

*The Economic and Social Review*, Vol. 45, No. 3, Autumn, 2014, pp. 349–369

## Informational Efficiency in Distressed Markets: The Case of European Corporate Bonds

AURELIO FERNÁNDEZ BARIVIERA\*

*DGE, Universitat Rovira i Virgili, Reus, Spain*

*Centro de Estudios Científicos y Técnicos, FACPCE, Buenos Aires*

M. BELÉN GUERCIO

*Instituto de Investigaciones Económicas y Sociales del Sur, CONICET-*

*Universidad Nacional del Sur*

*Universidad Provincial del Sudoeste, Bahía Blanca, Argentina*

LISANA B. MARTINEZ

*Instituto de Investigaciones Económicas y Sociales del Sur, CONICET-*

*Universidad Nacional del Sur*

*Universidad Provincial del Sudoeste, Bahía Blanca, Argentina*

---

**Abstract:** This paper investigates the effect of the 2008 financial crisis on informational efficiency by carrying out a long-memory analysis of European corporate bond markets. We compute the Hurst exponent for fifteen sectorial indices to scrutinise the time-varying behaviour of long-range memory, applying a shuffling technique to avoid short-term correlation. We find that the financial crisis has uneven effects on the informational efficiency of all corporate bond sectors, especially those related to financial services. However, their vulnerability is not homogeneous and some non-financial sectors suffer only a transitory effect.

### I INTRODUCTION

The study of informational efficiency, a cornerstone of which is the Efficient Market Hypothesis (EMH), is possibly one of the most elusive issues in financial economics. Its origins can be traced back to Gibson (1889), who wrote

**Acknowledgements:** The authors would like to thank the two anonymous reviewers and an associate editor for helpful comments. Remaining errors are our sole responsibility.

\* Corresponding author: Telephone: +34 977759833, Fax: +34 977759810.

Email addresses: [aurelio.fernandez@urv.net](mailto:aurelio.fernandez@urv.net) (Aurelio Fernández Bariviera), [mbguercio@iess-conicet.gob.ar](mailto:mbguercio@iess-conicet.gob.ar) (M. Belén Guercio), [lisanabelen.martinez@gmail.com](mailto:lisanabelen.martinez@gmail.com) (Lisana B. Martinez).

that the prices of publicly traded shares “may be regarded as the judgment of the best intelligence regarding them”. In spite of the fact that one of the first models of an informationally efficient market (Bachelier, 1900) was based on the price changes of French government bonds, the literature focused on the study of stock markets rather than bond markets.

However, the systematic study of informational efficiency was taken up in the 1960s, when financial economics emerged as a new area within economics. Fama’s classic definition (Fama, 1976) states that a market is informationally efficient if it “fully reflects all available information”. Therefore, the key element in assessing efficiency is to determine the appropriate set of information that drives prices. Following Fama (1970), informational efficiency can be divided into three categories: (i) weak efficiency, if prices reflect the information contained in past series of prices; (ii) semi-strong efficiency, if prices reflect all public information; and (iii) strong efficiency, if prices reflect all public and private information. As a corollary of EMH, the presence of long memory in financial time series cannot be accepted because it would allow risk-free profitable trading strategies. If markets are informationally efficient, arbitrage prevents the possibility of such strategies.

Ross (2005) indicates that this definition leads one to believe that prices are the result of decisions made by individual agents and that they therefore depend on underlying information. As a corollary, higher returns cannot be obtained with the same information set. This implies that future returns depend to a great extent not only on historic information but also on new information received by the market. Therefore no investor whose information set is the same as or inferior to the market’s information set can beat the market.

In a recent paper Bariviera *et al.* (2012) study the impact of the crisis on corporate and sovereign bond markets of seven European countries, with similar results being found in all the countries examined. The interesting finding that the crisis brings about an enhancement of informational efficiency in sovereign bond indices and a deterioration in corporate bond indices leads us to carry out a more detailed study of the effect of the crisis on the informational efficiency of corporate bonds. According to Bariviera *et al.* (2012), there do not appear to be any country-specific characteristics that influence informational efficiency. We therefore select a tout-court European corporate bond index for each economic sector in order to detect the permeability of certain sectors to crisis influence, as reflected in their informational efficiency.

The aim of this paper is to analyse the time-varying dynamics of informational efficiency as measured by the long memory of time series and the impact of the 2008 financial crisis on fifteen sectorial indices of European

corporate bonds. This article contributes to the literature on EMH in four important aspects. First, we expand the empirical studies by analysing the long memory of corporate bond indices. Second, we perform a comparative analysis of the most important and most recognised sectors of the economy. Third, we throw some light on the uneven impact of the 2008 financial crisis across sectors. And fourth, we analyse the European market, where the most visible effects have taken place and which emerges as an alternative financing source for companies.

The paper is organised as follows. Section II presents a brief review of the literature on long memory in corporate bond markets. Section III introduces the Hurst exponent as a measure for long-range dependence and the corresponding break point relating to structural changes in the time series. Section IV presents the data and methodology used in the paper. Section V sets out the empirical results. Finally, Section VI contains the main conclusions.

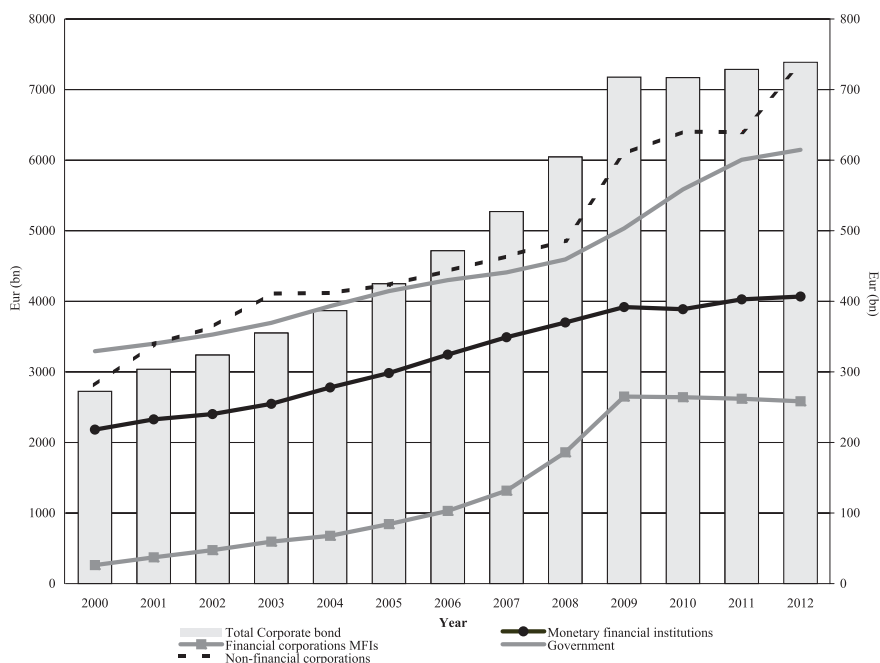
## II LITERATURE REVIEW

### 2.1 *The Corporate Bond Market*

Corporate bond markets are some of the least studied markets in the financial literature. However, there are a number of reasons why a detailed study should be made of their behaviour. Fink *et al.* (2003), for example, find that an increase in bond firm financing triggers economic growth. They also state that the corporate bond market could substitute the banking sector, enhancing the development of the market. Corporate bond financing also allows longer maturities and lower lending rates. This means the substitution of current liabilities by non-current liabilities, which improves a company's current ratio. Furthermore, longer maturities allow firms to venture for long-term investment projects. From an investor's point of view, corporate bonds offer an opportunity for portfolio diversification into assets of different maturities, different credit ratings and, therefore, different yields. Apart from being one of the main financing sources for European firms, the market for corporate bonds in this area is one of the biggest in the world. The European corporate bond market has undergone huge growth in recent years, albeit interrupted in some sectors due to the 2008 crisis. It is useful to see the effect of the crisis on certain segments of the corporate bond market. As shown in Figure 1, the outstanding volume of monetary financial institutions and financial corporations is maintained unaltered since 2009. Non-financial corporation bonds have meanwhile been undergoing sustained growth since 2008. There are several reasons for this behaviour. First of all there has been

a portfolio rebalance in favour of corporate bonds at the expense of sovereign bonds due to the yield gap between the two types of bond. Second, due to the credit crunch, managers were forced to go to the market to finance investment projects.<sup>1</sup>

Figure 1: *Outstanding Volume of Corporate Bonds by Sector. Non-Financial Corporations Are Shown on the Right-Hand Axis. Both Axes Represent the Circulation Volume in Billions of Euros*



Source: Own calculations based on data from the European Central Bank.

## 2.2 Weak Informational Efficiency

Much of the literature focuses on long-range dependence in stock markets. In spite of the fact that the market for corporate bonds is very large in volume and is popular with portfolio managers, who see these bonds as an attractive way to invest, there are fewer empirical studies in this area. Barkoulas *et al.* (2000), for example, estimate the fractional differencing parameter using the spectral regression method to measure long memory in the Greek Stock Exchange. Along similar lines Blasco and Santamaría (1996), using the Brock-Dechert-Scheinkman (BDS) statistic and Hurst-Mandelbrot R/S analysis,

<sup>1</sup> Corporate bond issuance in Europe: Where do we stand and where are we heading? 31 January 2013 in Deutsche Bank Research Macroeconomic Research Bank.

prove the existence of strong memory processes in the Spanish Stock Exchange. Cheung and Lai (1995) report long memory in 5 out of 18 developed stock markets applying a modified rescaled range test and a fractional differencing test. Barkoulas and Baum (1996) apply the spectral regression method to test for fractal structure in aggregate stock returns but find no strong evidence against the random walk model in US stock returns.

Another issue unsolved in the literature is the time-varying behaviour of market efficiency. On this aspect Ito and Sugiyama (2009) claim that inefficiency varies over time in the US stock market. They use a time-varying structure of autocorrelations of stock return data based on the moving window method and estimate the time-varying AR(1) coefficients using a state space model. Applying the Hurst exponent (R/S), Bariviera (2011) argues that time-varying long-range dependence in the Thai Stock Market is weakly influenced by the liquidity level and market size. Cajueiro *et al.* (2009) conclude that financial market liberalisation increases informational efficiency in the Greek Stock Market. Kim *et al.* (2011) observe that return predictability is altered by political and economic crises but not market crashes, considering different statistics tests as measures of the degree of return predictability. Alvarez-Ramirez *et al.* (2012) categorise market efficiency in terms of entropy and find that US stock market efficiency varies over time between 1929 and 2012, that economic context could affect market efficiency and that the strength and duration of the efficiency deviation could be considered measures of the effect of specific events. Hooy and Lim (2013) analyse stock market integration by exploring its association with informational efficiency. By applying an OLS model and employing the adjusted pricing error from an equilibrium international asset pricing model as a proxy for market integration, they show robust evidence supporting the hypothesis that the level of market integration is significantly and positively related to the degree of informational efficiency.

Despite the importance of fixed income instruments in the composition of investment portfolios and in company and government financing, these have not been studied as much as stocks. The fixed income market is divided into two categories, depending on the legal status of the issuer. The corporate bond market refers to debt instruments issued by private and public corporations, whereas the sovereign bond market refers to debt instruments whose borrowers are autonomous nation states. Bollerslev *et al.* (2000) uncover long-memory volatility dependencies in future US Treasury bond market contracts. They use intraday data from January 1994 to December 1997 partitioned into 5-minute intervals and employ a fractionally integrated GARCH (FIGARCH) model to capture the daily price volatility of future contracts. Carbone *et al.* (2004) determine long memory in log returns for the German stock and sovereign bond markets using detrending moving average (DMA) scaling

techniques. Bariviera and de Andrés (2005) discuss the existence of daily seasonalities in Spanish sovereign bonds for different maturities, analysing the return volatilities of representative portfolios published by Analistas Financieros Internacionales. They confirm heterogeneous behaviour throughout the week. Using methods based on wavelets, Thupayagale (2011) observes long memory in South African 10-year government bonds, considering three bond volatility proxies: absolute, squared and log-squared returns. Jordan and Jordan (1991), using a standard ANOVA test for daily and weekly data from the Dow Jones Composite Bond Average from January 1963 to December 1986, detect a January effect. Alexander and Ferri (2000) reveal patterns of daily seasonality in high-yield corporate bonds for daily trading volume and closing price from Nasdaq's Fixed Income Pricing System (FIPS). They use ANOVA and an F-statistic to evaluate the means and medians of differences in measures of trading volume proxied by the number of bonds traded, the number of trades and the market value of the traded bonds. ANOVA and t-statistics are used to gauge differences in the daily percentage price change. McCarthy *et al.* (2009) confirm long memory in yields for corporate bonds and in the spread of returns for corporate bonds and treasury bonds. The analysis is carried out on Aaa and Baa corporate and 10-year Treasury bonds. They estimate a Hurst exponent and the degree of fractional integration of the yield spread in two ways, using a semi-parametric aggregated series and a discrete wavelet. Hotchkiss and Ronen (2002) study the informational efficiency of the bond market relative to the stock market for a sample of US market companies. Analysing daily and hourly transactions for 55 high-yield bonds between January and October 1995 they find no significant difference in the informational efficiency of the two markets. They use a vector autoregression approach (VAR) to establish the causal relationship. Downing *et al.* (2009), however, employ bivariate vector autoregressions in order to examine lead-lag relations between bond and equity returns. From the daily and hourly returns for 3,000 bonds and equities issued by 439 firms over the period from October 2004 to December 2005, they find that the corporate bond market is less informationally efficient than the stock market. Bariviera *et al.* (2012) carry out a comparative analysis of the effect of the 2008 financial crisis on European sovereign and corporate bond markets using a Hurst exponent. They suggest that the effect of the crisis was more evident in the informational efficiency of the corporate bond market than in the sovereign bond market. Bariviera *et al.* (2013) illustrate that relative informational efficiency proxies based on information theory quantifiers tally with the classification provided by credit rating agencies such as Moody's and Standard & Poors.

There are other ways of assessing the evolution of efficiency. Rosso *et al.* (2007) introduce the complexity-causality plane in order to distinguish between Gaussian and non-Gaussian processes. Zunino *et al.* (2010) show that this innovative approach is very useful for discerning the stage of stock market development. In particular it enables quantification of the influence of two sources of inefficiency that are present in the underlying stochastic process: long-range correlation and fat tails. In Zunino *et al.* (2011), an application of the complexity-entropy causality plane was extended to the study of the efficiency of commodity prices.

### III LONG-RANGE DEPENDENCE USING A HURST EXPONENT

A classic assumption in financial models is that stock price changes are independent and identically distributed and can be represented by a Brownian motion. Hence an asset pricing model like the Black-Scholes option formula precludes the possibility of long-term memory in price changes. This assumption has been controversial because, as mentioned in Section 2.2, there are numerous empirical studies that document departures from the Brownian motion model. The presence of such behaviour is essential for time-series modelling and forecasting. Mandelbrot and Wallis (1968) and Mandelbrot (1972) propose an alternative model which includes long memory. This stochastic process, called Fractional Brownian Motion (FBM), is a generalisation of the classic Brownian motion and can be described as:

$$\omega_H(t) = \frac{1}{\Gamma(H + 0.5)} \int_0^t (t - \tau)^{H-0.5} d\omega(\tau) \quad (1)$$

where  $\omega(t)$  is a standard Brownian motion and  $\Gamma(\cdot)$  is the standard Gamma function. For  $H = 0.5$ , Equation (1) is a standard Brownian motion. If  $H \neq 0.5$  the process exhibits long range correlation. If  $H < 0.5$  the stochastic process is anti-persistent, i.e., negative changes are most likely followed by positive changes than at a point chosen at random. On the contrary, if  $H > 0.5$  the stochastic process is persistent, i.e., it exhibits positive long-term correlation.

There are several techniques for assessing the existence of long memory. These include the Hurst exponent.<sup>2</sup> The Hurst exponent's  $H$  characterises the

<sup>2</sup> Autoregressive Fractionally Integrated Moving Average models, ARFIMA ( $p, d, q$ ) are also a family of stochastic processes with long memory. An alternative way of testing for long memory is to assess the order of  $d$  of fractional integration of the time series. In fact, parameter  $d$  from ARFIMA and parameter  $H$  from FBM are functionally related. A discussion of ARFIMA models is beyond the scope of this paper, so we refer readers to Geweke and Porter-Hudak (1983) and Mills and Markellos (2012) for a deeper insight.

scaling behaviour of the range of cumulative departures of a time series from its mean.

There are several methods (both parametric and non-parametric) for calculating the Hurst exponent. For a survey on the different methods of estimating long-range dependences, see Taqqu *et al.* (1995) and Montanari *et al.* (1999). Serinaldi (2010) carries out a comprehensive review of different methods for estimating the Hurst exponent and concludes that applying an inappropriate estimation method can lead to incorrect conclusions about the persistence or anti-persistence of financial series. These methods include rescaled range analysis ( $R/S$ ), as used in Hurst (1951) and Mandelbrot and Wallis (1968) and detrended fluctuation analysis (DFA), as developed by Peng *et al.* (1994). The former is selected because it is the most popular method in the economic literature, while the latter is chosen because it produces better estimates of long-range dependence and is not affected by non-stationarities in time series (Grau-Carles, 2000).

We reject using Lo's modified  $R/S$  statistics (Lo, 1991) since this procedure is biased toward accepting the null hypothesis of no long-range dependence and is less conclusive than the DFA method. For a more detailed discussion on the weaknesses of Lo's  $R/S$ , see Teverovsky *et al.* (1999) and Willinger *et al.* (1999).

### 3.1 Rescaled Range

One of the most common and classic measures of long-range dependence was proposed by Hurst (1951) and is a method widely used in the economic literature. It uses the range of the partial sums of deviations of a time series from its mean, rescaled by its standard deviation. If we have a sequence of continuous compounded returns  $\{r_1, r_2, \dots, r_\tau\}$ ,  $\tau$  in which  $\tau$  is the length of the estimation period and  $\bar{r}_\tau$  is the sample mean, the  $R/S$  statistic is given by

$$(R/S)_\tau \equiv \frac{1}{s_\tau} \left[ \max_{1 \leq t \leq \tau} \sum_{i=1}^t (r_i - \bar{r}_\tau) - \min_{1 \leq t \leq \tau} \sum_{i=1}^t (r_i - \bar{r}_\tau) \right] \quad (2)$$

where  $s_\tau$  is the standard deviation

$$s_\tau \equiv \left[ \frac{1}{\tau} \sum (r_t - \bar{r}_\tau)^2 \right]^{1/2} \quad (3)$$

Hurst (1951), found that the following relation

$$(R/S)_\tau = (\tau/2)^H \quad (4)$$

is verified by many time series in natural phenomena. The use of  $R/S$  analysis in economic time series was pioneered by Mandelbrot (1972) and became very popular with the development of econophysics.



### 3.2 Detrended Fluctuation Analysis

Peng *et al.* (1994) develop the detrended fluctuation analysis (DFA) that is most appropriate when dealing with non-stationary data. This method has received good feedback from researchers in different fields. The algorithm is described in detail in Peng *et al.* (1995) and begins by computing the mean of stochastic time series  $y(t)$ , for  $t = 1, \dots, M$ . An integrated time series  $x(i)$ ,  $i = 1, \dots, M$  is then obtained by subtracting the mean and adding up to the  $i$ -th element,  $x(i) = \sum_{t=1}^i [y(t) - \bar{y}]$ . Then  $x(i)$  is divided into  $M/m$  non-overlapping subsamples and a polynomial fit  $x_{pol}(i, m)$  is computed in order to determine the local trend of each subsample. Next the fluctuation function

$$F(m) = \sqrt{\frac{1}{M} \sum_{i=1}^M [x(i) - x_{pol}(i, m)]^2} \quad (5)$$

is computed. This procedure is repeated for several values of  $m$ . The fluctuation function  $F(m)$  behaves as a power-law of  $m$ ,  $F(m) \propto m^H$ , where  $H$  is the Hurst exponent. Consequently, the exponent is computed by regressing  $\ln(F(m))$  onto  $\ln(m)$ . In this paper, we use a linear polynomial fit and  $4 < m < M/2$ ,  $m \in \mathbb{N}$ . Details of the algorithm and parameters selection can be found in Goldberger *et al.* (2000). As recognised by Grau-Carles (2000), the DFA method avoids spurious detection of long-range dependence due to non-stationary data. DFA has also been used successfully in finance by Podobnik *et al.* (2006), Jiang *et al.* (2007), Yuan *et al.* (2009), Wang *et al.* (2009) and Wang and Liu (2010), among others.

## IV DATA AND METHODOLOGY

We use daily data from the *Markit iBoxx* corporate bond indices, which are market leaders in fixed-income benchmark indices. In particular we use indices classified by sectors of activity. These sectors are banks, financial services, insurance, basic resources, chemicals, automobiles, media, food, energy, healthcare, construction, industrial, technology, telecommunications and utilities. For a full description of index methodology, see Markit Group Limited (2012). The period under examination is from 04/06/2001 to 08/02/2013 for a total of 3,050 observations. All data used in this paper were retrieved from DataStream.

We estimate the Hurst exponent for daily returns<sup>3</sup> using 1,024 datapoints determined by sliding windows corresponding to a period of roughly 4 years.

<sup>3</sup> The continuous compounded return  $r_\tau$  is computed as usual, i.e.:  $r_{t+1} = (\ln P_{t+1} - \ln P_t) 100$ .

A selection of this length is made because it is long enough to provide consistent estimates of  $H$  and reflects political cycles in most countries. This approach has been successfully applied by Cajueiro and Tabak (2004a), Cajueiro and Tabak (2004b), Bariviera (2011) and Bariviera *et al.* (2012). The sliding window approach works as follows: we compute the Hurst exponent for the first 1,024 returns, then discard the first return and add the following return of the time series. We continue in this way until the end of the data. Thus each  $H$  estimate is calculated from data samples of the same size. We obtained 2,026 Hurst estimates. Figures 2 and 3 show the evolution over time of the Hurst exponents for the different sectors under study. We compute the Hurst exponent using the  $R/S$  and DFA methods not only for the original series but also for the shuffled time series. The rationale for using shuffled data is to remove short-range correlations in the data. Following Erramilli *et al.* (1996), we perform an “internal shuffle”. We select blocks of 5, 10 and 20 consecutive returns and randomise the sequence within each block, keeping the order of the blocks unchanged. This procedure was also used by Cajueiro and Tabak (2004b) and Zunino *et al.* (2007) in order to reduce contamination of the Hurst exponent with short-range correlation.

#### 4.1 *Estimation of Time Series Break Points*

When analysing time series, it would be interesting to detect changes in trend. Since we are computing the Hurst exponent with sliding windows, we explore the possibility of finding a disruption point in the time series of Hurst estimates. A break point is the observation that separates the time series into segments of different slopes or trends.

There are several ways of testing structural changes in statistics and econometrics, most of which are designed for a single structural change (Zacks, 1982; Garcia and Perron, 1996). Bai and Perron (1998) and Liu *et al.* (1997) estimate and test linear models with multiple structural changes by minimising the sum of least squared residuals. However, their assumptions and arguments are different. Bai and Perron (1998) obtain rates of convergence for the estimated break points for fixed and shrinking magnitudes. Other papers relating to multiple change points include Gombay and Horváth (1994), Bai (1997) and Hawkins (2001). Zeileis *et al.* (2010) apply structural change tools to Chinese and Indian interest rate evolution taking into account different environment changes in each economy. Bai (1997) studies the relationship between changes in market interest rates and changes in discount rates, including lagged dependent variables and trending regressors. Bai and Perron (2003) continue their previous theoretical work (Bai and Perron, 1998) on the limiting distribution of estimators and test statistics in the linear model with multiple structural changes, also

performing empirical applications. Zeileis *et al.* (2003) test for the existence of structural changes for three different sets of data developed with an R package for statistical computing. They highlight some advantages of the R package *strucchange* relating to the visualisation and graphical analysis and sequences of F statistics, which often carry information about the presence and allocation of break points in the data. In this paper, we include break point analysis in order to discover the effect of the 2008 financial crisis on different corporate bond sectors. In line with this aim we, therefore, look for a single structural change in the Hurst estimate time series using an R package *strucchange* (Zeileis *et al.*, 2002).

## V RESULTS

We compute the Hurst exponent using two different methods: the rescaled range (R/S) and detrended fluctuation analysis (DFA).

According to the Hurst estimates obtained using the *R/S* method (see Figure 2), a large change in informational efficiency can be detected in four sectors around 2008 and 2009, which could be considered the start of the 2008 financial crisis.<sup>4</sup> As explained in Section III, *R/S* estimates may suffer from short-term correlation contamination, a situation that could lead to erroneous conclusions.

We, therefore, perform the same analysis using the DFA method. First of all, a common feature of all Hurst series between 2008 and 2010 is their U-shape, an effect that could be due to the ongoing financial crisis. This means that informational efficiency was increasing for almost all sectors during the period before the financial crisis (see Figure 3). However, the successive impact was asymmetric among the sectors under scrutiny. We can divide this dynamic behaviour into two groups. The first, comprising the chemicals, healthcare, industrial, media, technology, telecommunications and utilities sectors, after a period of distress returned to efficiency levels similar to those of the pre-crisis period. This shows that the impact was transitory for these sectors. The second group, made up of the automobile, banking, basic resources, construction, energy, financial services and insurance sectors, was more severely affected by financial distress. For these sectors it was not temporary but lasted at least until the end of the sample period. In particular they exhibit much worse efficiency levels than in the preceding period, as

<sup>4</sup> The collapse of Lehman Brothers on September 15 2008 is frequently used in the literature as the landmark for the financial crisis. See, for example, Barrios *et al.* (2009), Bernoth and Erdogan (2012), Grammatikos and Vermeulen (2012) and Martinez *et al.* (2013).

Figure 2: *Evolution of the Hurst Exponent with Sliding Windows, Computed by the R/S Method*

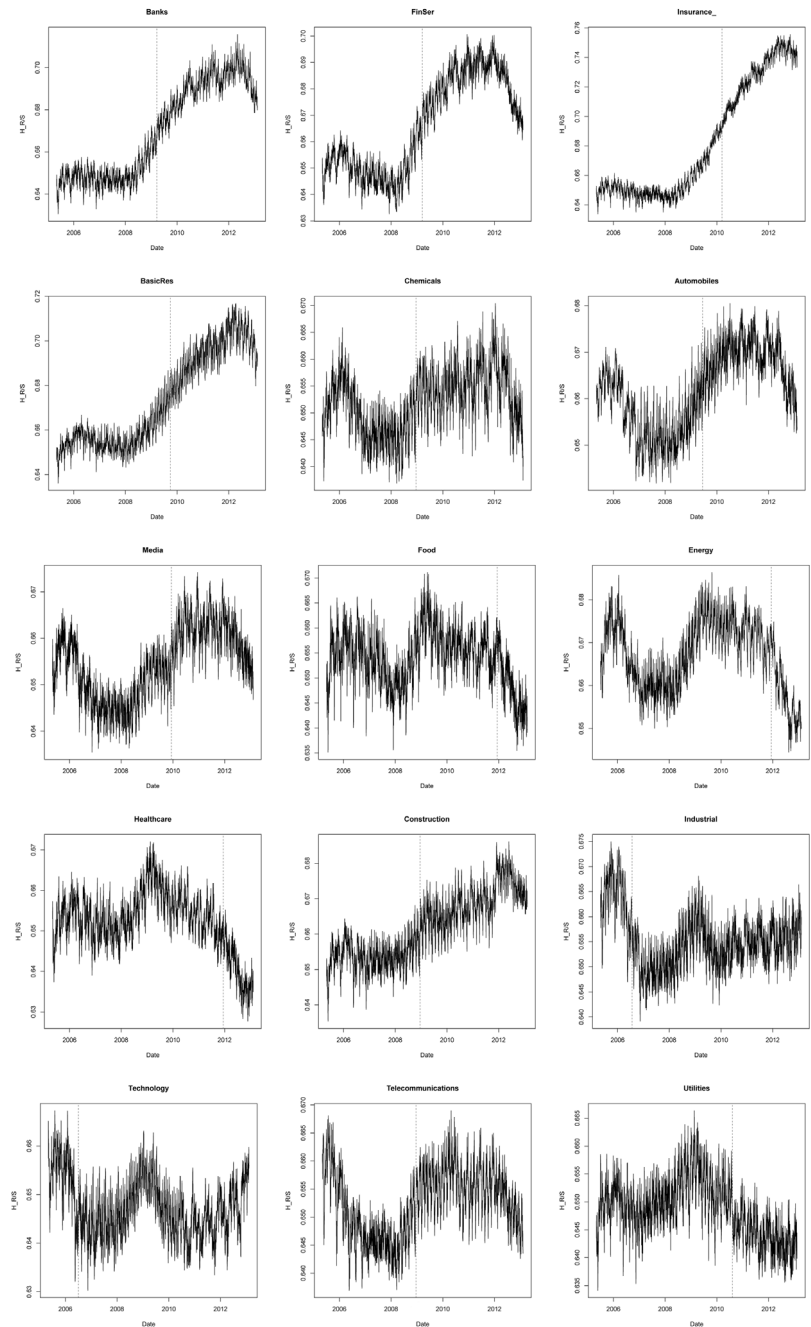
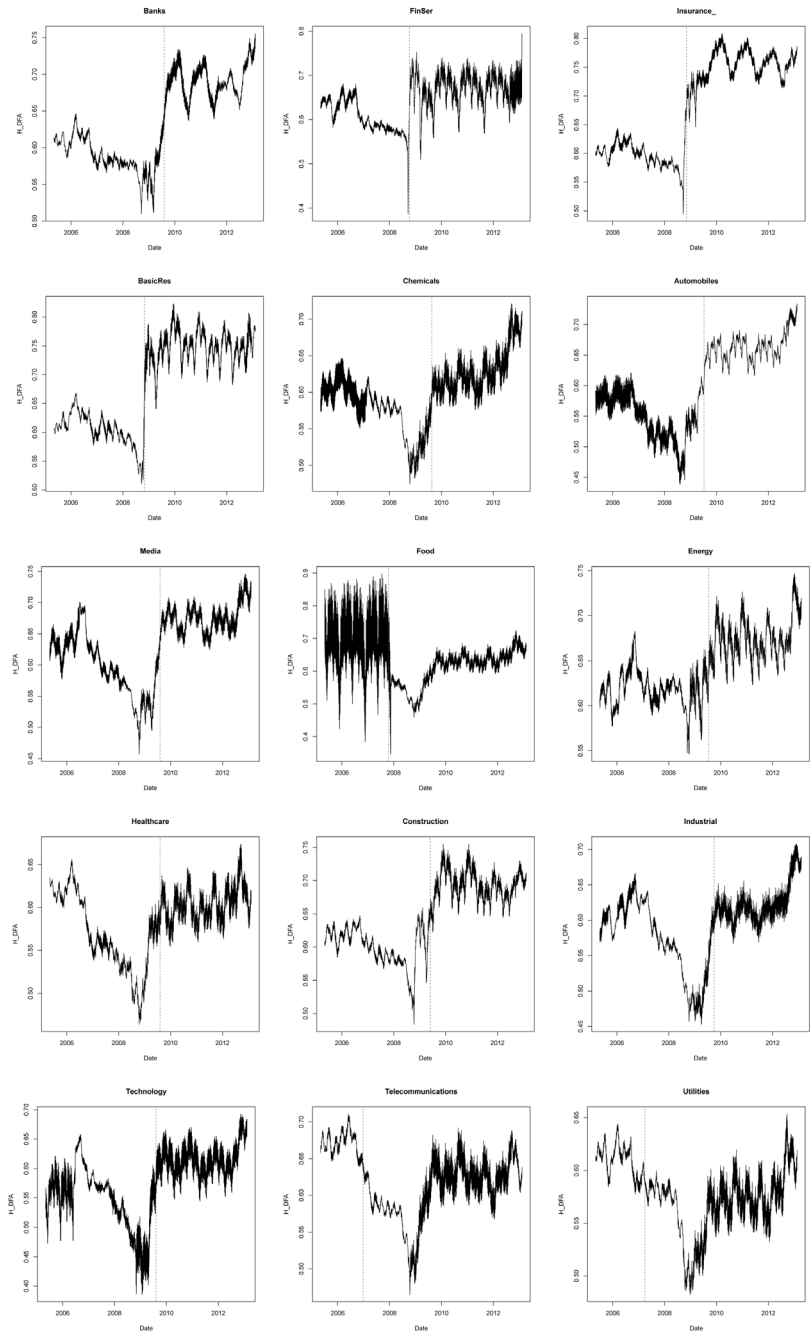


Figure 3: *Evolution of the Hurst Exponent With Sliding Windows, Computed by the DFA Method*



reflected in the upward trend of the Hurst estimates. The food sector presents an erratic behaviour during the pre-crisis period, which prevents a formal analysis from being made.

In order to analyse the effect of the crisis, we test for the existence of a break point in the Hurst estimates time series using the R package developed by Zeileis *et al.* (2002). The estimated break points can be grouped into several sets according to break point date. The results are shown in Table 1. The telecommunications, utilities and food sectors have an early break point at the end of 2006 and during 2007. The sectors most closely related to financial services present a disruption point in the time series from October 7 to November 4 2008, subsequent to the collapse of Lehman Brothers. This result makes sense because the 2008 crisis started as financial turmoil. The only exception is the banking sector, which along with the other remaining sectors shows a break point during 2009. The chronological cascade of break points could be looked at through different lenses. First, how an important economic event, such as the bankruptcy of a leading financial institution in the US, affected the European corporate bond market. Second, how the crisis started in the financial world and quickly crossed over into the real economy of the EU. The rapid spillover was helped by the development of the financial market, which not only suffered the disease but also acted as a very dangerous transmission vector throughout the whole economy.

In order to check the robustness of our analysis and remove any remaining short-term correlation, we compute DFA Hurst estimates with shuffled data. As explained in Section IV and following Erramilli *et al.* (1996) and Cajueiro and Tabak (2004b), we shuffle data in blocks of 5, 10 and 20 consecutive returns. Figures 4 and 5 show that the temporal shape is very similar for each sector and the break points are around the same dates. This reaffirms the strong effect of the 2008 financial crisis on the informational efficiency of the European corporate bond market and the dissimilar shock across sectors.<sup>5</sup>

<sup>5</sup> Due to lack of space we have not included a figure for the 20-point shuffle. However, one is available on request from the corresponding author.

Figure 4: *Evolution of the Hurst Exponent with Sliding Windows, Computed Over Shuffled Data in Blocks of Five Elements, Using the DFA Method*

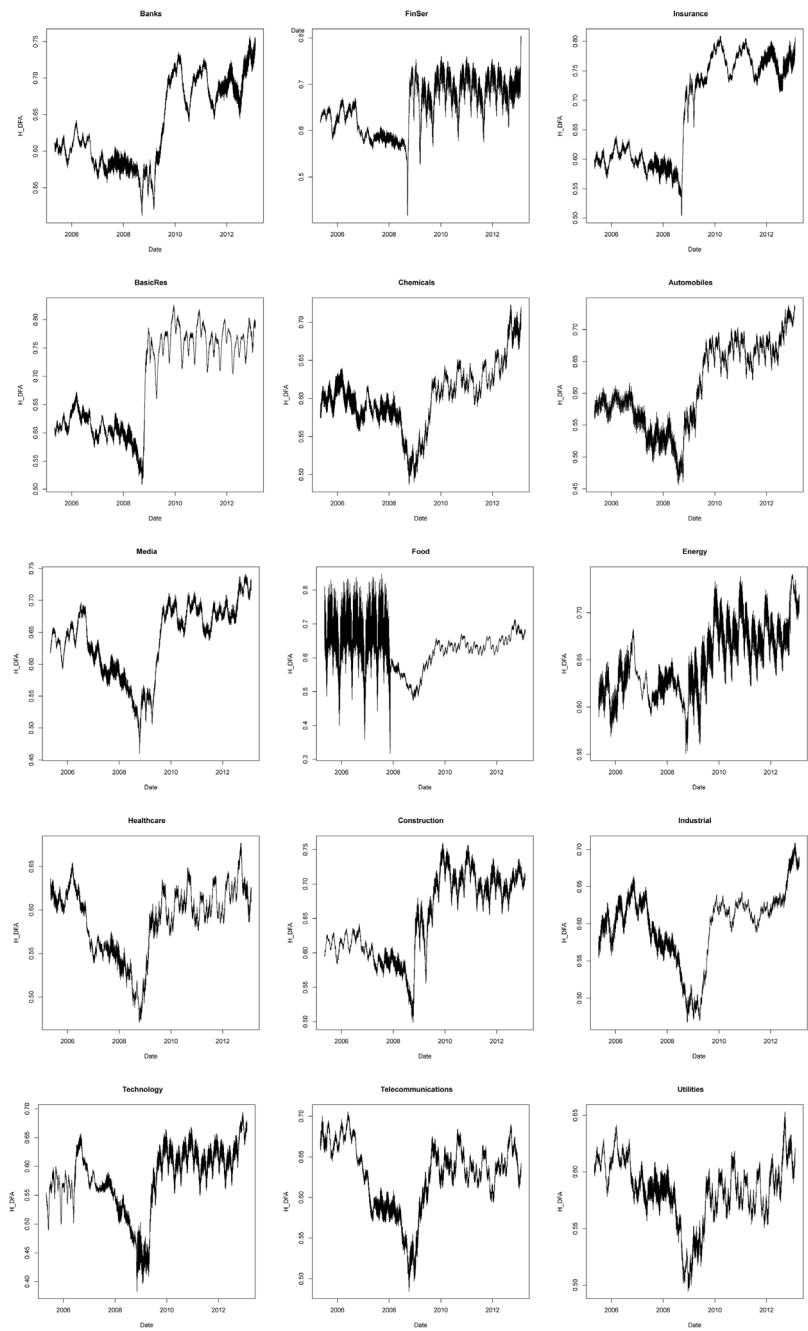
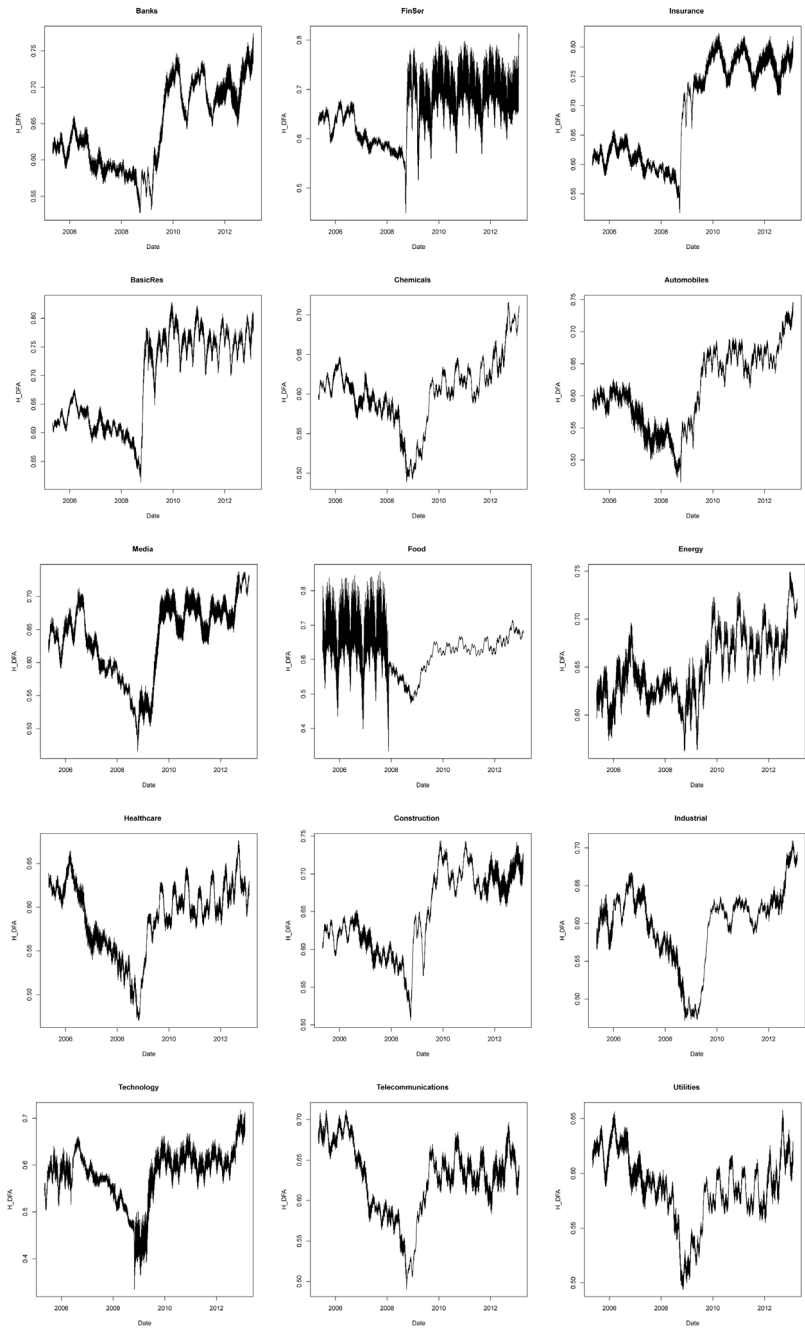


Figure 5: *Evolution of the Hurst Exponent with Sliding Windows, Computed Over Shuffled Data in Blocks of Ten Elements, Using The DFA Method*





## VI CONCLUSIONS

This paper carries out a detailed analysis of the long memory content of 15 sectorial indices of European corporate bonds between 2001 and 2013. The main results relate to the time-varying behaviour of informational efficiency. We detect a downward trend in the Hurst exponent until 2008. The Hurst estimates tend to converge to  $H = 0.5$ . This movement reflects a general improvement in informational efficiency. In line with the origin of the 2008 crisis, the turmoil became a financial crisis and later crossed over into the real economy. This could be seen in the informational efficiency deterioration cascade for 12 sectors of the sample. Our analysis differentiates between two distinct sets of sectors. One set suffered temporary stress but returned to its previous level of efficiency. This set was made up of the chemicals, healthcare, industrial, media, technology, telecommunications and utilities sectors. The other set underwent an enduring effect, which remained significant until the end of the sample period. This set, comprising the automobile, banking, basic resources, construction, energy, financial services and insurance sectors, saw a reduction in its informational efficiency. These results provide new evidence concerning the efficiency of the bond market, showing the extent of different reactions in terms of informational efficiency due to the financial crisis, which is very useful for when investors make decisions regarding investment portfolios. Our results could also be useful for policymakers when designing prudential regulations with respect to risk bearing.

Table 1: *Break Point Dates for the Hurst Estimate Time Series*

| <i>Sector</i>      | <i>Date</i> |
|--------------------|-------------|
| Telecommunications | 25-12-06    |
| Utilities          | 30-03-07    |
| Food               | 18-10-07    |
| Financial Services | 07-10-08    |
| Basic Resources    | 30-10-08    |
| Insurance          | 04-11-08    |
| Construction       | 29-05-09    |
| Automobiles        | 09-07-09    |
| Energy             | 16-07-09    |
| Banks              | 04-08-09    |
| Media              | 05-08-09    |
| Healthcare         | 06-08-09    |
| Technology         | 06-08-09    |
| Chemicals          | 18-08-09    |
| Industrial         | 01-10-09    |

## REFERENCES

- ALEXANDER, G. J. and M. G. FERRI, 2000. "Day-of-the-week Patterns in Volume and Prices of Nasdaq High-Yield Bonds", *Journal of Portfolio Management*, Vol. 26, pp. 33-41.
- ALVAREZ-RAMIREZ, J., E. RODRIGUEZ and G. ESPINOSA-PAREDES, 2012. "Is the US Stock Market Becoming Weakly Efficient Over Time? Evidence From 80-Year-long Data", *Physica A: Statistical Mechanics and its Applications*, Vol. 391, pp. 5643-5647.
- BACHELIER, L., 1900. *Théorie de la spéculation*, Paris: Annales scientifiques de l'école Normale Supérieure.
- BAI, J., 1997. "Estimation of a Change Point in Multiple Regression Models", *The Review of Economics and Statistics*, Vol. 79, pp. 551-563.
- BAI, J. and P. PERRON, 1998. "Estimating and Testing Linear Models with Multiple Structural Changes", *Econometrica*, Vol. 66, pp. 47-78.
- BAI, J. and P. PERRON, 2003. "Computation and Analysis of Multiple Structural Change Models," *Journal of Applied Econometrics*, Vol. 18, pp. 1-22.
- BARIVIERA, A. F., 2011. "The Influence of Liquidity on Informational Efficiency: The Case of the Thai Stock Market", *Physica A: Statistical Mechanics and its Applications*, Vol. 390, pp. 4426-4432.
- BARIVIERA, A. F. and J. DE ANDRÉS, 2005. "¿Existe estacionalidad diaria en el mercado de bonos y obligaciones del estado? Evidencia empírica en el periodo 1998-2003", *Análisis Financiero*, Vol. 98, pp. 16-21.
- BARIVIERA, A. F., M. B. GUERCIO and L. B. MARTINEZ, 2012. "A Comparative Analysis of the Informational Efficiency of the Fixed Income Market in Seven European Countries", *Economics Letters*, Vol. 116, pp. 426-428.
- BARIVIERA, A. F., L. ZUNINO, M. GUERCIO, L. MARTINEZ and O. ROSSO, 2013. "Efficiency and Credit Ratings: A permutation-Information-Theory Analysis", *Journal of Statistical Mechanics: Theory and Experiment*, P08007.
- BARKOULAS, J. T. and C. F. BAUM, 1996. "Long-term Dependence in Stock Returns", *Economics Letters*, Vol. 53, pp. 253-259.
- BARKOULAS, J. T., C. F. BAUM and N. TRAVLOS, 2000. "Long Memory in the Greek Stock Market", *Applied Financial Economics*, Vol. 10, pp. 177-184.
- BARRIOS, S., P. IVERSEN, M. LEWANDOWSKA and R. SETZER, 2009. *Determinants of Intra-Euro Area Government Bond Spreads During the Financial Crisis. European Economy – Economic Papers*, Luxembourg: European Commission, Directorate General Economic and Monetary Affairs.
- BERNETH, K. and B. ERDOGAN, 2012. "Sovereign Bond Yield Spreads: A Time-varying Coefficient Approach", *Journal of International Money and Finance*, Vol. 31, pp. 639-656.
- BLASCO, N. and R. SANTAMARÍA, 1996. "Testing Memory Patterns in the Spanish Stock Market", *Applied Financial Economics*, Vol. 6, pp. 401-411.
- BOLLERSLEV, T., J. CAI and F. M. SONG, 2000. "Intraday Periodicity, Long Memory Volatility and Macroeconomic Announcement Effects in the US Treasury Bond Market", *Journal of Empirical Finance*, Vol. 7, pp. 37-55.
- CAJUEIRO, D. O. and B. M. TABAK, 2004a. "Evidence of Long Range Dependence in Asian Equity Markets: The Role of Liquidity and Market Restrictions", *Physica A: Statistical Mechanics and its Applications*, Vol. 342, pp. 656-664.

- CAJUEIRO, D. O. and B. M. TABAK, 2004b. "The Hurst Exponent over Time: Testing the Assertion that Emerging Markets are Becoming More Efficient", *Physica A: Statistical and Theoretical Physics*, Vol. 336, pp. 521-537.
- CAJUEIRO, D. O., P. GOGAS and B. M. TABAK, 2009. "Does Financial Market Liberalization Increase the Degree of Market Efficiency? The Case of the Athens Stock Exchange", *International Review of Financial Analysis*, Vol. 18, pp. 50-57.
- CARBONE, A., G. CASTELLI and H. E. STANLEY, 2004. "Time-dependent Hurst Exponent in Financial Time Series", *Physica A: Statistical Mechanics and its Applications*, Vol. 344, pp. 267-271.
- CHEUNG, Y. and K. S. LAI, 1995. "A Search for Long Memory in International Stock Market Returns", *Journal of International Money and Finance*, Vol. 14, pp. 597-615.
- DOWNING, C., S. UNDERWOOD and Y. XING, 2009. "The Relative Informational Efficiency of Stocks and Bonds: An Intraday Analysis", *Journal of Financial and Quantitative Analysis*, Vol. 44, 1081-1102.
- ERRAMILI, A., O. NARAYAN and W. WILLINGER, 1996. "Experimental Queueing Analysis with Long-Range Dependent Packet Traffic", *IEEE/ACM Transactions on Networking*, Vol. 4, pp. 209-223.
- FAMA, E. F., 1970. "Efficient Capital Markets: A Review of Theory and Empirical Work", *The Journal of Finance*, Vol. 25, pp. 383-417.
- FAMA, E. F., 1976. *Foundations of Finance: Portfolio Decisions and Securities Prices*, New York: Basic Books.
- FINK, G., P. R. HAISS and S. HRISTOFOROVA, 2003. *Bond markets and economic growth*, "<http://ssrn.com/abstract=1003763orhttp://dx.doi.org/10.2139/ssrn.1003763>".
- GARCIA, R. and P. PERRON, 1996. "An Analysis of the Real Interest Rate Under Regime Shifts", *The Review of Economics and Statistics*, Vol. 78, pp. 111-125.
- GEWEKE, J. and S. PORTER-HUDAK, 1983. "The Estimation and Application of Long Memory Time Series Models", *Journal of Time Series Analysis*, Vol. 4, pp. 221-238.
- GIBSON, G. R., 1889. *The Stock Exchanges of London, Paris and New York: A Comparison*, New York: G. P. Putnam.
- GOLDBERGER, A. L., L. A. N. AMARAL, L. GLASS, J. M. HAUSDORFF, P. C. IVANOV, R. G. MARK, J. E. MIETUS, G. B. MOODY, C. K. PENG and H. E. STANLEY, 2000. "Physiobank, Physiokit and Physionet: Components of a New Research Resource for Complex Physiologic Signals", *Circulation* 101, pp. e215-e220. <http://circ.ahajournals.org/content/101/23/e215.full.pdf+html>.
- GOMBAY, E. and L. HORVÁTH, 1994. Limit Theorems for Change in Linear Regression, *Journal of Multivariate Analysis*, Vol. 48, pp. 43-69.
- GRAMMATIKOS, T. and R. VERMEULEN, 2012. "Transmission of the Financial and Sovereign Debt Crises to the EMU: Stock Prices, CDS Spreads and Exchange Rates", *Journal of International Money and Finance*, p. 31.
- GRAU-CARLES, P., 2000. "Empirical Evidence of Long-Range Correlations in Stock Returns", *Physica A: Statistical Mechanics and its Applications*, Vol. 287, pp. 396-404.
- HAWKINS, D. M., 2001. "Fitting Multiple Change-Point Models to Data", *Computational Statistics & Data Analysis*, Vol. 37, 323-341.
- HOOY, C. W. and K. P. LIM, 2013. "Is Market Integration Associated With Informational Efficiency of Stock Markets?", *Journal of Policy Modeling*, Vol. 35, pp. 29-44.

- HOTCHKISS, E. S. and T. RONEN, 2002. "The Informational Efficiency of the Corporate Bond Market: An Intraday Analysis", *Review of Financial Studies*, Vol. 15, pp. 1325-1354.
- HURST, H. E., 1951. "Long-term Storage Capacity of Reservoirs", *Transactions of the American Society of Civil Engineers*, Vol. 116, pp. 770-808.
- ITO, M. and S. SUGIYAMA, 2009. "Measuring the Degree of Time Varying Market Inefficiency", *Economics Letters*, Vol. 103, pp. 62-64.
- JIANG, J., K. MA and X. CAI, 2007. "Non-linear Characteristics and Long-Range Correlations in Asian Stock Markets", *Physica A: Statistical Mechanics and its Applications*, Vol. 378, 399-407. Cited By (since 1996)17.
- JORDAN, S. D. and B. D. JORDAN, 1991. "Seasonality in Daily Bond Returns", *The Journal of Financial and Quantitative Analysis*, Vol. 26, pp. 269-285.
- KIM, J. H., A. SHAMSUDDIN and K. P. LIM, 2011. "Stock Return Predictability and the Adaptive Markets Hypothesis: Evidence from Century-Long US Data", *Journal of Empirical Finance*, Vol. 18, pp. 868-879.
- LIU, J., S. WU, S. and J. V. ZIDEK, 1997. "On Segmented Multivariate Regression", *Statistica Sinica*, Vol. 7, pp. 497-526.
- LO, A., 1991. "Long-term Memory in Stock Market Prices", *Econometrica*, Vol. 59, pp. 1279-1313.
- MANDELBROT, B. B., 1972. "Statistical Methodology for Nonperiodic Cycles: From the Covariance to RS Analysis" in *Annals of Economic and Social Measurement*, Vol. 1, No. 3, National Bureau of Economic Research, including NBER Chapters, pp. 259-290.
- MANDELBROT, B. B. and J. R. WALLIS, 1968. "Noah, Joseph and Operational Hydrology", *Water Resources Research*, Vol. 4, pp. 909-918.
- MARKIT GROUP LIMITED, 2012. *Markit iBoxx EUR Benchmark Index Guide*.
- MARTINEZ, L. B., A. TERCEÑO and M. TERUEL, 2013. "Sovereign Bond Spreads Determinants in Latin American Countries: Before and During the XXI Financial Crisis", *Emerging Markets Review*, Vol. 17, pp. 60-75.
- MCCARTHY, J., C. PANTALONE and H. C. LI, 2009. "Investigating Long Memory in Yield Spreads", *Journal of Fixed Income*, Vol. 19, pp. 73-81.
- MILLS, T. C. and R. N. MARKELLOS, 2012. *The Econometric Modelling of Financial Time Series*. Cambridge: Cambridge University Press, 3rd edition.
- MONTANARI, A., M. S. TAQQU and V. TEVEROVSKY, 1999. "Estimating Long-Range Dependence in the Presence of Periodicity: An Empirical Study", *Mathematical and Computer Modelling*, Vol. 29, pp. 217-228.
- PENG, C. K., S. V. BULDYREV, S. HAVLIN, M. SIMONS, H. E. STANLEY and A. L. GOLDBERGER, 1994. "Mosaic Organization of DNA Nucleotides", *Physical Review*, Vol. E 49, pp. 1685-1689.
- PENG, C. K., S. HAVLIN, H. E. STANLEY and A. L. GOLDBERGER, 1995. "Quantification of Scaling Exponents and Crossover Phenomena in Nonstationary Heartbeat Time Series", *Chaos: An Interdisciplinary Journal of Nonlinear Science*, Vol. 5, pp. 82-87.
- PODOBNIK, B., D. FU, T. JAGRIC, I. GROSSE and H. STANLEY, 2006. "Fractionally Integrated Process for Transition Economics", *Physica A: Statistical Mechanics and its Applications*, Vol. 362, pp. 465-470. Cited By (since 1996) 42.
- ROSS, S. A., 2005. *Neoclassical finance*. Princeton (NJ): Princeton University Press.

- ROSSO, O. A., H. A. LARRONDO, M. T. MARTIN, A. PLASTINO and M. A. FUENTES, 2007. "Distinguishing Noise from Chaos", *Physical Review Letters*, Vol. 99, 154102.
- SERINALDI, F., 2010. "Use and Misuse Of Some Hurst Parameter Estimators Applied to Stationary and Non-Stationary Financial Time Series", *Physica A: Statistical Mechanics and its Applications*, Vol. 389, pp. 2770-2781.
- TAQUU, M. S., V. TEVEROVSKY and W. WILLINGER, 1995. "Estimators for Long-Range Dependence: An Empirical Study", *Fractals*, Vol. 3, pp. 785-798.
- TEVEROVSKY, V., M. A. TAQUU and W. WILLINGER, 1999. "A Critical Look at Lo's Modified R/S Statistic", *Journal of Statistical Planning and Inference*, Vol. 80, pp. 211-227.
- THUPAYAGALE, P., 2011. "Long Memory in the Volatility of an Emerging Fixed-income Market: Evidence from South Africa", *South African Journal of Economics*, Vol. 79, pp. 290-300.
- WANG, Y. and L. LIU, 2010. "Is WTI Crude Oil Market Becoming Weakly Efficient Over Time?. New Evidence from Multiscale Analysis Based on Detrended Fluctuation Analysis", *Energy Economics*, Vol. 32, pp. 987-992. Cited By (since 1996) 24.
- WANG, Y., L. LIU and R. GU, 2009. "Analysis of Efficiency for Shenzhen Stock Market Based on Multifractal Detrended Fluctuation Analysis", *International Review of Financial Analysis*, Vol. 18, pp. 271-276.
- WILLINGER, W., M. S. TAQUU and V. TEVEROVSKY, 1999. "Stock Market Prices and Long-Range Dependence", *Finance and Stochastics*, Vol. 3, pp. 1-13.
- YUAN, Y., X. TIAN ZHUANG and X. JIN, 2009. "Measuring Multifractality of Stock Price Fluctuation Using Multifractal Detrended Fluctuation Analysis", *Physica A: Statistical Mechanics and its Applications*, Vol. 388, pp. 2189-2197.
- ZACKS, S., 1982. Classical and Bayesian Approaches to the Change-Point Problem: Fixed Sample and Sequential Procedures. *Statistique et analyse des données*, Vol. 7, pp. 48-81.
- ZEILEIS, A., C. KLEIBER, W. KRMER and K. HORNIK, 2003. "Testing and Dating of Structural Changes in Practice", *Computational Statistics & Data Analysis*, Vol. 44, pp. 109-123.
- ZEILEIS, A., F. LEISCH, K. HORNIK and C. KLEIBER, 2002. "Strucchange: An R Package for Testing for Structural Change in Linear Regression Models", *Journal of Statistical Software*, Vol. 7, pp. 1-38.
- ZEILEIS, A., A. SHAH, A. and I. PATNAIK, 2010. "Testing, Monitoring and Dating Structural Changes in Exchange Rate Regimes", *Computational Statistics & Data Analysis*, Vol. 54, pp. 1696-1706.
- ZUNINO, L., B. M. TABAK, D. G. PÉREZ, M. GARAVAGLIA and O. A. ROSSO, 2007. "Inefficiency in Latin-American Market Indices", *The European Physical Journal B – Condensed Matter and Complex Systems*, Vol. 60, pp. 111-121.
- ZUNINO, L., B. M. TABAK, F. SERINALDI, M. ZANIN, D. G. PÉREZ and O. A. ROSSO, 2011. "Commodity Predictability Analysis with a Permutation Information Theory Approach", *Physica A: Statistical Mechanics and its Applications*, Vol. 390, pp. 876-890.
- ZUNINO, L., M. ZANIN, B. M. TABAK, D. G. PÉREZ and O. A. ROSSO, 2010. "Complexity-Entropy Causality Plane: A Useful Approach to Quantify the Stock Market Inefficiency", *Physica A: Statistical Mechanics and its Applications*, Vol. 389, pp. 1891-1901.

