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Testing the Efficient Markets Hypothesis on the Romanian Stock Exchange

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EMH general aspects

- **<u>EMH</u>** (Fama, 1960s): financial assets' prices fully and instantaneously reflect all available information relevant to their fundamental value -> there is no use for technical analysis (*weak* EMH), fundamental analysis (*semi-strong*) or the access to inside information (*strong* EMH) in obtaining excess returns

- **random walk**: $p_t = \mu + p_{t-1} + \varepsilon_t$, where p_t =log of price at time *t*, μ = expected price change or drift

Campbell, Lo and MacKinlay (1997) present 3 forms:

- **<u>RWI</u>**: $\varepsilon_t \sim iid\ (0, \sigma^2)$; not only the increments are uncorrelated, but also any nonlinear function of the increments as well; $E[p_t|p_0] = p_0 + \mu t$ and $var[p_t|p_0] = \sigma^2 t$; the most frequently implied distribution is Gaussian;
- **<u>RWII</u>**: The residuals are independent, but not identically distributed: $var[\varepsilon_t] = \sigma_t^2$; RWI is a special case of RWII;
- **<u>RWIII</u>**: The residuals are dependent, but uncorrelated, e.g. a series satisfying $cov(\varepsilon_t, \varepsilon_{t-k}) = 0\ for\ all\ k \neq 0$, but with $cov({\varepsilon_t}^2, {\varepsilon_{t-k}}^2) \neq 0\ for\ some\ k \neq 0$; RWI and RWII are special cases of RWIII.

Theory relaxation:

- Grossman-Stiglitz paradox (1980) - informationally efficient markets are impossible (no single agent would have sufficient incentive to acquire the information on which prices are based, and markets would collapse)
- Bounded rationality (Simon, 1955) – given that optimization is costly and humans are naturally limited in their computational abilities, they engage in the process of satisficing
- *Rational* vs *unbeatable* markets (Statman, 2011) – are departures from EMH financially exploitable?
- *Adaptive markets hypothesis* (Lo, 2004) – investors' trial and error and natural selection, efficiency may vary

Aims of this paper

- ✓ Check whether the EMH holds in weak form

➡ 3 main types of tests →
- short term autocorrelation
- trading rules
- long term dependence

- ✓ Avoid pitfalls of first generation tests (e.g. lack of robustness, spurious results, dependence on distribution, structural breaks, all-or-nothing hypotheses, lack of statistical or concrete significance)

- ✓ What are the advantages brought by modern EMH tests?
- ✓ Do departures from EMH exist and if so, can investors obtain consistent excess returns from them?
- ✓ Does market efficiency evolve over time?
- ✓ Can this evolution be explained by financial/behavioural theory and economic cycles?

- ✓ Data source: daily returns extracted from Reuters database
- ✓ Overall periods: 23.09.1997-26.04.2013 for the BET index, 21.04.1998-26.04.2013 for the BET-C index, 21.09.2006-26.04.2013 for 13 blue chip shares listed on the BSE

Short term autocorrelation tests

- Random walk theory: $VR(k) = \frac{\sigma^2(k)}{\sigma^2(1)} = 1, \forall k$, where $\sigma^2(k) = \frac{1}{T}\sum_{t=k}^{T}\frac{1}{k}(r_t + \cdots + r_{t-k+1} - k\mu)^2$

  $VR(k) < 1$: mean reversion, negative autocorrelation

  $VR(k) > 1$: mean aversion, positive autocorrelation, persistence

- **Automatic Variance Ratio test with wild bootstrap** (Choi, 1999; Kim *et al.*, 2011) advantages:

  (1) data-dependent method of choosing the optimal lag

  (2) re-sampling of data in order to deal with unknown forms of heteroskedasticity

  (3) improved small sample performance

- **Rank and sign tests** (Wright, 2000) advantages:

  (1) avoid the failure of asymptotic tests on too small/non-normal data samples

  (2) non-parametric -> not affected by heteroskedasticity

- **Automatic Portmanteau test** (Escanciano and Lobato, 2009; Kim *et al.*, 2011) advantages:

  (1) data-dependent method of choosing the optimal lag (info criterion)

  (2) robust to heteroskedasticity of unknown form

  (3) no need for wild bootstrap

- **Runs test** (Fama, 1965; Borges, 2010) advantages:

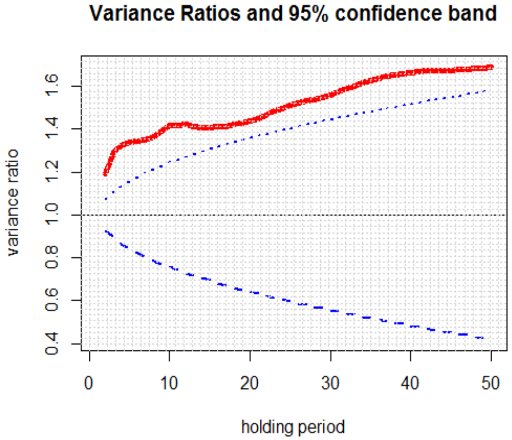
  (1) non-parametric -> not affected by heteroskedasticity

  (2) not influenced by extreme values

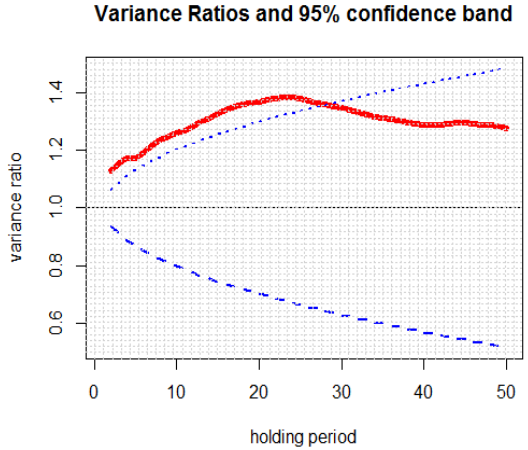
Short term autocorrelation tests

- Results of classical variance ratio test for the BET index during 5 non-overlapping periods

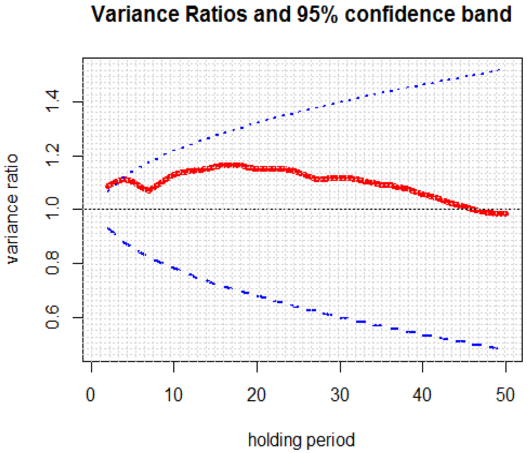
1. 23.09.1997-28.08.2000



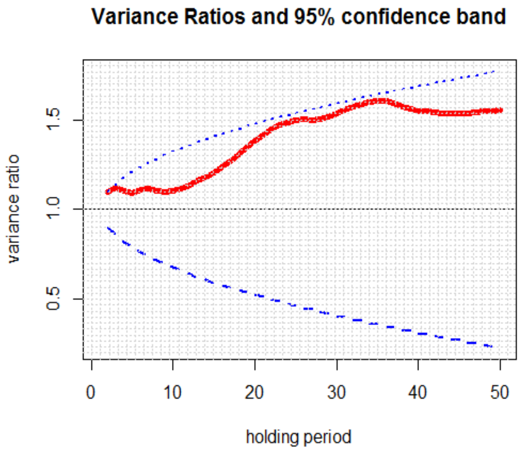
2. 29.08.2000-24.12.2004



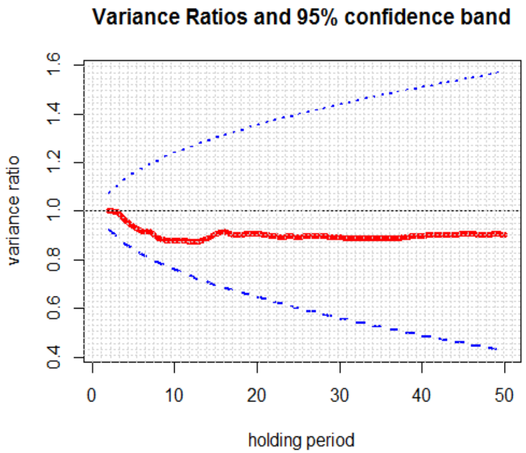
3. 03.01.2005-04.09.2008



4. 05.09.2008-03.05.2010



5. 04.05.2010-26.04.2013



Short term autocorrelation tests

- Results for both market indices and selected shares show an improvement in short-term efficiency, from positive autocorrelation to independence
- The cases where autocorrelation was detected at a p-value of below 5% are marked in bold red

Index	BET index					BET-C index				
Period	1. 23.09.1997-28.08.2000	2. 29.08.2000-24.12.2004	3. 03.01.2005-04.09.2008	4. 05.09.2008-03.05.2010	5. 04.05.2010-26.04.2013	1. 21.04.1998-28.08.2000	2. 29.08.2000-24.12.2004	3. 03.01.2005-04.09.2008	4. 05.09.2008-03.05.2010	5. 04.05.2010-26.04.2013
No. of observations	739	1071	920	412	757	601	1071	920	412	757
Ljung Box statistic	**44.67**	**35.78**	**34.45**	28.99	**32.11**	**87.97**	**75.37**	**41.34**	**35.15**	**34.86**
Breusch Godfrey Statistic	**45.80**	**51.29**	**33.71**	27.62	29.94	**95.13**	**81.75**	**40.39**	30.28	**34.87**
Automatic Portmanteau Test statistic	**7.60**	**8.09**	3.80	1.68	0.00	**20.84**	**21.02**	**5.37**	2.67	0.15
Automatic VR test with wild bootstrapping statistic	**4.56**	**3.21**	**2.18**	1.28	-0.01	**6.84**	**6.15**	**2.89**	1.73	0.89
Wright's test -rank statistic	**8.94**	**4.76**	**3.72**	2.14	1.72	**9.86**	**6.13**	**4.13**	2.79	1.40
Wright's test -rank score statistic	**7.99**	**4.94**	**3.61**	2.21	1.55	**9.23**	**6.71**	**4.16**	2.76	1.91
Wright's test -sign statistic	**8.22**	**4.27**	1.71	1.97	1.94	**9.44**	**5.74**	**3.03**	1.78	0.25

- Runs tests render same conclusion (positively autocorrelated securities decrease from 8 to 2)
- Can an investor exploit the anomalies identified via a mechanical trading rule?

Trading rules

- ***Filter rule***: **buy** when asset price increases by x% from a recent minimum and **sell** when the price decreases by x% from a previous maximum
- ***Dual moving average rule:*** **buy** when the short term moving average increases up to reaching the long term moving average; **sell** when the STMA decreases to the level of the LTMA
- **Impact on EMH**: market predictability -> information is disseminated gradually and not instantaneously
- Checked whether trading rule returns systematically beat the buy and hold strategy (the latter involving an ownership period of 1-5 years); no short selling was allowed; compared results against 0.5% brokerage fee

Filter rule test

- Filters from 0.5% to 5%, at an increment of 0.5%
- Test statistic: $X = \overline{R_f} - \overline{R_{BH}} + \left(\frac{N_{neutral}}{N_{tot}}\right)\overline{R_{BH}} = \overline{R_f} - \left(\frac{N_f}{N_{tot}}\right)\overline{R_{BH}}$ =excess return from buy and hold
- Normalized by $\sigma_x = \sqrt{[(\frac{\sigma_{BH}^2}{N_{tot}})(\frac{N_{neutral}}{N_{tot}})(\frac{N_f}{N_{tot}})]}$ in order to apply a bilateral Z test for significance
- Intermediate filters appeared most successful overall, indifferent to BH horizon
- In at least 10 cases out of 15, the 1.5% to 3% filters rendered excess returns
- Most successful securities: BET (1.26% for 2% filter), 5 SIFs, BIO, BRD

Trading rules

Dual moving average test

- Pairs of dimensions used: 1/50, 5/50, 1/120, 5/120, 10/120, 1/250, 5/250, 10/250
- The most successful strategy (10 out of 15 securities): 10/120
- Together with the 5/120 pair, it rendered the highest returns as well
- The SIFs and the indices had the highest and most frequent excess returns (e.g. 1.42% for 10/250 for BET)

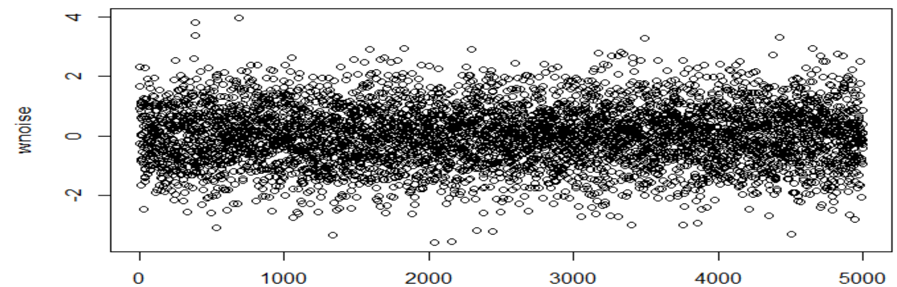
Disclaimers

- The time span analysed (September 2006 – April 2013), after an initial climb, was a fundamentally **bearish** period, with steep falls in share market prices -> even BH investors would not be willing to hold on to their securities for a long period.
- The excess returns may only prove that the filter tests fared better than the BH strategy, but do not confirm that the investor's **net wealth** has increased.
- The time series are comprised of **closing share prices**, not actual transaction costs.

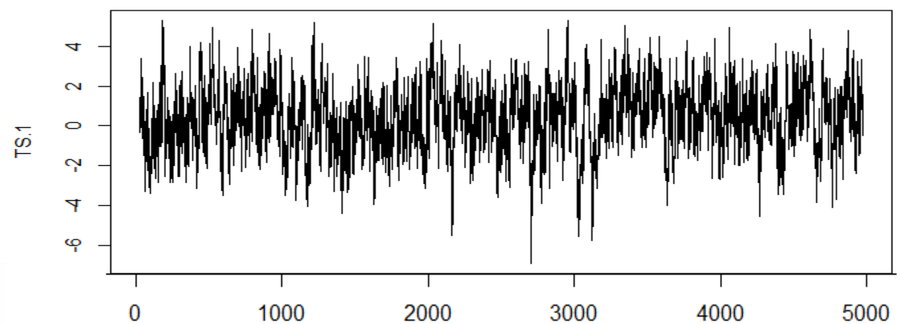
Long term dependence via the Hurst exponent

- Square root of time rule: $\sigma_t \sim t^H$
- Advantages: **(1)** robust to highly non-Gaussian series (high skewness and kurtosis);
  (2) superior method to autocorrelation tests (Monte Carlo simulations);
  (3) convergence of statistic for stochastic processes with infinite variance;
  (4) detection of non-periodical cycles, with periods equal to or greater than the sample period.

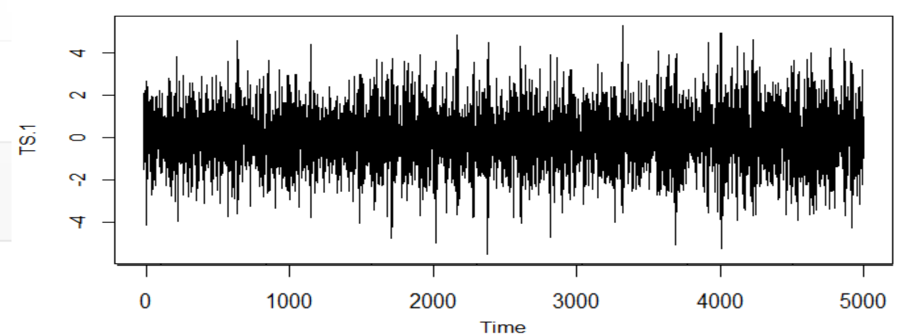
✓ **H=0.5**: *brown noise* – a random, hence efficient series



✓ **H>0.5**: *persistent or black noise* – covers a longer distance than the RW -> (1) a high value in the series will probably be followed by a high value (Joseph effect); (2) the values a long time into the future will also tend to be high (with potential catastrophic switches, or Noah effects)



✓ **H<0.5**: *antipersistent, mean reverting or pink noise* – covers a shorter distance than the RW; long term tendency to switch direction more often; a high value will probably be followed by a low value



Long term dependence via the Hurst exponent

- Rescaled range analysis: $R/S_n \sim cn^H$, where $R/S_n \equiv \frac{1}{\sigma_n}\left[\max_{1\le k\le n}\sum_{j=1}^{k}(X_j-\overline{X_n}) - \min_{1\le k\le n}\sum_{j=1}^{k}(X_j-\overline{X_n})\right]$

(range of partial sums of deviations of a time series from its mean, rescaled by its standard deviation)

- **Vulnerability of method to short term autocorrelation** – two solutions:

  (1) Lo's correction – adds q covariance lags in σ_n; for q too large, long term dependence may not be detected

  (2) data filter through an autoregressive model with stochastic volatility

  –> chose **AR(5)-Beta-t-EGARCH(1,1)** (Harvey, 2008) and computed H based on standardized series $\boldsymbol{\varepsilon_t/\sigma_t}$:

✓ $r_t = \alpha r_{t-1} + \beta r_{t-5} + y_t$

✓ $y_t = \sigma_t \varepsilon_t$, where $\sigma_t > 0$ is the scale or volatility, $\sigma_t^2 = e^{\lambda_t}$, and ε_t is *iid* and t-distributed with ν d.f.

✓ $\lambda_t = \delta + \varphi\lambda_{t-1} + ku_{t-1} + m\, sgn[-y](u_{t-1}+1)$, where $|\varphi| < 1$ is the GARCH factor, $k \neq 0$ is the ARCH factor, m>0 shows leverage, white noise $u_t \in [-1, \nu]$ is the conditional score, $u_t = \frac{(\nu+1){y_t}^2}{\nu{\sigma_t}^2} - 1$ M.D.

Advantages of model:

(1) handles excess kurtosis better – unconditional volatility is Student-t distributed;
(2) more realistic – conditional volatility is no longer a linear combination of squared observations;
(3) more resistant to extreme observations, as outliers are down-weighted;
(4) $\frac{u_t+1}{\nu+1} \sim BETA(\frac{1}{2}, \frac{\nu}{2})$ facilitates the derivation of the model's properties;
(5) the unconditional moments can be computed;
(6) handles leverage effects and asymmetry.

Long term dependence via the Hurst exponent

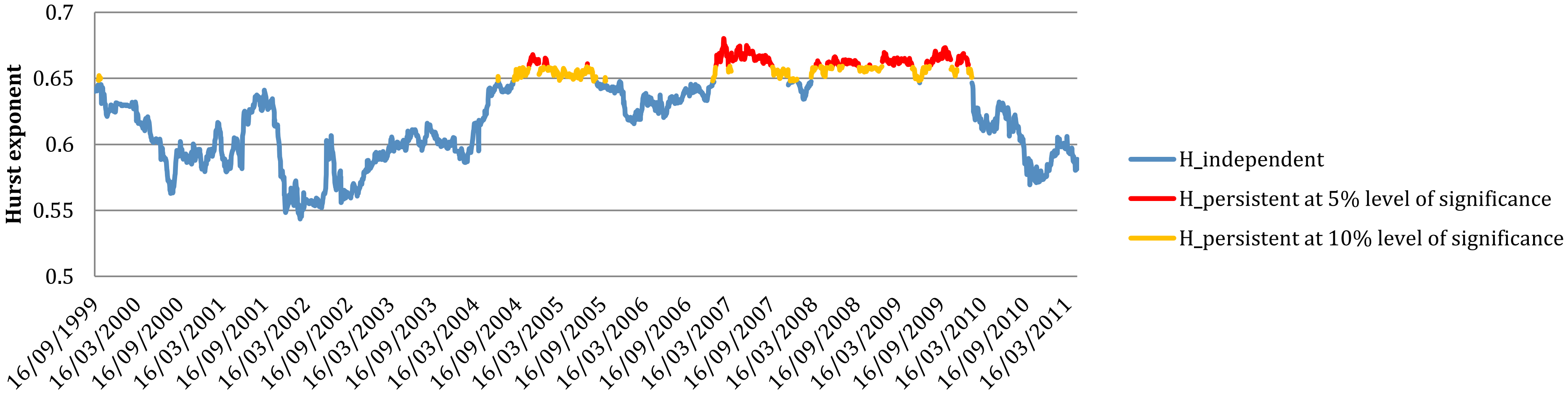
- Computed H on **rolling window samples** of 4 years to study evolution of efficiency over time (Cajueiro and Tabak, 2003)
- Used sample size-dependent statistics proposed by Couillard and Davison (2005) in order to check statistical significance
- **Overall efficiency** for all securities, except TEL and TBM (natural monopolies)
- Short term autocorrelation and heteroskedasticity are in majority ruled out, proving reliability of model

Symbol	TEL	TBM	SNP	ATB	BIO	OIL	BCC	BRD	BET	BET-C	SIF1	SIF2	SIF3	SIF4	SIF5
ARMA components (all models include Beta-t-EGARCH(1,1) component)	-	-	AR(4)	AR(1) AR(5) MA(5)	AR(1)	AR(1) AR(4) MA(4)	AR(5) MA(5)	AR(1)	AR(1) AR(5)	AR(1) AR(5)	AR(1) AR(5) MA(5)	AR(1) MA(5)	AR(1)	AR(1) MA(5)	AR(1) MA(5)
% of series with no short term autocorrelation after data filtering (Ljung Box test)	87%	70%	58%	100%	100%	100%	100%	100%	99%	97%	57%	84%	100%	100%	100%
% of series with no short term heteroskedasticity after data filtering (ARCH-LM test)	99%	100%	100%	100%	47%	61%	100%	72%	88%	65%	83%	100%	100%	100%	92%
p-value for actual H series' median = theoretical H as per Couillard & Davison	2%	3%	67%	88%	43%	23%	33%	18%	25%	20%	22%	36%	36%	82%	24%
degree of market efficiency (% of rolling window series not exhibiting persistence)	6%	32%	100%	96%	93%	99%	100%	100%	83%	69%	98%	99%	99%	100%	92%
conclusion after studying rolling window graph	Inefficient, except for current financial crisis		efficient						overall efficiency, with episodes of persistence		efficient				

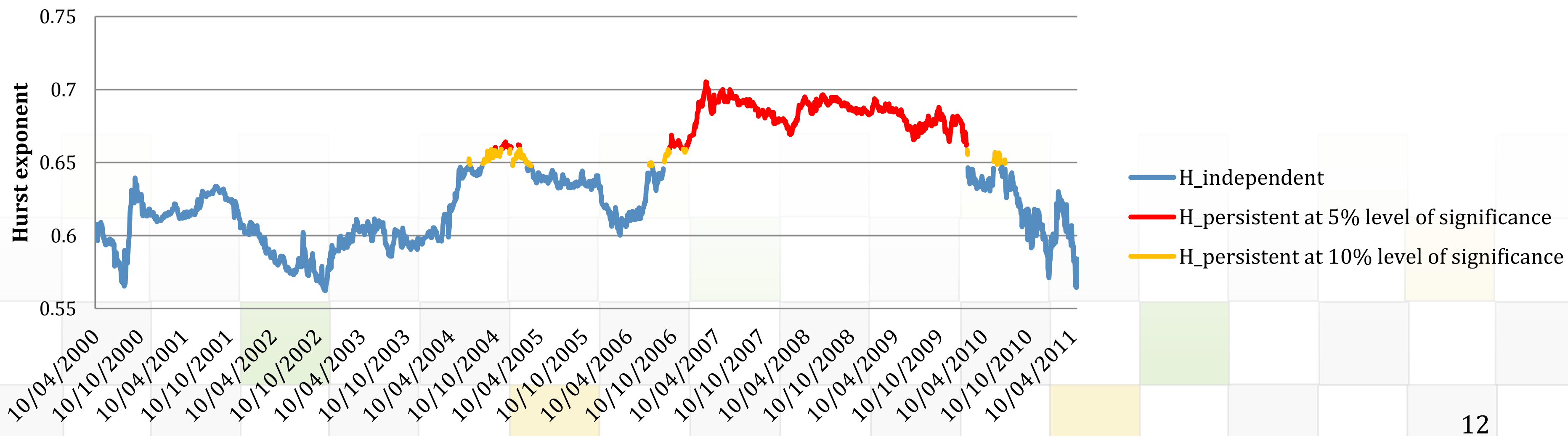
- **The market appears to have manifested persistence during the speculative boom up to the onset of the financial crisis**
- Efficient/inefficient oscillation is in line with the **Adaptive Markets Hypothesis** (Lo, 2004)
- Caveats which could lead to spurious autocorrelation: thin trading, aggregation of data, normality assumption

Long term dependence via the Hurst exponent

Hurst exponents for 4-year rolling samples with middle point dates ranging from 1999 to 2011, BET index



Hurst exponents for 4-year rolling samples with middle point dates ranging from 2000 to 2011, BET-C index



CONCLUSIONS

I. **Short term autocorrelation tests** show that **efficiency improves over time** (i.e. positive autocorrelation is identified until the debut of the current financial crisis), both at market level and for individual securities. The results are corrected for heteroskedasticity, small sample bias and structural breaks.

II. **Trading rules** – short term anomalies may be exploited to beat the market through filters and dual moving average strategies, even after deducting transaction costs; they are, however, unable to generate net welfare for investors.

III. **Long term dependence tests**

Indices: over time, oscillation between efficiency and its absence; overall efficiency; market is characterised by persistence (predictability) during the speculative bubble years (boom and subsequent burst)
Shares: mostly efficient (11 out of 13)
The results are corrected for short term heteroskedasticity and autocorrelation by applying an ARMA-Beta-t-EGARCH filter to the initial data.

IV. **Further potential research**

- ✓ Study comparability of results to other emerging markets.
- ✓ Ascertain with future data whether the Hurst exponent may actually be used to detect periods when securities take long swings from their fundamentals.
- ✓ Perform semi-strong tests (calendar and size effects, event studies, regressions on financial indicators)
- ✓ Check more ellaborate trading strategies, involving elements of behavioural finance such as investor under- or overreaction

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Thank you for your attention!
Any questions?