Communications for Statistical Applications and Methods
2018, Vol. 25, No. 2, 185–197

https://doi.org/10.29220/CSAM.2018.25.2.185
Print ISSN 2287-7843 / Online ISSN 2383-4757

A case study for intercontinental comparison of herd behavior in global stock markets

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Abstract

Measuring market fear is an important way of understanding fundamental economic phenomena related to financial crises. There have been several approaches to measure market fear or panic level in a financial market. Recently, herd behavior has gained its popularity as important economic phenomena explaining the fear in the financial market. In this paper, we investigate herd behavior in global stock markets with a focus on intercontinental comparison. While various risk measures are available for the detection of herd behavior in the market, we use the standardized herd behavior index in Dhaene *et al.* (*Insurance: Mathematics and Economics*, **50**, 357–370, 2012b) and Lee and Ahn (*Dependence Modeling*, **5**, 316–329, 2017) for the comparison of herd behaviors in global stock markets. A global stock market data from Morgan Stanley Capital International is used to study herd behavior especially during periods of financial crises.

Keywords: comonotonicity, herd behavior, global stock market

1. Introduction

Measuring market fear is an important way of understanding fundamental economic phenomena, especially related to recent financial crises. There have been several approaches to measure market fear or panic level in a financial market. For example, the Chicago Board Options Exchange's Volatility Index (VIX) and the liquidity risk (Exchange, Chicago Board Options, 2009; Dhaene *et al.*, 2012a; Oh *et al.*, 2017) are classical approaches. Alternatively, heard behavior has gained increasing attention in finance as a barometer for market fear. Several recent studies about herd behavior were conducted; see for example Dasgupta *et al.* (2011), Scarsini (2004), Kim and Pantzails (2003), and Bikhchandani and Sharma (2001). In literature, herd behavior has been referred to as the degree of comovement in stock markets.

A motivational example is shown in Figure 1. It shows the daily stock indices for some selected countries in Europe from 1996 to April 2013. The movement of a representative stock index of one country almost imitates that of other countries' stock indices. The tendency of comovement in European stock markets appears to be strong, perhaps because all countries in European countries are in continual contact with one another. Based on this observation, we ask the followings. Are there comovements, such as those in Europe, in the stock markets of other continents? If so, can we identify herd behavior? How do we measure such herd behavior? These questions lead us to the study of how to measure and compare the comovement of stock prices among continents.

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Published 31 March 2018 / journal homepage: http://csam.or.kr

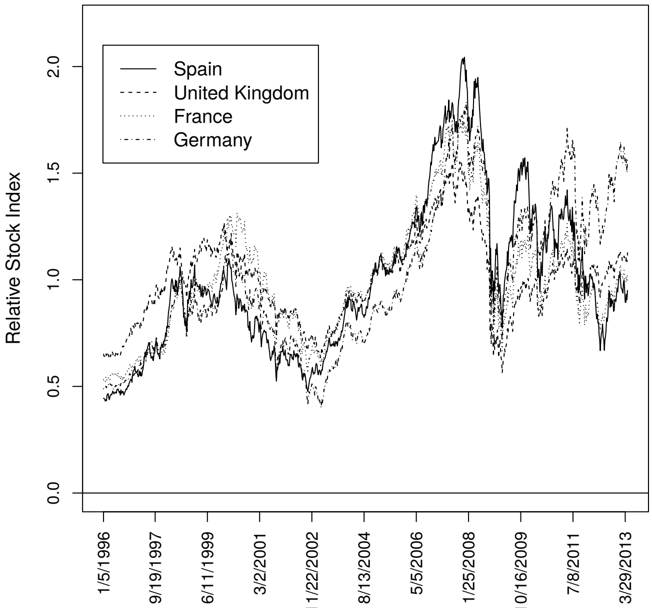


Figure 1: *Stock index: selected European countries.*

In this paper, we discuss herd behavior in global stock markets and also make an intercontinental comparison. Our purpose is not a prediction but a historical examination. We focus particularly on periods of financial crisis: the Asian financial crisis beginning in July 1997, the dot com bubble burst starting in early 2000, the global financial crisis beginning in 2008, and the ongoing European sovereign debt crisis.

Several herd behavior measures have been proposed to quantify panic level of financial market. Examples are the implied correlation index (CIX) by Skintzi and Refenes (2005) and the herd behavior index (HIX) by Dhaene *et al.* (2012b), but these measures are targeted for only one market. Following Lee and Ahn (2017), they are not well-normalized measures in the sense that they have different interpretations even when they have the same value. Measures failing the normalization are not appropriate for the purpose of a comparative study. Instead, the revised herd behavir index (RHIX) by Kim *et al.* (2013) and Dhaene *et al.* (2012b) mitigates the normalization problem and has desirable properties for analyzing herd behavior in the financial market across continents. Therefore, we use RHIX in empirical analysis.

This paper is organized as follows. In Section 2, RHIX is reviewed. The details about the global stock market data from Morgan Stanley Capital International (MSCI), one of the leading providers of investment decision support tools to investment institutions, are provided and we describe how to estimate RHIX in Section 3. Empirical analysis results are given in Section 4, followed by conclusion.

2. A review of the revised herd behavior index

We introduce basic notations to describe RHIX in a formal way. We take the common approach to describe the financial market via a filtered probability space $(\Omega, \mathfrak{F}, (\mathfrak{F}_t)_{0\leq t\leq T}, \mathbb{P})$, where $\mathbb{P}$ is real-world probability rather than risk neutral probability. In fact, RHIX can be represented by both the implied version using the option price data (under risk-neutral condition) and the realized version using the stock price data (under real-world condition). In order to calculate the implied version of RHIX, we need the prices of options based on a continent's index. However, due to the absence of option price on continential stock index, use of the historical stock price data (hence the realized version of the indices) is the only option in intercontinental comparison of herd behavior. Furthermore, options with the same maturity dates cannot be observed properly in our case. In order to get rid of such technical difficulties, we focus the realized version of RHIX, where all calculations are based on historical measures based on historical stock price data.

We assume a global financial market with d different stock indices from d different countries. Let $\mathbf{X}(t) = (X_1(t), \ldots, X_d(t))$ where $X_i(t)$ is the stock index of the i^{th} country at time t, and the weight vector $\mathbf{w} = (w_1, w_2, \ldots, w_d)$ with $w_i \geq 0$ for all i. Let $F_{X_i(t)}(x_i) = P(X_i(t) \leq x_i)$ be the marginal distribution of $X_i(t)$. In order to describe the strongest herd behavior corresponding to perfect positive dependence, we need the concept of comonotonicity (Dhaene *et al.*, 2012a). One of the most intuitive definitions for comonotonicity is that $\mathbf{X}(t)$ is comonotonic if and only if

$$\mathbf{X}(t) \overset{\mathfrak{D}}{=} \left(F^{-1}_{X_1(t)}(U), \ldots, F^{-1}_{X_d(t)}(U)\right),$$

where U is a uniform $(0, 1)$ random variable and $\overset{\mathfrak{D}}{=}$ means equal in the distribution. This means that a single risk factor U drives the market risk. For convenience, we write

$$\left(X^c_1(t), \ldots, X^c_d(t)\right) := \left(F^{-1}_{X_1(t)}(U), \ldots, F^{-1}_{X_d(t)}(U)\right)$$

to represent the comonotonic elements of $\mathbf{X}(t)$.

With these notations, RHIX is defined as

$$\text{RHIX}\left(\mathbf{w}, \mathbf{X}(t)\right) = \frac{\sum_{i \neq j} w_i w_j \text{cov}\left(X_i(t), X_j(t)\right)}{\sum_{i \neq j} w_i w_j \text{cov}\left(X^c_i(t), X^c_j(t)\right)}, \tag{2.1}$$

which is the ratio of the weighted average covariance of stock indices to the weighted average covariance of comonotonic stock indices.

As shown in Lee and Ahn (2017), regardless of the parameters involved in marginal distributions, RHIX is always 0 as long as $X_i(t)$ and $X_j(t)$ are uncorrelated for all i and j and is always 1 as long as $X_i(t)$ and $X_j(t)$ are comonotonic for all i and J. Therefore, 0 becomes the reference for the no herd behavior and 1 becomes the reference for the perfect behavior. However, CIX and HIX are difficult to set their references at a fixed constant.

3. Statistical estimation and data

A stochastic model to estimate RHIX is described first.

3.1. Statistical estimation

Consider a stochastic stock index process

$$\{\mathbf{Y}(t) |\, t \geq 0\} = \{(Y_1(t), \ldots, Y_d(t)) \,|\, t \geq 0\},$$

whose components represent the representative stock index of each country. We also consider the stochastic currency process

$$\{\mathbf{C}(t) |\, t \geq 0\} = \{(C_1(t), \ldots, C_d(t)) \,|\, t \geq 0\},$$

whose components represent the currency of each country in dollar units.

We define the dollar calibrated stock index, $\mathbf{X}(t)$, by the currency rate as

$$\mathbf{X}(t) := \mathbf{Y}(t) \cdot \mathbf{C}(t),$$

and define the weight vector, $\mathbf{w}(t) = (w_1(t), \ldots, w_d(t))$, so that the product of the weight and the dollar calibrated index becomes the aggregated value of the stocks as follow

$$\mathbf{w}(t) \cdot \mathbf{X}(t) = \mathbf{V}(t), \tag{3.1}$$

where $\mathbf{V}(t) = (V_1(t), \ldots, V_d(t))$ is a vector of the aggregated value of the stocks in US dollars at each country at time t. For the simplicity we assume the weight vector to be a constant through the observed period, hence we denote it as $\mathbf{w}$ satisfying

$$\mathbf{w} \cdot \mathbf{X}(t^*) = \mathbf{V}(t^*) \tag{3.2}$$

for predetermined fixed time t^*. Hence, we can compute the aggregated value of the stocks $\mathbf{V}(t)$ using the dollar calibrated stock $\mathbf{X}(t)$ and weight $\mathbf{w}$ only.

Previously, we defined RHIX as a summary of herd behavior on the interval $[0, t]$, while we are interested in the spot herd behavior at a fixed time $t = t_0$. Hence in the following, we define RHIX in a time interval around $t = t_0$, say $[t_0 - \epsilon, t_0 + \epsilon]$.

For the given time interval

$$[t_1, t_2] = [t_0 - \epsilon, t_0 + \epsilon],$$

we define RHIX on the interval as follows.

$$\mathrm{RHIX}_{[t_1,t_2]}(\mathbf{w}, \mathbf{X}) := \frac{\sum_{i \neq j} w_i w_j \mathrm{cov}\left[X_i(t_2), X_j(t_2)\right]}{\sum_{i \neq j} w_i w_j \mathrm{cov}\left[X_i^c(t_2), X_j^c(t_2)\right]}, \tag{3.3}$$

where $\{\mathbf{X}(t) | t \geq t_1\}$ is a stochastic process whose starting point is $t = t_1$: i.e., $\mathbf{X}(t)$ is known at $t = t_1$.

Because RHIX is a model free measure, it can be calculated without any model assumption. However for the easiness of confidence interval estimation of RHIX, we assume that the stochastic stock process, $\{\mathbf{X}(t) | t \geq t_1\}$, follows the multivariate Brownian motion in the given small local interval, $[t_1, t_2]$. Under the assumption, (3.3) can be estimated as follows.

$$\mathrm{RHIX}_{[t_1,t_2]}(\mathbf{w}, \mathbf{X}) = \frac{\sum_{i \neq j} w_i w_j \sigma_{X_i(t_2)} \sigma_{X_j(t_2)} \mathrm{corr}\left[X_i(t_2), X_j(t_2)\right]}{\sum_{i \neq j} w_i w_j \sigma_{X_i(t_2)} \sigma_{X_j(t_2)} \mathrm{corr}\left[X_i^c(t_2), X_j^c(t_2)\right]}, \tag{3.4}$$

where $\sigma_{X_i(t_2)}$ represents

$$\sigma_{X_i(t_2)} = X_i(t_1) e^{r_i(t_2 - t_1)} \sqrt{e^{\sigma_i^2 (t_2 - t_1)} - 1}, \tag{3.5}$$

and $\mathrm{corr}[X_i(t_2), X_j(t_2)]$ and $\mathrm{corr}[X_i^c(t_2), X_j^c(t_2)]$ in the model can be expressed as

$$\mathrm{corr}\left[X_i(t_2), X_j(t_2)\right] = \frac{e^{\rho_{ij} \sigma_i \sigma_j (t_2 - t_1)} - 1}{\sqrt{\left(e^{\sigma_i^2 (t_2 - t_1)} - 1\right)\left(e^{\sigma_j^2 (t_2 - t_1)} - 1\right)}}, \tag{3.6}$$

and

$$\operatorname{corr}\left[X_i^c(t_2), X_j^c(t_2)\right] = \frac{e^{\sigma_i \sigma_j (t_2 - t_1)} - 1}{\sqrt{\left(e^{\sigma_i^2 (t_2 - t_1)} - 1\right)\left(e^{\sigma_j^2 (t_2 - t_1)} - 1\right)}}. \tag{3.7}$$

Here, unknown parameters are r_i, σ_i, and ρ_{ij} in (3.5), (3.6), and (3.7). In our application, we set $\epsilon = 25$ i.e.,

$$[t_1, t_2] = [t_0 - \epsilon, t_0 + \epsilon],$$

where the unit is a week. Thus, given the stock prices in the time window

$$\{\mathbf{X}(t_0 - \epsilon), \mathbf{X}(t_0 - \epsilon + 1), \ldots, \mathbf{X}(t_0 + \epsilon)\},$$

we have the following independently and identically distributed (iid) observations

$$\{\mathbf{Z}(t_0 - \epsilon), \mathbf{Z}(t_0 - \epsilon + 1), \ldots, \mathbf{Z}(t_0 + \epsilon - 1)\}, \tag{3.8}$$

where $\mathbf{Z}(t) := (Z_1(t), \ldots, Z_d(t))$ with

$$Z_i(t) = \log \frac{X_i(t+1)}{X_i(t)}.$$

Based on the given iid data, the parameter estimates are given as

$$\hat{r}_i = \frac{\sum_t Z_i(t)}{n}, \quad \hat{\sigma}_i = \frac{\left(\sum_t Z_i(t) - \hat{r}_i\right)^2}{n-1}, \quad \text{and} \quad \hat{\rho}_{ij} = \frac{\frac{\sum_t (Z_i(t) - \hat{r}_i)(Z_j(t) - \hat{r}_j)}{n-1}}{\hat{\sigma}_i \hat{\sigma}_j},$$

where summations are on the set $\{t_0 - \epsilon, t_0 - \epsilon + 1, \ldots, t_0 + \epsilon - 1\}$. Because observations in (3.8) are iid, we can easily estimate the confidence interval of HIX and RHIX. Finally, we note that the local multivariate Brownian motion assumption can minimize model risk, see for example Barrieu and Scandolo (2015).

3.2. Data

In this subsection, the details about the dataset are given. We analyze the representative stock indices from 11 Asian countries between the first week of 1996 and the last week of April in 2013: Australia (1.185), China (5.109), Hong Kong (1.659), India (1.241), Indonesia (0.051), Japan (4.542), Malaysia (0.488), Philippines (0.256), South Korea (1.134), Taiwan (0.866), and Thailand (0.477). The numbers in the brackets at the right of each country represent the aggregate value of the stock market in trillions of US dollars (at the last week of April in 2013). Further, we also use the currency data in the countries to calculate the dollar values of the aggregate value of the stock markets. Note that in Section 4, we estimate the RHIX of Asia with and without China in order to study the effect of China's stock index on the RHIX of Asia.

In Europe, we observe a total of nine countries: Belgium (0.262), Denmark (0.261), England (0.644), France (1.654), Germany (3.222), the Netherlands (0.325), Norway (1.894), Spain (1.683), and Switzerland (0.806). In South America, we observe Argentina (0.045), Brazil (1.250), Chile (0.328), and Venezuela (0.021). Stock prices in Brazil and Chile account for over 95% of the aggregate market value. In North America, we observe Canada (1.90), Mexico (0.003), and USA (20.5). Stock prices in Canada and the USA account for over 99% of the aggregate market value.

For Africa and the Middle East, we cannot collect data for the entire period. In Africa, we observe Egypt (0.052), Mauritius (0.011), Morocco (0.052), and South Africa (0.500) from the first week of July 1998 to the last week of April 2013. More than 80% of the money is concentrated in South Africa. The data on the Egyptian market is not available during the Egyptian Revolution period from late January 2011 to late March 2011. In the Middle East, we observe Jordan (0.026), Oman (0.022), Qatar (0.132), and Saudi Arabia (0.384) from the first week of July 2000 to the last week of April 2013. Almost 70% of the money is concentrated in Saudi Arabia.

4. Empirical analysis results

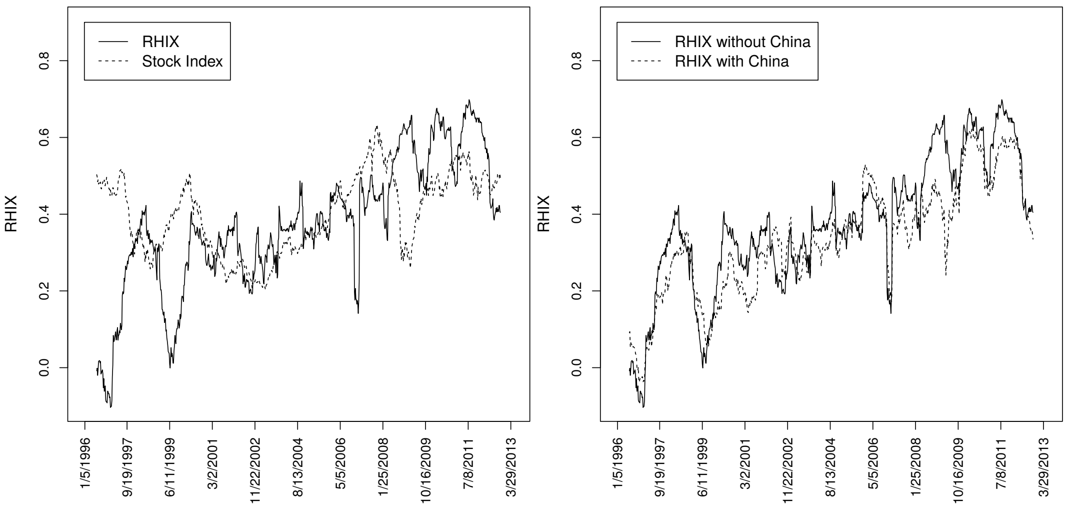
In this section, the herd behaviors of different continents are compared using the MSCI stock index data. Data from 1996 to April 2013 are used for the main analysis but data of Africa and the Middle East can not be used in the 90's because the exchange rates to the US dollar are specified after 2000. Here, we use t^* as the final week of April 2013 for the calculation of the weight vector $\mathbf{w}$ in (3.2). Through this comparative analysis, peculiar features, resemblances, differences, and trends of each continent's herd behavior are observed; however, this paper focuses on the observed phenomena but not their causes, which goes beyond the scope of this study.

A comparative analysis on the herd behavior from each continent at various financial crises is conducted as follows. The RHIX of each continent is described in Figures 2–4. Firstly, during the period of the Asian financial crisis, Asia's RHIX surged rapidly and that of South America also increased. This coincides with Scholes (2000), which describes the effect of the Asian financial crisis on South America. No such increase has been observed in other continents' RHIXs, as the Asian financial crisis mainly impacted regions of Asia and South America. Next, herd behavior due to the dot-com bubble burst that began in 2000 is analyzed. The RHIXs of most continents revealed a gradual increase during the period, while there were rapid drops in the stock indices during the same period.

The analysis during the period from 2001 to 2005 reflects the occurrence of the September 11 attacks and the Iraq War. As specified in Nanto (2004), the world experienced a small recession immediately after 9/11, and this was reflected in the increase of the RHIX in most continents. Throughout the period, a sharp rise in the RHIXs of the Middle East and North America was shown; other RHIXs experienced small increases except for that of Europe, which decreased.

RHIXs are also analyzed during the period from 2008 to the present in order to consider the global financial crisis and the European sovereign debt crisis. During the global financial crisis period, all continents showed the maximum RHIX. Until today, most of the continents maintain a fairly high RHIX, which indicates the severe and persistent impact of the global financial crisis and the European sovereign debt crisis on all continents.

As shown in Figure 2, the RHIXs of Asia during and after the Asian and global financial crises have an increasing trend. In fact, our observation is coherent with Cheng and Glascock (2006) and Nieh *et al.* (2012), where the herd behavior of the stock market in Asia was described during and after the Asian financial crisis and the global financial crisis. As shown in Figure 2(b), it is interesting to observe that the RHIX of Asia is reduced when China is considered in the analysis. Specifically, the effect of China decreased the level of the RHIX of Asia substantially during the recent global financial crisis and the European sovereign debt crisis periods. This observation is also found in Morrison (2013), which describes the emergence of the Chinese stock market during the recent global financial crisis.



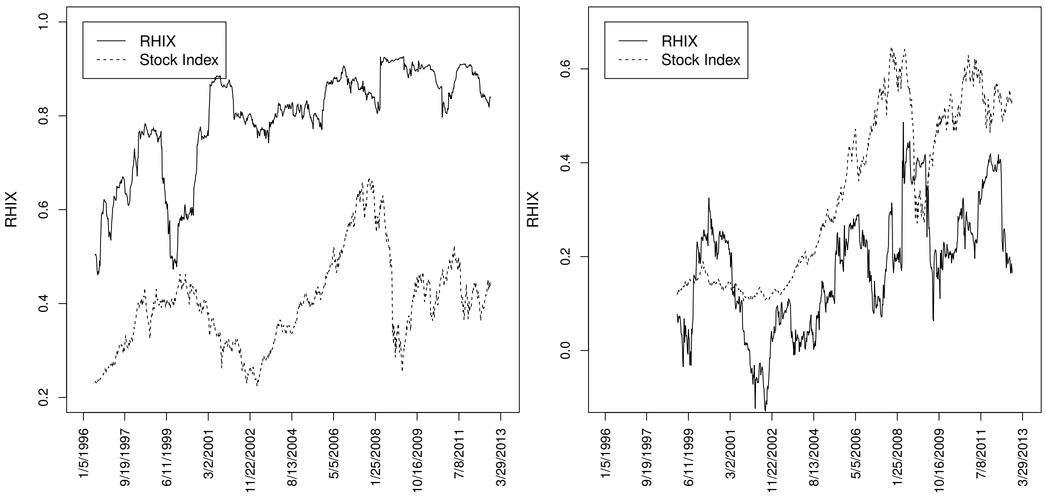
(a) Asia RHIX and stock index (without China) (b) Asia RHIX (with and without China)

Figure 2: *Asia RHIX. RHIX = revised herd behavir index.*

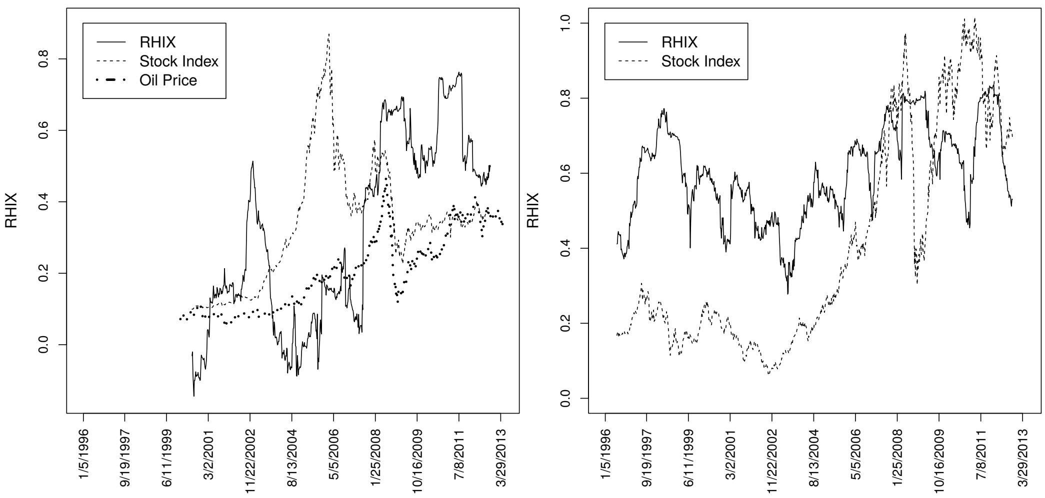
We can observe the main economic crises that affected Europe from Figure 3(a). The first is the economic crisis that commenced in early 2000. This is related to the dot com bubble burst starting in 2000. The second is the global financial crisis and the European sovereign debt crisis. During the crisis periods, stock prices dropped sharply and RHIX soared rapidly. It appears that the Asian financial crisis of 1997 did not significantly affect the European economy or herd behavior. The European RHIX is very high for the entire observation period. This is because European economies are connected under the EU's economic and monetary union. From 2002 to 2008, the stock market index increased, whereas the RHIX stayed nearly constant at around 0.7. Over the entire observation period, the RHIX in Europe slowly increased. The next referential papers explain the trend of RHIX shown in Figure 3(a). Horta *et al.* (2010) analyze the change of the stock index in Europe before and after the global financial crisis using copula. After the crisis, the financial contagion in the stock market is revealed and comovements between the analyzed stock markets have become more noticeable. Baglioni and Cherubini (2013) and Metiu (2012) prove that the financially cross-border contagion in Europe increases on and after the sovereign debt crisis.

The African RHIX is around 0 from 1997 to 2005 except for the years 1999 and 2000, as shown in Figure 3(b). We can observe that the RHIX of Africa is high during the global financial crisis, which is coherent with Adamu (2009) where the relation between the global financial crisis and some developing countries in Africa, such as Nigeria is reported. However, even during the global financial crisis, the RHIX was around 0.4, which is relatively low compared to RHIX of other continents.

The RHIX in the Middle East was as low as 0 from 2000 through 2001 and from 2003 to 2005, as shown in Figure 3(c). It then became very high around 9/11, the Iraq War, the global financial crisis, and the European sovereign debt crisis. Along with the highly volatile stock index, the Middle East's RHIX also demonstrated the most dramatic changes compared to those for other continents. The high RHIX after 9/11 indicates that herd behavior commenced among countries in the Middle East. It is interesting to observe that the RHIX was below 0, when the stock price increased rapidly from 2003 to 2005. According to Al-Rjoub (2011), stock market returns in the Middle East move negatively most of time during the global financial crisis. However, stock returns temporarily increase, particularly in



(a) Europe RHIX and stock index (b) Africa RHIX and stock index



(c) The Middle East RHIX and stock index (d) South America RHIX and stock index

Figure 3: *RHIX and stock index: Europe, Africa, the Middle East, and South America. RHIX = revised herd behavir index.*

Jordan, during the Iraq War because money transfers from Iraq to Jordan.

South America's RHIX was very high during the Asian financial crisis and the global financial crisis, as shown in Figure 3(d). Further stock prices in South America during the observation period are more dynamic compared to that for other continents. Such high herd behavior and dynamic movement of stock market in South America are also described in Almeida *et al.* (2012) and Salman *et al.* (2012).

From 2001 through to 2006, the RHIX in North America decreased and the stock price increased, as shown in Figure 4. Although this is reasonable, it cannot be observed in other continents. In the calculation of the RHIX, Mexico is almost excluded because its aggregate stock prices are too low.

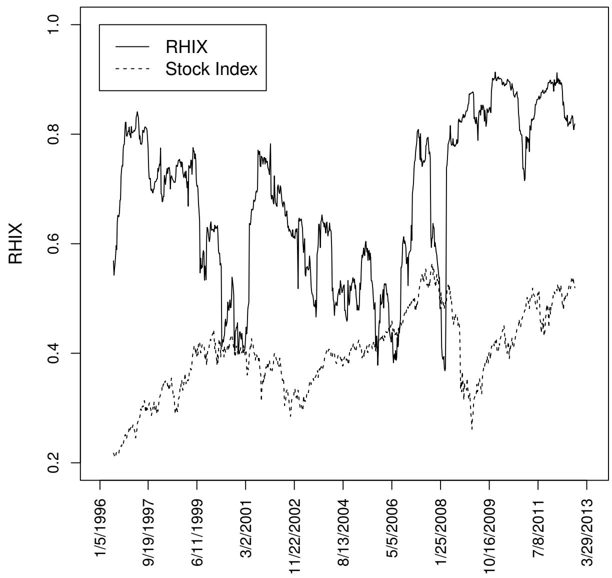


Figure 4: *North America RHIX and stock index.*

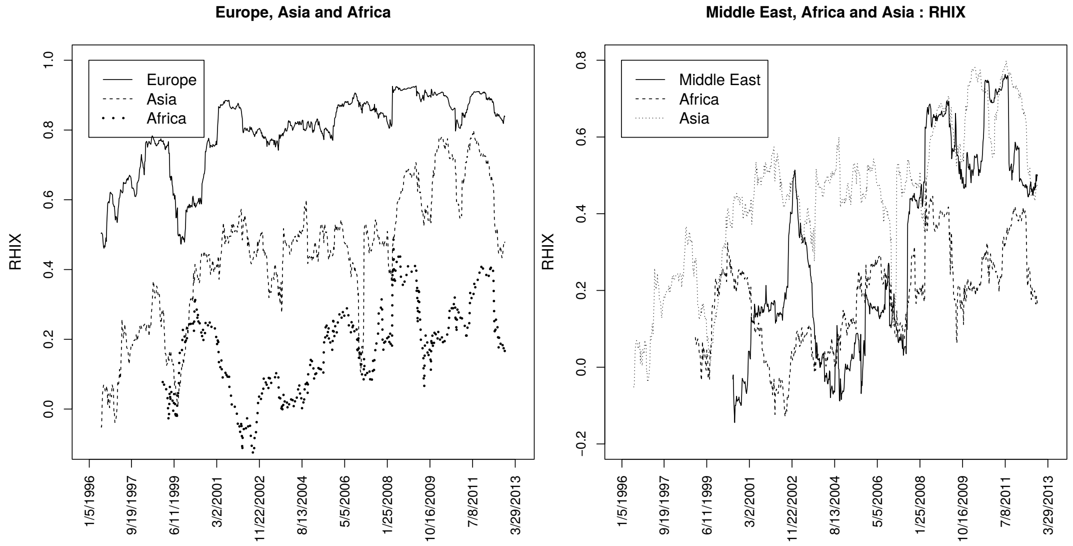
Hence, we can, in essence, regard that Canada has been highly correlated to the USA. This explains why the RHIX is so high for almost the entire observation period for North America. Even during the Asian financial crisis, while the stock price was increasing, the RHIX was very high.

From another point of view, we carry out a further comparative analysis of some continents. In Europe, Asia, and Africa, the RHIXs were at their maximum during the global financial crisis and at their local maximum during the European sovereign debt crisis, as shown in Figure 5(a). However, the RHIX in Asia is unusually high; yet this is not the case for Europe during the Asian financial crisis. As Figure 5(c) illustrates, the stock price movement pattern in the three continents is somewhat similar after 2004. During the Asian financial crisis, Asian markets demonstrated a dramatic volatility.

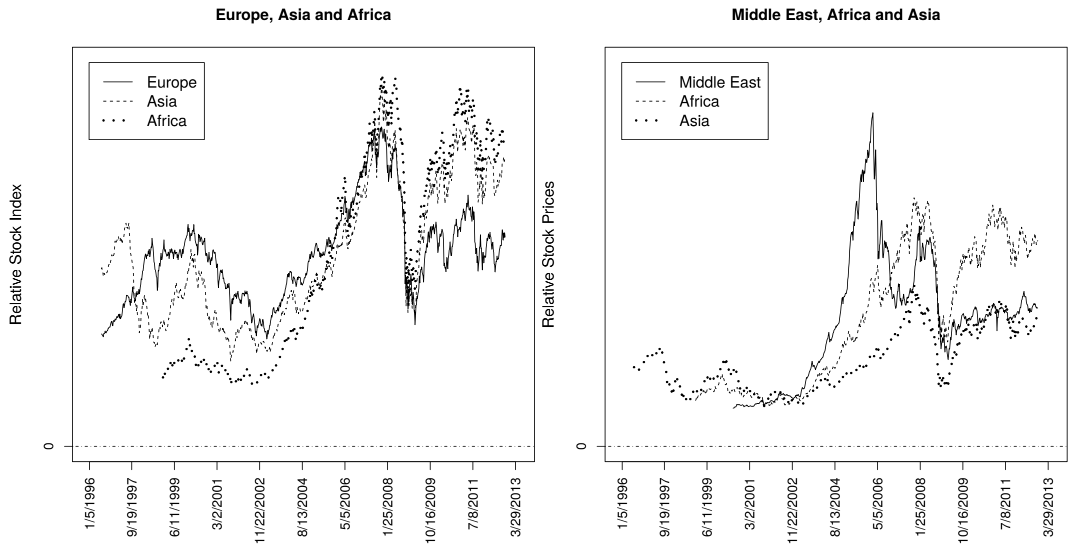
As Figure 5(b) shows, the RHIX of the Middle East is as low as Africa's when it is at a lower stage. However, when it is at a higher stage, it exceeds that of Asia. This is indicative of the extreme movement of herd behavior in the Middle East, which experiences instability due to oil prices and politics. Figure 5(d) also shows the extreme dynamics of stock prices in the Middle East compared to those of Africa and Asia.

Generally, the order of the RHIX scale is as follows. The RHIXs in Europe and North America maintain the highest level, followed by, in order, South America, Asia, the Middle East, and Africa. Nevertheless, the RHIX shows a similar pattern among the continents in the recent period and an increasing trend over time. This is related to the globalization of the world economy. Table 1 shows the RHIXs of all continents in special periods.

Finally, we briefly mention the confidence interval of the RHIX. As specified earlier, the RHIX of Africa and the Middle East are not only relatively smaller than that of the other continents, but also close to 0 in many time intervals. Hence, it is interesting to investigate the confidence interval of the RHIX in the two continents. For the confidence interval estimation, we use the bootstrap method with resample size 1,000 based on the weekly log-return vectors which can be viewed as iid samples under the multivariate version of geometric Brownian motion. The detailed procedure and related asymptotic results can be found in, for example, Lee and Ahn (2015) (Similar to the multivariate



(a) Comparison of RHIX: Europe, Asia, and Africa (b) Comparison of RHIX: Middle East, Africa, and Asia



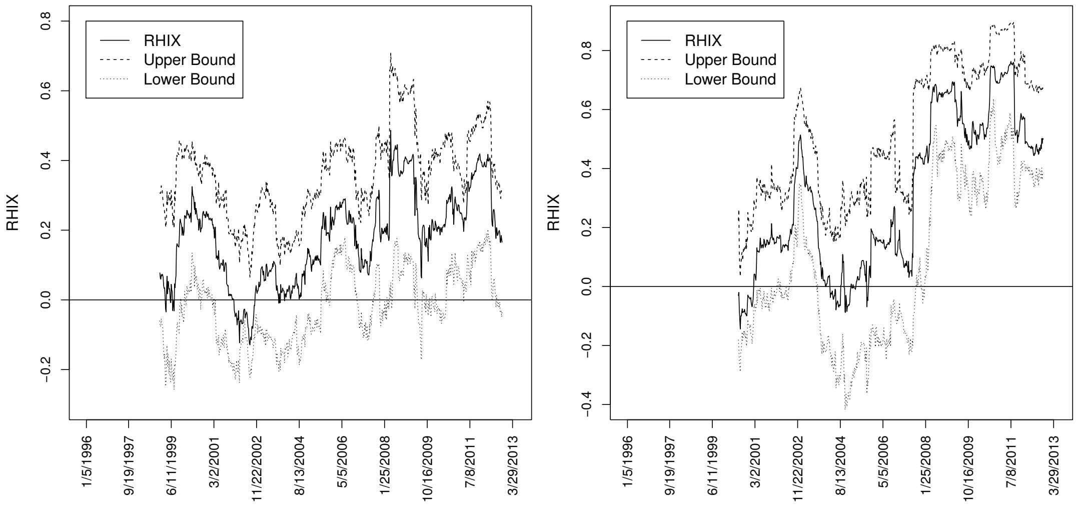
(c) Comparison of Stock Prices: Europe, Asia, and Africa (d) Comparison of Stock Prices: Middle East, Africa, and Asia

Figure 5: *Comparison of RHIXs and stock prices among continents. RHIX = revised herd behavir index.*

version of geometric Brownian motion, the interval estimation of RHIX is possible under various models including (G)ARCH models Engle (1982), Bollerslev (1986)). As seen from Figure 6, in most time interval, the 95% confidence intervals of RHIXs include 0.

5. Conclusion

In this paper, we investigated herd behavior within each continent and among continents. In particular,



(a) RHIX in Africa: 95% confidence interval (b) RHIX in the Middle East: 95% confidence interval

Figure 6: *Confidence interval of the RHIX with resample size 1,000. RHIX = revised herd behavir index.*

Table 1: Summarization of RHIX in different periods

Continents	Avereage RHIX (standard deviation)			
	AFC	DBB	GFC	Entire Periods
Asia	0.3153 (0.0589)	0.3157 (0.0436)	0.9581 (0.0633)	0.3723 (0.1732)
Europe	0.7117 (0.0572)	0.7236 (0.1043)	0.8906 (0.0309)	0.7932 (0.1116)
North America	0.7346 (0.0351)	0.4983 (0.0879)	0.8524 (0.0408)	0.6818 (0.1467)
South America	0.6937 (0.0397)	0.5242 (0.0716)	0.7019 (0.0957)	0.6000 (0.1252)
Africa	NA	0.2140 (0.0570)	0.2814 (0.0850)	0.1770 (0.1290)
The Middle East	NA	−0.0036 (0.0921)	0.6159 (0.0911)	0.3090 (0.2589)

RHIX = revised herd behavir index; AFC = Asian financial crisis; DBB = dot com bubble burst; GFC = global financial crisis; NA = not available.

the latter study required a comparison of the herd behavior in one continent relative that in others, and therefore the use of RHIX is appropriate. Using RHIX, both well-known facts and new interesting facts are observed through empirical analysis. During the initial period of our empirical analysis, herd behavior and the stock index were negatively correlated, i.e., the RHIX was high when the stock index dropped rapidly, while the RHIX was relatively low when the stock index was increasing. However, this pattern has weakened over time as financial globalization has increased. The RHIX also shows an increasing trend across all of the continents, but the slopes differ sunstantially. It is noteworthy that major financial crises such as the global financial crisis in 2008 and the European sovereign debt crisis affected all the countries significantly and led to high RHIXs in most continents.

We demonstrate the period of strong herding. For example, the RHIXs from most of the continents hit the upper limit during the period of the global financial crisis. However, only Asia and South America showed a significant degree of comovement during the period of the Asian financial crisis. We also observe that the RHIXs of all continents have been increasing with time. This is a strong evidence that the world forms a financially unified body. Furthermore, generally, higher RHIXs are observed in developed countries than in developing countries. The level of information delivery might be one of the reasons for the higher RHIXs in developed countries; however, more research should be done on this phenomenon.

Although the current model is believed to capture the essential characteristics of herd behavior, more elaborate stock index models can be considered. This topic should be further analyzed in order to see how RHIX depends on the choice of these models. It is also interesting to apply RHIX to the stock index data with different time scales or to investigate the herd behavior of volatility Baek and Oh (2016).

Acknowledgements

Woojoo Lee was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2016R1D1A1B03936100). This research was supported by a grant from the Asian Institute of Corporate Governance (AICG) at Korea University. Jae Youn Ahn was supported by a National Research Foundation of Korea (NRF) grant funded by the Korean Government (NRF-2017R1D1A1B03032318).

References

Adamu A (2009). The effects of global financial crisis on Nigerian economy, *Social Science Research Network*.

Al-Rjoub S (2011). Business cycles, financial crises, and stock volatility in Jordan stock exchange, *International Journal of Economic Perspectives*, **5**, 83–95.

Almeida RP, Costa HC, and Costa NCA (2012). Herd Behavior in Lation American Stock Markets, *Latin American Business Review* **13**, 81–102.

Baglioni A and Cherubini U (2013). Within and between systemic country risk. Theory and evidence from the sovereign crisis in Europe, *Journal of Economic Dynamics and Control*, **37**, 1581–1597.

Barrieu P and Scandolo G (2015). Assessing financial model risk, *European Journal of Operational Research*, **242**, 546–556.

Baek EA and Oh MS (2016). Volatility spillover between the Korean KOSPI and the Hong Kong HSI stock markets, *Communications for Statistical Applications and Methods*, **23**, 203–213.

Bikhchandani S and Sharma S (2001). Herd behavior in financial markets, *International Monetary Fund*, **47**, 279–310.

Bollerslev T (1986). Generalized autoregressive conditional heteroskedasticity, *Journal of Econometrics*, **31**, 307–327.

Cheng H and Glascock JL (2006). Stock market linkages before and after the Asian Financial Crisis: evidence from three greater China Economic Area Stock Markets and the US, *Review of Pacific Basin Financial Markets and Policies*, **9**, 297–315.

Dasgupta A, Prat A, and Verardo M (2011). Institutional trade persistence and long-term equity returns, *The Journal of Finance*, **66**, 635–653.

Dhaene J, Linders D, Dony J, Forys MB, and Schoutens W (2012a). FIX: the fear index-measuring market fear, *Springer Proceedings in Mathematics and Statistics*, **19**, 37–55

Dhaene J, Linders D, Schoutens W, and Vyncke D (2012b). The herd behavior index: a new measure for the implied degree of co-movement in stock markets, *Insurance: Mathematics and Economics*, **50**, 357–370.

Engle RF (1982). Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation, *Econometrica: Journal of the Econometric Society*, 987–1007.

Exchange, Chicago Board Options (2009). The CBOE volatility index-VIX, *White Paper*, 1–23.

Horta P, Mendes C, and Vieira I (2010). Contagion effects of the subprime crisis in the European

NYSE Euronext markets, *Portuguese Economic Journal*, **9**, 115–140.
Kim C, Choi Y, Lee W, and Ahn JY (2013). *Analyzing Herd Behavior in Global Stock Markets: An Intercontinental Comparison*, arXiv:1308.3966v1 [q-fin.ST]
Kim C and Pantzails C (2003). Global/Industrial Diversification and analyst herding, *Financial Analysts Journal*, **59**, 69–79.
Lee W and Ahn JY (2015). Financial interpretation of herd behavior index and its statistical estimation, *Journal of the Korean Statistical Society*, **44**, 295–311.
Lee W and Ahn JY (2017). Measuring herd behavior: properties and pitfalls, *Dependence Modeling*, **5**, 316–329.
Metiu N (2012). Sovereign risk contagion in the Eurozone, *Economics Letters*, **117**, 35–38.
Morrison WM (2013). China's economic rise: history, trends, challenges, and implications for the United States, *CRS Report for Congress*, **RL33534**.
Nanto DK (2004). 9/11 Terrorism: Global Economic Costs, Congressional Information Service, Library of Congress.
Nieh CC, Yang CH, and Kao YS (2012). Who has more influence on Asian Stock Markets around the Subprime Mortgage Crisis-the U.S. or China?, *Applied Economics Letters*, **19**, 329–335.
Oh R, Shin DW, and Oh MS (2017). Bayesian analysis of financial volatilities addressing long-memory, conditional heteroscedasticity and skewed error distribution, *Communications for Statistical Applications and Methods*, **24**, 507–518.
Salman N, Abbas M, Ahmad M, Majid MA, Khan N, and Raheel A (2012). Impact of financial crisis on Asian stock Markets, *European Financial Management*, **3**, 736–741.
Scarsini M (2004). Institutional herding, *Review of Financial Studies*, **17**, 165–206.
Scholes MS (2000). Crisis and risk management, *The American Economic Review*, **90**, 17–21.
Skintzi VD and Refenes APN (2005). Implied correlation index: A new measure of diversification, *Journal of Futures Markets*, **25**, 171–197.

Received October 10, 2017; Revised December 3, 2017; Accepted December 29, 2017