Characterization of the Philippine Stock Market Dynamics

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The behavior of the stock market is widely regarded as unpredictable and erratic. However, erratic physical systems can be predicted to some extent by using appropriate models. In this study, the empirical behavior of the Philippine stock market was considered by using the daily historical values of the Philippine Stock Exchange Composite Index (PSEi) from 1993 to 2009. Analysis of the time series for the index, return, and acceleration suggests that the regularity of the dynamics of PSEi is more transparent when studied in terms of return rather than the index itself. Regularity in the probability distribution is however found only in the acceleration of the index. The empirical probability distributions of index, return, and acceleration suggest that simple random walk, random walk with drift, geometric Brownian motion, and Levy flight models do not apply to the Philippine stock market index. A study of autocorrelation however showed that the PSE index is independent and identically distributed. A study of the probability of the scaled return to origin shows a power law characteristic, indicative of fractal behavior. Phase space diagram analysis, however, revealed that the seemingly chaotic behaviour of the Philippine stock market is only approximate.

Keywords— econophysics, stock market dynamics, random walk, time series, autocorrelation, scaling power law, phase portrait

1. INTRODUCTION

Stock markets have always been very complex, and with today's information and communication technology, the market is even more prone to rapid changes. The erratic changes of stock markets had been a subject of study by econophysicists, particularly for developed countries like the United States, Germany (Voit, 2003; Drozdz, Gruemmer, Ruf, & Speth, 2001), and Korea (Lee, Lee, & Rikvold, 2006; Lee & Lee, 2007; Yang, Chae, Jung, & Moon, 2006), and the emergent economy of Brazil (Gleria, Matushita, & Da Silva, 2002; Costa & Vasconcelos, 2003), with strong interest in the scaling and multifractal behavior of the markets (Lee et al., 2006; Lee & Lee, 2007; Gleria et al., 2002; Ho, Lee, Wang, & Chuang, 2004), and the probability distributions of stock indices (Lee & Lee, 2007; Yang et al., 2006; Silva & Yakovenko, 2003; Drozdz, Forczek, Kwapien, Oswiecimka, & Rak, 2007; Lan & Tan, 2007). In this paper, we undertook an analysis of the time series of the Philippine stock market index (PSEi) from January 1993 to December 2009, determining the probability distribution not only of the index, but that of the return and the acceleration as well. Autocorrelation, scaling behavior, and phase portrait analyses were likewise conducted to provide a more complete picture of the market behavior.

2. TIME SERIES ANALYSIS

Bachelier's Théorie de la Spéculation is one of the earliest studies on the dynamics of a financial instrument. In his study, Louis Bachelier modeled the bond prices by a random walk superimposed on a constant drift. In order to eliminate the drift from the data, he considered a Wiener process with zero mean and a variance increasing linearly with time and found out that its probability density function (PDF) follows the Gaussian distribution (Voit, 2003).

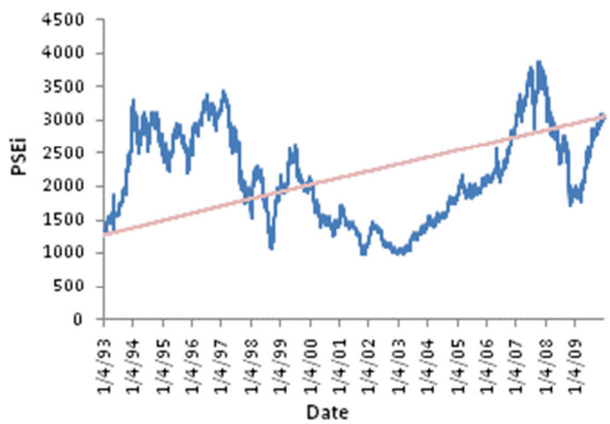

***Figure 1.* Time series with trend line of PSEi from January 1993 – December 2009.**

Analysis of the PSEi time series as shown in Figure 1, shows a positive drift, but the distribution of the index, as shown in Figure 2a, indicates that the best-fit PDF is the General Gamma distribution

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad (1)$$

where σ is a continuous scale parameter, and μ is a continuous location parameter.

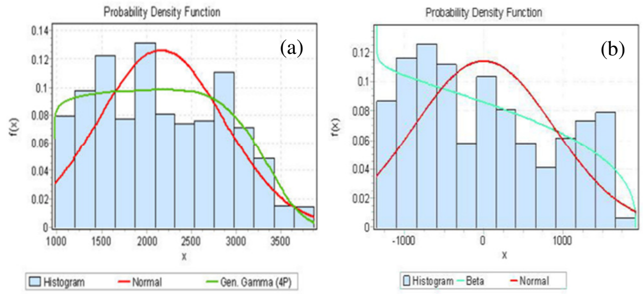

***Figure 2*. Best PDFs of (a) PSEi and (b) drift-discounted PSEi.**

A Chi-Squared Test for Normality with a significance level of $\alpha = 0.05$ also revealed that the data does not fit the Gaussian distribution. This non-normality, which is similarly found in the empirical study of Palagyi and Mantegna (1999) on some heavily trade stocks in the Budapest Stock Exchange, indicates that like the Budapest stock market, Bachelier's model of a simple random walk with a constant drift is not applicable to the Philippine stock market.

Subtracting out the drift allows us to focus on the fluctuations of prices and take out the effect of appreciation of money through time. Figure 2b shows that the best fit PDF of the drift-discounted PSEi is the Beta distribution which is given by

$$f(x) = \frac{1}{B(\alpha_1, \alpha_2)} \frac{(x-a)^{\alpha_1 - 1}(b-x)^{\alpha_2 - 1}}{(b-a)^{\alpha_1 + \alpha_2 - 1}} \qquad (2)$$

where α_1, α_2 are continuous shape parameters, and a,b are continuous boundary parameters. Chi-Square test for Normality, however, revealed that even the drift-free series does not have a Gaussian distribution.

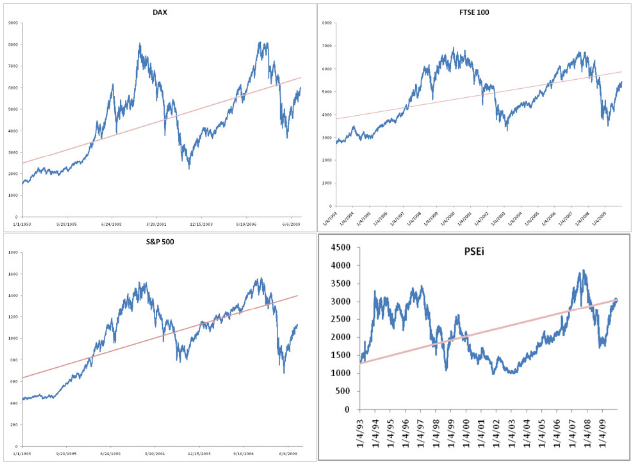

***Figure 3*. Time series plot of four indices namely DAX, FTSE 100, S&P 500, and PSEi.**

A comparison of the PSEi with other indices, as shown in Figure 3, indicate that PSEi behaves differently from the German DAX, British FTSE, and the American S&P 500 indices over the same period, suggesting that the behavior of a developing market index differ from those of the developed markets that appear to mirror each other.

As seen in Figure 4, the PSEi seem to be divisible into three distinct sets which as it turns out, coincides with the administration of three presidents: Fidel V. Ramos (January 1993–June 1998), Joseph Ejercito Estrada (July 1998–January 20, 2000), and Gloria Macapagal-Arroyo (January 21, 2000–December 2009).

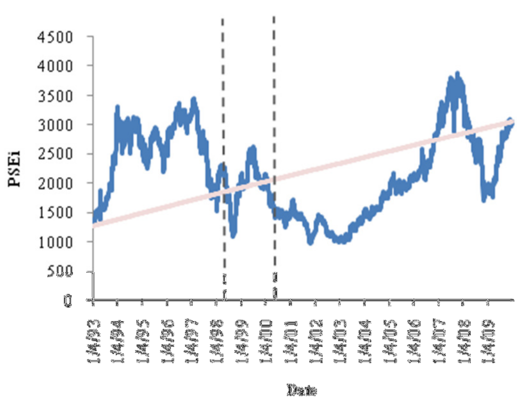

***Figure 4.* Time series and trend line of PSEi divided (vertical broken lines) according to presidency.**

The Ramos administration started with an uptrend and ended with a down trend; the Estrada administration started and ended in a down trend while the Arroyo administration started with a down trend but ended with an uptrend. The market in the three administrations have positive drifts with values of 0.32, 2.04, and 0.79 respectively. Although the drift is highest during Estrada's administration, it must be noted that the value of PSEi is also lowest during his term. Although the drift is lowest during Ramos administration, it must be noted that the market during most of his term is consistently high such that the time series is characterized by a low-slope diagram with steep rise at the start and then a fall at the end, coinciding with the 1997 Asian Financial Crisis. The market during Arroyo's term, on the other hand, more closely resemble the rise and fall of other stock markets.

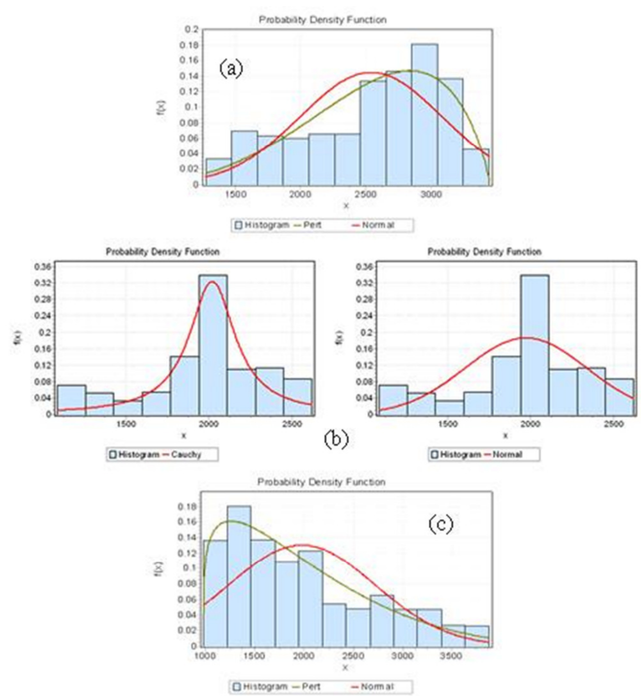

***Figure 5.* Best PDFs and best-fit Gaussian distribution of PSEi during (a) Ramos, (b) Estrada, (c) Arroyo administrations.**

The best-fit PDFs during the administrations of Ramos, Estrada, and Arroyo also vary with each other. Fluctuations of the index during the

Ramos and Arroyo administrations are best described by the Pert distribution while that of Estrada, by the Cauchy distribution (Figure 5). The market in all the three administrations fail the Chi-squared goodness of fit test for the Gaussian distribution. Considering the drift-free index, we found that the index during the time of Ramos most closely follow the General Gamma distribution. In the Estrada period, the distribution is closest to Johnson SB distribution while during Arroyo's term, it is close to Log-logistic distribution. The drift-free index does not have a Gaussian distribution during any of the three administrations.

The time series may also be divided into four boom and three bust periods: Boom 1 (January 1993–January 1997), Bust 1 (February 1997–August 1998), Boom 2 (September 1998–July 1999), Bust 2 (August 1999–December 2002), Boom 3 (January 2003–October 2007), Bust 3 (November 2007–March 2009), and Boom 4 (April 2009–December 2009). It was found out that the General Extreme Value distribution

$$f(x) = \begin{cases} \frac{1}{\sigma}\exp\left(-(1+kz)^{1/k}\right)(1+kz)^{-1-1/k} & k \neq 0 \\ \frac{1}{\sigma}\exp\left(-z-\exp(-z)\right) & k = 0 \end{cases}$$

(3)

where k is a continuous shape parameter, σ is a continuous scale parameter, and μ is a continuous location parameter, best fits all the boom periods.

On the other hand, the Cauchy distribution

$$f(x) = \left(\pi\alpha\left(1+\left(\frac{x-\mu}{\alpha}\right)\right)\right) \quad (4)$$

where σ is a continuous scale parameter, μ is a continuous location parameter, best fits all bust periods.

We next considered the return of the PSEi, which may be likened to velocity in particle dynamics. Defined as

$$Z_t = S_t - S_{t-1} \quad (5)$$

the return time series is shown in Figure 6. The large swings in the return time series can be more typified as flights rather than walks, and the good number of large fluctuations indicates that the probability distribution of the return will have fatter tails than the Gaussian distribution. The return time series is leptokurtic, that is, it peaked at around its mean as shown in Figure 7, and is best-fit by the Laplace distribution

$$f(x) = \frac{1}{2b}\exp\left(-\frac{|x-\mu|}{b}\right) \quad (6)$$

where μ is a location parameter, b is a scale parameter. Although the Chi-squared test precludes a Gaussian distribution for the return, the distribution of the return is much closer to normal than that of the index. This suggests that the dynamics of the market may lend itself to easier study if viewed through the return rather than the index itself.

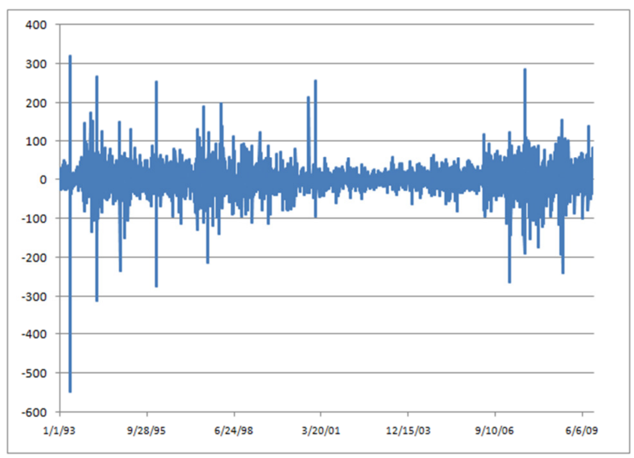

***Figure 6*. Time series of daily returns of PSEi from 1993-2009.**

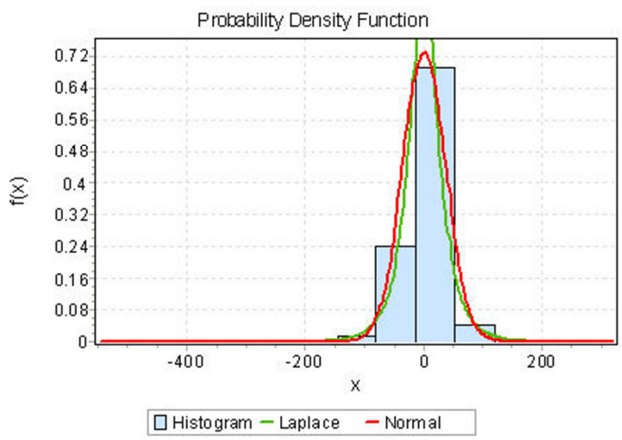

Figure 7. **Laplace (Best Fit PDF) and Gaussian distributions of the return.**

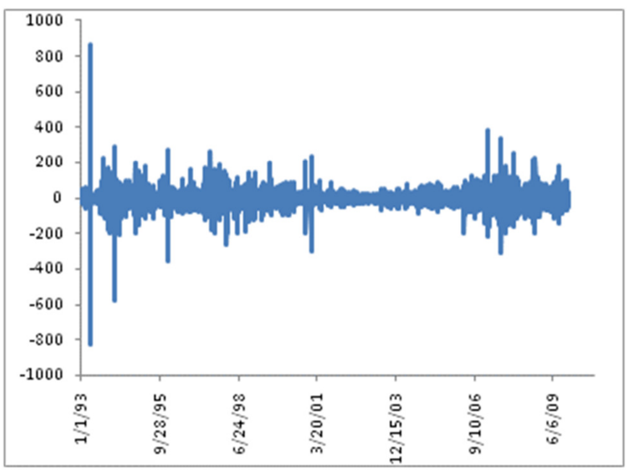

Figure 8. **Time series of acceleration of PSEi from 1993-2009.**

Defining the acceleration of the index as

$$A_t = Z_t - Z_{t-1} \tag{7}$$

We note that the time series plot of the acceleration (Figure 8) exhibits the same large fluctuations found in the return time series. When the acceleration time series is however divided into sections, we found that while the PDF that best fit the acceleration time series is not Gaussian, it is consistently the same distribution, the Johnson SU shown in Figure 9, albeit with different parameters. This regularity, not found in the index time series nor the return time series, suggests that if a stochastic model is constructed for the market, it may be best to start with a simple model for the acceleration.

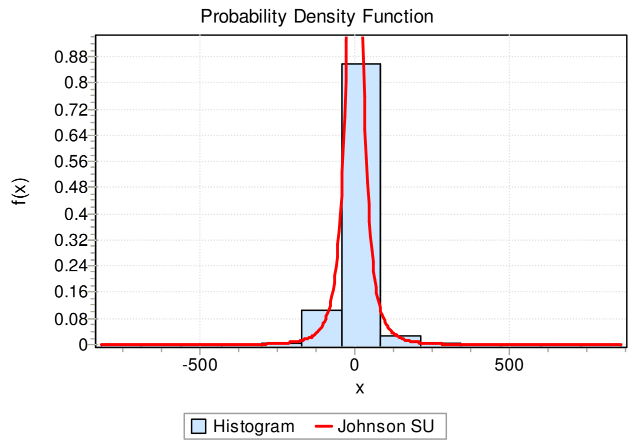

Figure 9. **Johnson SU distribution of the acceleration of PSEi.**

3. SCALED AND NORMALIZED RETURN

The effect of the drift may be factored out not only by subtraction, but also by scaling. We may do this by defining the scaled return as

$$\delta S_\tau(t) = \ln\left[\frac{S(t)}{S(t-\tau)}\right] \approx \frac{S(t)-S(t-\tau)}{S(t-\tau)} \tag{8}$$

The time series of the scaled return shown in Figure 10 exhibit the same fat tail and leptokurtic characteristic of the return time series. Because the scaled return is approximately a logarithmic function, a log-normal distribution would indicate a market modeled by geometric Brownian motion (Voit, 2003). Chi-square test, however, reveals that the Philippine stock market cannot be modeled as such. This finding can be accounted for by the fact that Geometric Brownian motion assumes constant parameters (Mantegna & Stanley, 2000) but the same does not hold for the Philippine stock market, where both the mean and variance are found to vary over time.

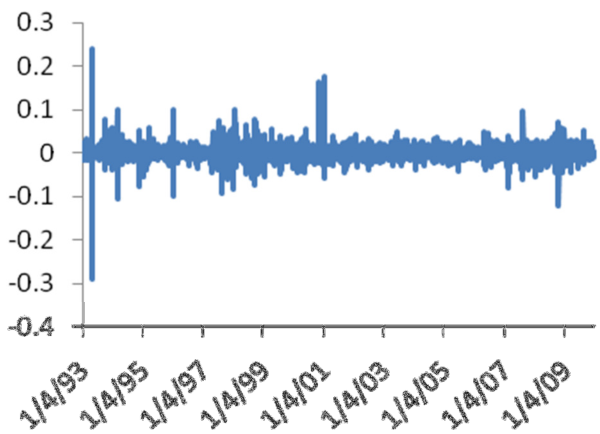

***Figure 10.* Time series of the daily scaled return of PSEi from 1993-2009.**

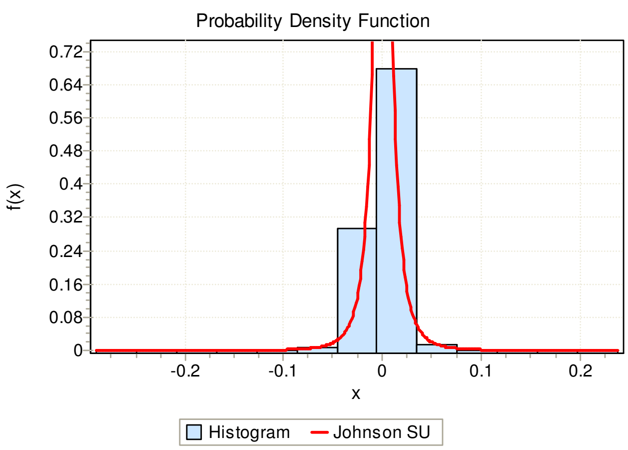

***Figure 11.* Johnson SU distribution of the scaled return.**

We may explore for regularity in the time series by dividing the series into several periods of equal length. Because the mean and variance vary over these periods, comparison of the three periods is facilitated by normalizing the return, carried out by subtracting the mean return of the period from the daily scaled return and the result divided by the standard deviation of the same period. This yields distributions that have zero mean and unit variance.

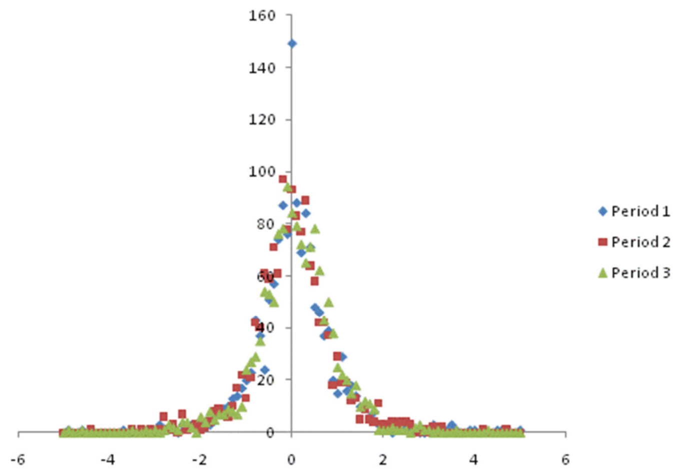

***Figure 12*. Probability distributions of normalized return of PSEi in the three equally long periods from 1993-2009.**

It is shown in Figure 12 that when the scaled return series is divided into three periods, the PDFs of the normalized return hew closely to each other, indicative of a regularity in the series.

4. AUTOCORRELATION OF PSEI

A study of the autocorrelation of the PSEi (Figure 13) revealed that the null hypothesis of the statistical independence of the price changes cannot be rejected. Moreover, since the autocorrelation falls within a band of $\pm\sigma$, it can be concluded that the daily returns are not correlated, indicating that it is independent and identically distributed (iid). The autocorrelation of the time series data is 0.0177, which implies that the price changes of PSEi, compares with that of other markets such as the United States stock market where the averages are close to zero (Serletis, & Shintani, 2003). This finding is similar to those discussed by Voit (2003) using the S&P 500 index, DEM US$ exchange rate, and BUND future (Voit, 2003). It must be noted that in some markets, for the example that of the Swedish, autocorrelation can be as high as 0.345 (Safvenblad, 2000).

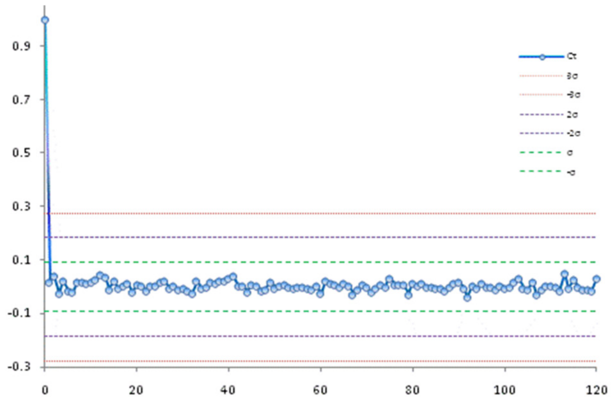

***Figure 13*. Autocorrelation function of PSEi over a time scale τ = 1 day. The horizontal dotted lines are the σ, 2σ, 3σ confidence levels with the value of 0.0921, 0.1843, and 0.2764, respectively.**

5. SCALING POWER LAW

One of the most popular tools in studying the dynamical properties of complex systems is scaling. In this study, we adopted Mantegna and Stanley's method (2000). The scaled return was used and the probability of return to the origin, *P (Z = 0)*, for lag τ = 1,2,…,1000 days was computed by counting the number of zeros and then dividing it by the number of data. The reason for using *P (Z = 0)* is that it allows one to investigate the point of each probability distribution that is least affected by the noise coming from the finiteness of the empirical data (Gleria et al., 2006).

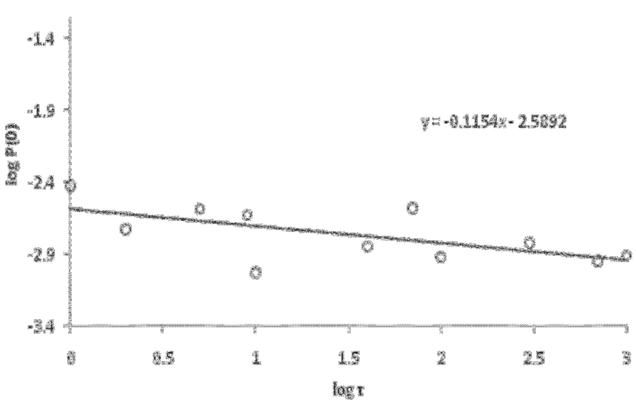

***Figure 14*. Log-log plot of the probability of the scaled return to the origin P(0) against the time lag τ from 1 to 1000 days. The slope for the three orders of magnitude for the data is -0.1154.**

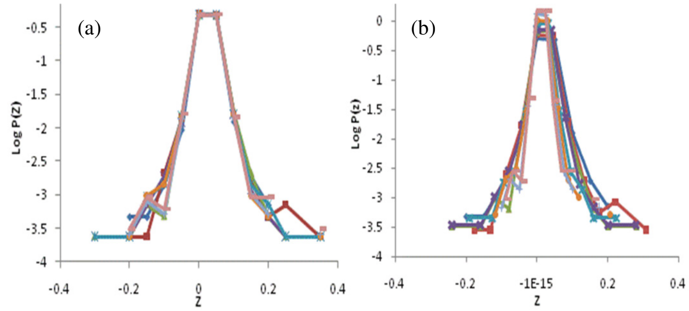

***Figure 15*. Probability density function of the (a) scaled return of the PSEi and (b) scaled return at scaled units both observed at different time intervals.**

The log-log plot of the scaled return shown in Figure 14 suggests a power law behavior for the PSEi. The scaling index μ of the Lévy distribution is just the negative inverse of the slope (-0.1154). Hence, μ = 8.6655. For τ = 1 day, P_τ = 0.3764 and the scale factor γ is 0.1458. Since μ is not equal to 2, the slope is consistent with the non-Gaussian scaling. The distribution however is not stable since μ is not less than 2 (Mantegna & Stanley, 2000).

The PDF of the scaled return, as shown in Figure 15a is non-Gaussian, consistent with our previous results. Figure 15b shows that the PSEi return does not follow the Lévy distribution either. This is because the data do not collapsed onto a single curve after scaling. Moreover, the computed parameters, especially the scale factor γ, are bigger compared to the previous studies of Mantegna and Stanley (2000), where μ = 1.40 and γ = 0.00375. It must be pointed that we did not have access to real-time data of the PSEi. As such, this part of the study, based on daily data, is exploratory at best and does not show a complete picture of the scaling behavior of the Philippine market.

6. PHASE PORTRAIT

Dynamical behavior of a physical system is often studied through phase space diagrams where position is plotted against momentum (Bocarra, 2004). In this study, seeing that the scaled return appeared to be a more suitable dynamical variable for the study of stock market behavior, we considered these as our generalized position and correspondingly, the acceleration as the generalized velocity. Snapshots of the phase portrait were also obtained through the generation of phase portraits of 10 random periods with the length of one month each, first trading day of each month, and the first trading day of each quarter.

The phase portrait shown in Figure 16 shows a trajectory that converges at the origin. The origin therefore appears to be the equilibrium state of the system. The fact that most state lie in the neighbourhood of the origin characterizes a subspace of stability, with occasional excursions. The PSEi return is recurring, just as S&P 500 is characterized to be a low-dimensional recurrent deterministic system by Baptista and Caldas (2000). The denseness of states around the origin seem to suggest chaos, but the occasional excursions indicate that the system is not topologically transitive. Thus, the seemingly chaotic characteristic is only approximate. This finding is similar to that of Serletis and Shintani (2003), who found statistically significant evidence against low-dimensional chaos in the US stock market.

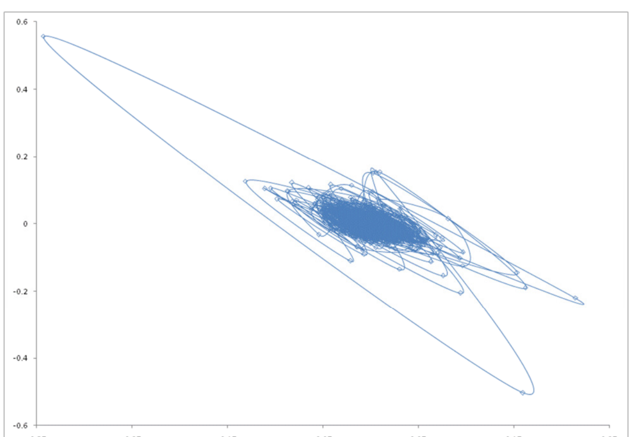

***Figure 16*. Phase portrait of PSEi using the scaled return and the change in scaled return from 1993-2009.**

7. CONCLUSION

A study of the PSEi time series showed that its behavior is best studied in terms of return, which is analogous to velocity for particle dynamics. Like other researchers in the field, we found that the dynamics of the PSE could be considered as a stochastic process. While it is true that we cannot predict exactly what the index will be tomorrow, we can at least determine the probability of the index having a particular value, and intelligent decisions can be made based on these numbers. Simple random walk, random walk with drift, geometric Brownian motion, and Levy flight models, however, do not seem to apply to the PSE. Although, the similarity of the PDF in the region around the mean indicates that the central limit theorem is still applicable to the PSE.

Because the consistent regularity of the stochastic distribution is found only in the acceleration of the index, any stochastic model for the PSE cannot be a simple model using a stochastic difference equation like $x(t+1) = x(t) + \varepsilon(t)$. Rather, such simple models must start with the acceleration, with $\varepsilon(t)$ taking a Johnson SU distribution. One can then work backwards, stochastically integrating the acceleration to obtain the return, and then determine the index from the return.

Autocorrelation studies showed that the PSEi is independent and identically distributed (iid), so some simplifying assumptions can be applied to the stochastic models. While the return has a power law relation with time, the fractal behavior that it suggests is only approximate as gleaned from the phase diagram analysis. On the whole, the PSE dynamics is not chaotic. The presence of a dense ellipse around the origin, however, suggests that the PSE dynamics can on first approximation be considered as a chaotic system. Excursions out of the dense region could be considered as corrections to the first approximation. These excursions are most likely related to the fat-tails of the PDFs and may require analysis using other theories, perhaps catastrophe theory.

Surprisingly, periods of great changes, those of booms and busts, lend themselves to easier analysis as their PDFs were shown to be consistently of the same type. The general trend of the PSEi does not share the pattern typical of other indices. It seems that the index is strongly related to governance, indicating that political situation is a major influence on the performance of the Philippine financial market.

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