



Recurrence quantification analysis of global stock markets

João A. Bastos*, Jorge Caiado

CEMAPRE, ISEG, Technical University of Lisbon, Rua do Quelhas 6, 1200-781 Lisboa, Portugal

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ABSTRACT

This study investigates the presence of deterministic dependencies in international stock markets using recurrence plots and recurrence quantification analysis (RQA). The results are based on a large set of free float-adjusted market capitalization stock indices, covering a period of 15 years. The statistical tests suggest that the dynamics of stock prices in emerging markets is characterized by higher values of RQA measures when compared to their developed counterparts. The behavior of stock markets during critical financial events, such as the burst of the technology bubble, the Asian currency crisis, and the recent subprime mortgage crisis, is analyzed by performing RQA in sliding windows. It is shown that during these events stock markets exhibit a distinctive behavior that is characterized by temporary decreases in the fraction of recurrence points contained in diagonal and vertical structures.

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1. Introduction

The question of whether the seemingly random behavior exhibited by the price of financial assets and commodities is partially explained by chaotic nonlinear deterministic processes has received considerable attention by financial economists. In classical finance theory, fluctuations in asset prices are driven either by homoscedastic random walks or heteroscedastic martingale difference sequences. However, simple nonlinear deterministic processes can emulate price dynamics that are indiscernible from stochastic processes, providing an alternative model for the behavior of asset prices. Furthermore, nonlinear determinism can potentially explain large movements in financial data that linear stochastic models cannot account for Ref. [1]. While evidence of violations of the random walk and martingale hypotheses has been found in financial markets (see, e.g., Refs. [2–4]) and despite the profusion of tests devised for detecting chaotic determinism in time series data (such as the Grassberger-Procaccia and BDS tests) there is little agreement whether the dynamics of financial data is consistent with stochastic or chaotic processes [5]. Despite that, strong evidence of non-chaotic nonlinear dependencies has been found in financial data (see, e.g., Ref. [6]).

Recurrence plots [7] and recurrence quantification analysis [8–10] are nonlinear time series analysis techniques that detect deterministic dependencies in time series. A recurrence plot (RP) is a visual representation of recurrences (similar system states attained at distinct times) that reveals complex deterministic patterns in dynamical systems. Recurrence quantification analysis (RQA) provides the instruments for quantification of these structures and detect critical transitions in the system. Although RPs and RQA originated in physics, they have been successfully employed in a large number of scientific disciplines [11]. These techniques are particularly appropriate for modeling financial and economics time series since they require no assumptions on stationarity, statistical distribution and minimum number of observations. In recent years, several articles employed RPs and RQA to study deterministic dependencies in financial data. These investigations contemplated various markets such as stocks [12–18], exchange rates [19–21] and electricity prices [22]. However, the research on stocks has focused on the largest market capitalization indices, including the Dow Jones [12,16], the S&P 500 [14,17], the NASDAQ and the DAX [15], and little empirical work has been done on the behavior of stocks in emerging markets and smaller

* Corresponding author. Tel.: +351 213 922 715; fax: +351 213 922 782.

E-mail address: jbastos@iseg.utl.pt (J.A. Bastos).

developed markets. In fact, to the best of the authors' knowledge, applications of RPs to emerging markets only considered the Warsaw stock index (WIG) [13] and the Indian stock index (NIFTY) [18]. This void in the extant literature is significant, given that smaller developed economies and many emerging economies progressively enjoy a greater role in the global economy, due to expanding capital and trade movements, and understanding deterministic dependencies in global stock markets is relevant not only to finance theorists but to portfolio managers who use international diversification to reduce risk.¹

The absence of studies on emerging markets and smaller developed markets leaves several research questions unanswered. First, it is well-known that stocks in emerging markets have distinct features from stocks in their developed counterparts, such as higher average returns and unconditional volatility, and greater levels of predictability of stock returns. Furthermore, emerging markets are typically characterized by small numbers of listed companies, low market capitalization, trading volumes and liquidity, and high levels of political risk and regulatory restrictions. Accordingly, it is important to understand whether these differences are reflected in recurrence plots and the corresponding RQA measures. Second, while smaller developed markets and emerging markets underwent a remarkable development and a greater integration in global capital markets, a substantial share of the integration may have occurred at a regional level. Thus, similarities in recurrence plots of markets across the same economic region should be investigated. Third, critical financial events increasingly affect both developed and emerging economies. Therefore, it is essential to understand the impact of these events on RQA measures and compare how they affect developed and emerging markets.

This paper attempts to address these questions by performing a comprehensive examination of the behavior of a large number of stock markets using recurrence plots and recurrence quantification analysis. The analysis is based on 15 years of daily prices of free float-adjusted market capitalization stock indices from 46 countries, representing about 70% of the world's population and 90% of the world's GDP. These indices are constructed and maintained by Morgan Stanley Capital International (MSCI) and are commonly adopted as the benchmark against which the performance of international equity portfolios are compared. Because the construction and maintenance of the MSCI index family follows a consistent methodology, idiosyncrasies associated to local stock exchange indices are avoided. The data employed in this study covers the period from January 1995 to December 2009. This period witnessed the 1997 Asian currency crisis, the 2000 burst of the dot-com bubble, and the 2008–09 subprime mortgage crisis. The dynamics of some selected indices during these financial events is analyzed by computing RQA measures in sliding windows.

The remainder of this paper is organized as follows. The next section describes the database of equity indices employed in this study. Section 3 briefly reviews the recurrence plot methodology and shows several plots of stock indices across different economic regions. The patterns on these plots are also analyzed. The recurrence quantification analysis measures for the complete data set are reported and discussed in Section 4. Statistical tests comparing RQA measures in developed and emerging stock markets are also presented. In Section 5, the temporal evolution of RQA measures during critical financial events is addressed using a windowed version of RQA. Finally, Section 6 presents some concluding remarks.

2. Data

The data employed in this study consists of free float-adjusted market capitalization stock indices of developed and emerging markets, constructed by Morgan Stanley Capital International (MSCI). Securities included in the indices are subject to minimum requirements in terms of market capitalization, free-float, liquidity, availability to foreign investors and length of trading. The MSCI market classification scheme depends on the following three criteria: economic development, size and liquidity, and market accessibility. A market is classified as developed if: (i) the country's Gross National Income per capita is 25% above the World Bank high income threshold for 3 consecutive years; (ii) there is a minimum number of companies satisfying minimum size and liquidity requirements; and (iii) there is a high openness to foreign ownership, ease of capital inflows/outflows, high efficiency of the operational framework and stability of the institutional framework. To be included in the emerging market category, a market is characterized by size, liquidity and market accessibility criteria that are less tight than those for the developed markets.² The dataset includes 23 markets classified as developed (Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Hong Kong, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom and United States) and 23 markets classified as emerging (Argentina, Brazil, Chile, China, Czech Republic, Colombia, Egypt, Hungary, India, Indonesia, Israel, Korea, Malaysia, Mexico, Morocco, Peru, Philippines, Poland, Russia, South Africa, Taiwan, Thailand and Turkey).

The time series consist of daily index prices, expressed in US dollars, between January 1995 and December 2009, corresponding to 3914 observations. In the event of days where there is a market holiday, the MSCI index construction methodology simply carries forward the index value from the previous business day. The index price series x were normalized between 0 and 1, according to

$$x \rightarrow \frac{x - \min(x)}{\max(x) - \min(x)}, \quad (1)$$

where $\min(x)$ and $\max(x)$ are the minimum and maximum values of the series in the analyzed period, respectively.

¹ While the developed world still comprised over 90% of the world's equity in the late 2000's, the emerging economies' share of equity has been growing rapidly and will continue to do so.

² For details, see <http://www.mscibarra.com>.

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