This article conducts a comprehensive time series segmentation study on the 36 Nikkei Japanese industrial indices from 1 January 1996 to 11 June 2010. The authors propose a method to classify each segment into four kinds of economical phases. Furthermore they compute MSTs of cross-correlation matrix for several periods and compare them with results of segmentation study. Specifically they attempt to compare states of Japanese economy in five macroeconomic periods: (i) 1997-1999 (Asian Financial Crisis), (ii) 2000-2002 (Technology Bubble Crisis), (iii) 2003-2006 (economic growth), (iv) 2007-2008 (Subprime Crisis), (v) 2008-2010 (Lehman Brothers Crisis).

The Referee thinks that this comprehensive study on the Japanese stock market is meaningful and that this may deserve the publication. However several unclear points are found. If the authors can revise them adequately, then the Referee can recommend to publish it in this journal.

**1. In abstract (iv) placed in front of 2008-2010 (Lehman Brothers Crisis) should be replaced as (v).**

This is a typo on our part, and has been corrected.

**2. In Eq. (4), the Referee thinks that  $1/2$  should be eliminated since the Shannon entropy of a normal distribution is written as  $-1/2 \ln(2\pi) - \ln \sigma - 1/2$ .**

In Eq. (4), the  $+1/2$  term is correct, because it comes from the normalizations  $\sum_{s=1}^n (x_s - \mu)^2 = (n - 1) \hat{\sigma}^2$ ,  $\sum_{s=1}^t (x_s - \mu_L)^2 = (t - 1) \hat{\sigma}_L^2$ , and  $\sum_{s=t+1}^n (x_s - \mu_R)^2 = (n - t - 1) \hat{\sigma}_R^2$  we used for the unbiased estimators of the variances  $\hat{\sigma}^2$ ,  $\hat{\sigma}_L^2$ , and  $\hat{\sigma}_R^2$ .

We have added a sentence to explain this, followed by a displayed equation giving the formulas for the maximum likelihood estimates of the means and variances.

**3. The labels (growth, correction, crisis, and crash) in Table. 4 seem to be misleading because the authors only consider volatilities of these states. The authors should discuss the meaning of labels more carefully.**

As described in the third paragraph of Section 2.3, we choose to group the time series segments of each of the 36 Nikkei 500 industry indices into four or five clusters, depending on which description is the most robust statistically. Thereafter, we color the time series segments blue to green to yellow to orange, from the least volatile cluster to the most volatile cluster, if there are only four clusters; or blue to green to yellow to orange to red, from the least volatile cluster to the most volatile cluster, if there are five clusters.

In general, extremely-high-volatility red segments are very short, and coincide with known periods of greatest market uncertainties. Therefore, their interpretation as the crash phase of the market is unambiguous. In our previous work on the US market (Wong et al., 2009; Lee et al., 2009; Zhang et al., 2011), and ongoing work on the European markets, we saw that moderate-volatility green segments are also short, and coincide with periods where the market underwent corrections according to

commentators. We therefore interpreted this as the correction phase. We believe this interpretation is sound, and chose thus to interpret the longer green time series segments in the Japanese market as evidence for structural difference between the US, Europe, and Japan. Similarly, based on the timings of low-volatility blue segments and high-volatility yellow/orange segments in the US and European markets, we associate these with the growth and crisis phases respectively.

In the economics literature, growth is defined as positive change to the gross domestic product (GDP), which is an aggregate measure of all goods produced and services rendered, over a given period of time. Frequently, this period is a year, although quarterly estimates and monthly corrections of the GDP are also published. Similarly, recession is defined as sustained decrease in the GDP, or the performance of a broad spectrum of industries. The duration over which the GDP must slide before the period is technically accepted as a recession vary from country to country. In the US, GDP change must be negative for three consecutive quarters before the economy is in recession.

From our study of dynamical systems, variables such as the GDP are called slow variables, whereas variables such as stock indices are called fast variables. Economists already understand that fast variables are slaved to slow variables, and sometimes use the long-term trend of stock indices as a proxy for the GDP. However, we understand that the fluctuations of a fast variable are also strongly influenced by the states of the slow variables. This is a generic feature of the dynamics of systems with many interacting degrees of freedom. We exploit this observation to make the association between clusters characterized primarily by their volatilities, and macroeconomic phases characterized by their slowly evolving long-term trends.

In response to the referee's comment, we deleted the last sentence in the second paragraph of Section 2.3, and gave a more detailed description of how we cluster the time series segments, and how these clusters are colored according to their volatilities in the third paragraph of Section 2.3. We then added three new paragraphs at the end of Section 2.3, to explain how our volatility-based association is consistent with the standard definitions of the macroeconomic phases in terms of slowly evolving long-term trends.

**4. The definition of start of recovery (Table 5) and that of start of crisis (Table 6) are not clarified. How did the authors determine these days?**

As mentioned in the third paragraph of Section 3, we adopt as a working definition economic recovery being the start of a sustained low-volatility blue segment lasting longer than two months. We realize that this working definition is not perfect, because the two month duration is arbitrary. We could have worked with a one month duration or a three month duration instead. In practice, we find that for most Japanese industries, the start of economic recovery is not ambiguous, because their first sustained blue segments lasted significantly longer than two months.

Accepting this working definition for lack of anything more precise, we can unambiguously identify in each industry which time series segment the economic recovery started. The starting time of the segment so identified can be determined down

to half an hour, because that is the temporal resolution we used in our time series segmentation. However, it is not so important whether the segment started when the market opened, after lunch, or close to when the market closed, so we take the date this starting time of the segment falls in as the start of economic recovery in the said industry.

Similarly, to date the Subprime Crisis in the Japanese market, we adopt as a working definition the start of a crisis being the first high-volatility segment lasting longer than two months. Again, the two months period is an arbitrary choice, though in practice, the transition from mostly blue and green segments to mostly yellow and orange segments is very sharp in most industries, so the start times so determined are very insensitive to the duration of the first high-volatility segment. Again, these start times are precise down to the half hour, but we report in Table 6 only the dates.

In response to this comment, we elaborated on the dating procedure in the third paragraph of Section 3 (for dating the economic recovery), and also in the fourth paragraph of Section 3 (for dating the crisis).

**5. The authors should discuss relationship between economical states (growth, correction, crisis, and crash) and structure of MST computed from the cross-correlation matrix more carefully. At this moment the Referee did not find the meaningful information from a lot of MSTs. Some summary quantities to measure the network structure can be used for this purpose.**

In response to this comment, we expanded the paragraph on the macroeconomic MSTs into two paragraphs, and also the paragraph on the segment MSTs and flight to quality into two paragraphs. Besides including network properties like the maximum degree, the betweenness centralities of the hubs, and also the network diameter of the MST, we elaborated on how we could make better use of the statistical distinction between fluctuations in growth versus crisis through correlational changes reflected in the changes in structure of the MST when we go from one macroeconomic phase to another.

**6. The authors often use terms such as star-like (open) and chain-like (closed) in order to express the structure of MSTs. But these terms to express structure of MSTs seem to be obscure. Adequate terms or quantities should be used for expressing these network structures.**

We have actually used “star-like” and “chain-like” only once in this paper, but have done so more liberally in our previous papers. Nevertheless, we agree with the referee that these are not standard terms used in the network community.

In response to this comment, we have added in parentheses “(presence of a highly-connected and central hub, and consequently small network diameter)” to “star-like”, and “(absence of highly-connected or central nodes, and large network diameter)” to “chain-like”, to clarify what we have in mind in terms of standard network terminology.