Minimal Spanning Trees (MST) analysis of random time series from different distributions

Ricardo Coelho

School of Physics
Trinity College Dublin

Porto, October 2006

Outline

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Introduction

Econophysics group of the Trinity College Dublin:

- Prof. Peter Richmond
- Dr. Stefan Hutzler
- Dr. Przemyslaw Repetowicz

Collaborations:

- Prof. Brian Lucey (Business School of Trinity College Dublin)
- Prof. Claire Gilmore (McGowan School of Business of King's College, Pennsylvania)

Part of this work can be found in the Physics arXiv:

`physics/0601189`

`physics/0607022`

We studied two different sets of data.

- A portfolio from the London Stock Exchange FTSE100 index:
  - 67 stocks
  - Daily closing price
  - From 2^{nd} August 1996 until 27^{th} June 2005
- Different World Indices
  - 53 countries' equity markets
  - Wednesday closing price (weekly returns)
  - From 8^{th} January 1997 until 1^{st} February 2006

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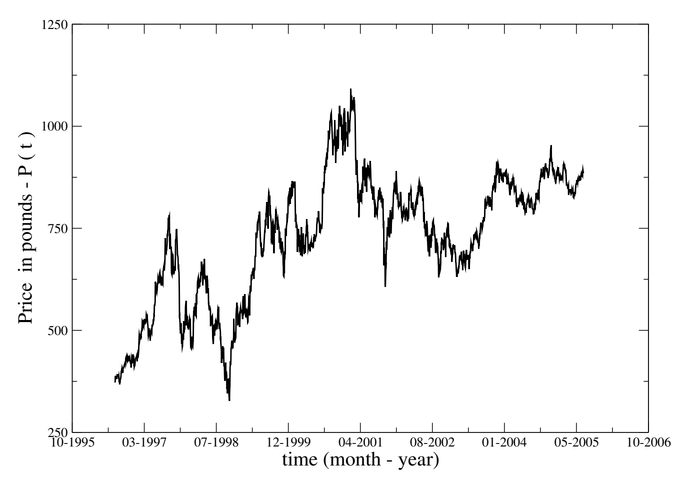
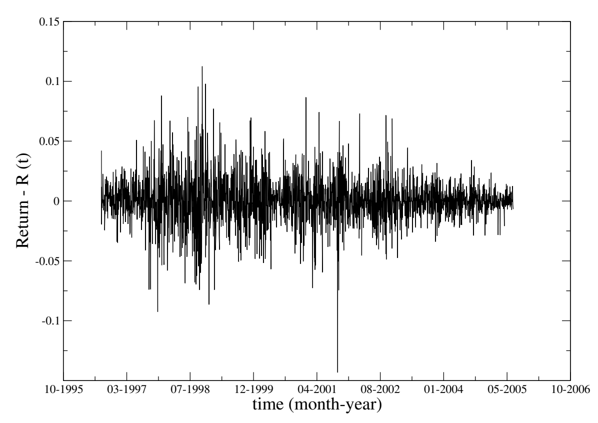
Price of a stock from the FTSE100 (HSBC)



Outline

Log-return of a stock from the FTSE100 (HSBC)

$$R_i(t) = \ln P_i(t) - \ln P_i(t-1) \quad (1)$$



Normalized return

Subtracting the mean and dividing by the standard deviation:

$$\tilde{\mathbf{R}}_i = \frac{\mathbf{R}_i - < \mathbf{R}_i >}{\sqrt{\langle \mathbf{R}_i^2 \rangle - \langle \mathbf{R}_i \rangle^2}} \quad (2)$$

Outline

Correlation between stocks i and j - $\tilde{\mathbf{R}}_i \cdot \tilde{\mathbf{R}}_j$

$$\rho_{ij} = \frac{\langle \mathbf{R}_i \mathbf{R}_j \rangle - \langle \mathbf{R}_i \rangle \langle \mathbf{R}_j \rangle}{\sqrt{\left(\langle \mathbf{R}_i^2 \rangle - \langle \mathbf{R}_i \rangle^2\right)\left(\langle \mathbf{R}_j^2 \rangle - \langle \mathbf{R}_j \rangle^2\right)}} \quad (3)$$

- $\langle \cdots \rangle$ is an average over time $\frac{1}{T}\sum_{t'=t}^{t+T-1} \cdots$, t is the first day, T is the length of our time series.
- $-1 \leq \rho_{ij} \leq 1$.
- ρ_{ij} form a symmetric $N \times N$ matrix. $\rho_{ii} = 1$.

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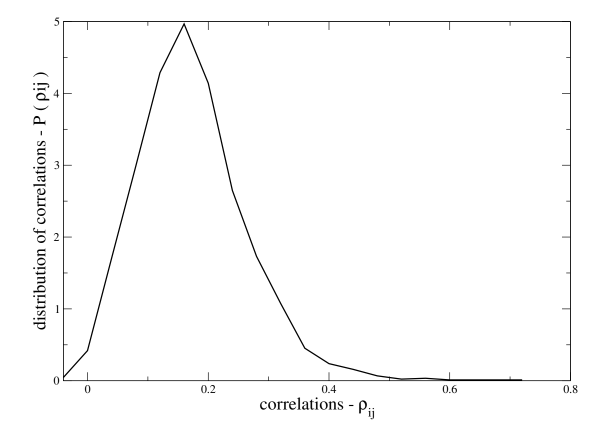
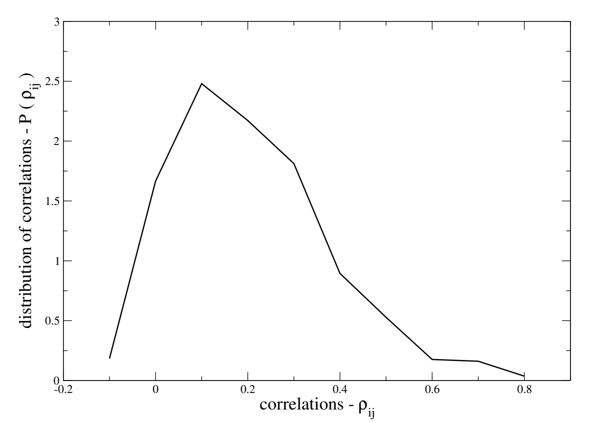
Distribution of the correlations

Full time series, $T = 2322$ days, for the FTSE100 stocks.



Distribution of the correlations

Full time series, $T = 475$ weeks, for the 53 World Indices.



Correlations in time

- With time series of $T = 2322$ days, we can divide in small windows of T' $(< T)$ days.
- T' must obbey $\frac{N}{T'} < 1$.
- For each window we calculate the correlations.

Moments of the correlations

- Mean

$$\bar{\rho} = \frac{2}{N(N-1)} \sum_{i<j} \rho_{ij} \tag{4}$$

- Variance

$$\lambda_2 = \frac{2}{N(N-1)} \sum_{i<j} (\rho_{ij} - \bar{\rho})^2 \tag{5}$$

- Skewness

$$\lambda_3 = \frac{2}{N(N-1)\lambda_2^{3/2}} \sum_{i<j} (\rho_{ij} - \bar{\rho})^3 \tag{6}$$

- Kurtosis

$$\lambda_4 = \frac{2}{N(N-1)\lambda_2^{2}} \sum_{i<j} (\rho_{ij} - \bar{\rho})^4 \tag{7}$$

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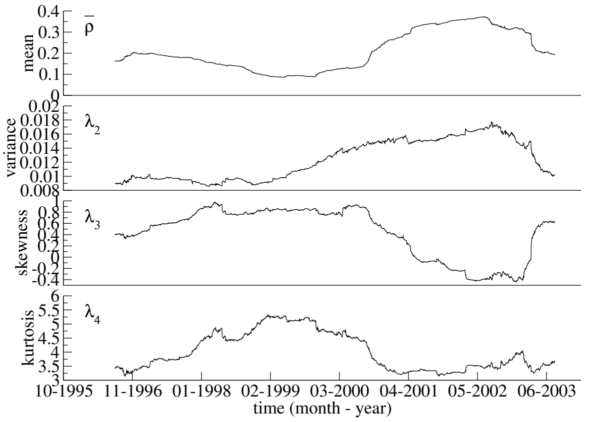
Correlations and anti-correlations between moments

FTSE100, $T = 500$ days, $\delta T = 1$ day.



Outline

Distance between stocks *i* and *j*

Metric distance, introduced by Rosario Mantegna, is determined from the Euclidean distance between vectors:

$$d_{ij} = |\tilde{\mathbf{R}}_i - \tilde{\mathbf{R}}_j| \tag{8}$$

So:

$$d_{ij}^2 = |\tilde{\mathbf{R}}_i - \tilde{\mathbf{R}}_j|^2 = |\tilde{\mathbf{R}}_i|^2 + |\tilde{\mathbf{R}}_j|^2 - 2\tilde{\mathbf{R}}_i \cdot \tilde{\mathbf{R}}_j = 2 - 2\rho_{ij} \tag{9}$$

Distance between stocks i and j

$$d_{ij} = \sqrt{2(1 - \rho_{ij})} \tag{10}$$

- $0 \leq d_{ij} \leq 2$, small values imply strong correlations.
- From distances we construct the Minimal Spanning Tree (MST).
- Analyse the properties of these networks.

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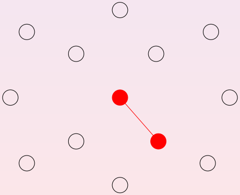
- Choose the minimum distance between 2 stocks - one link between these 2.
- Find the next minimum distance. If the 2 stocks are not linked or both linked, choose the next minimum distance. If just 1 of the stocks has already links, link them.



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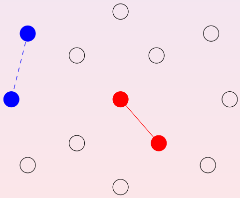

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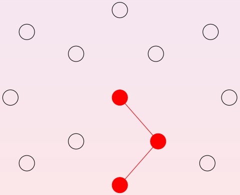

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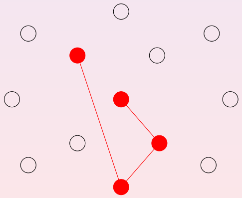

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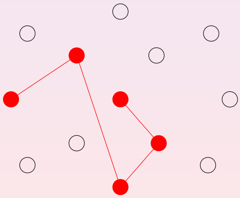

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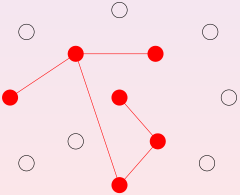

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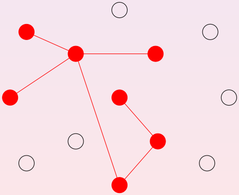

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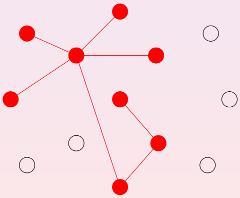

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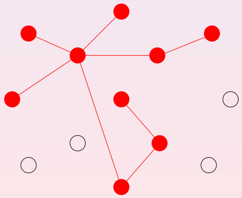

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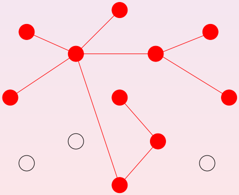

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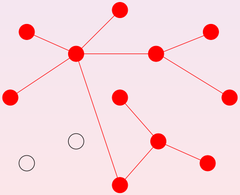

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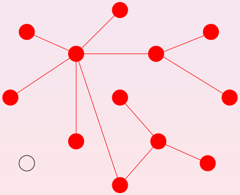

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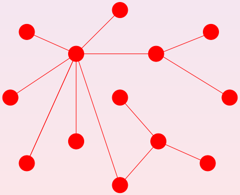

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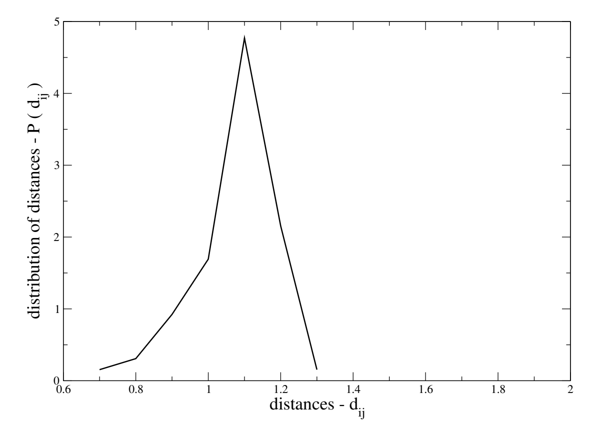

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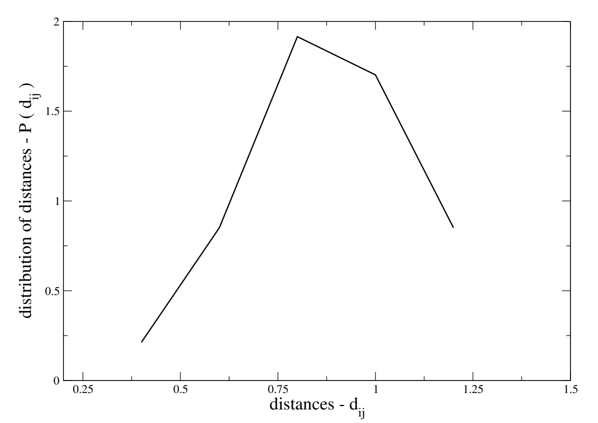
Full time series, $T = 475$ weeks, for the 53 World Indices.



Moments of the distances

- Mean

$$L = \frac{1}{N-1} \sum_{d_{ij} \in \Theta} d_{ij} \tag{11}$$

- Variance

$$\nu_2 = \frac{1}{N-1} \sum_{d_{ij} \in \Theta} (d_{ij} - L)^2 \tag{12}$$

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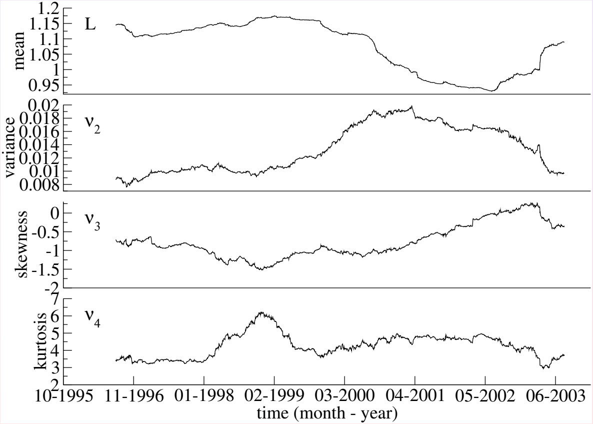

Outline

Stocks cluster in industrial sectors (ICB classification)

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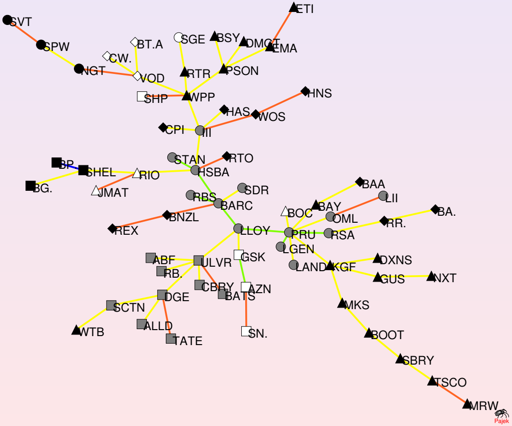
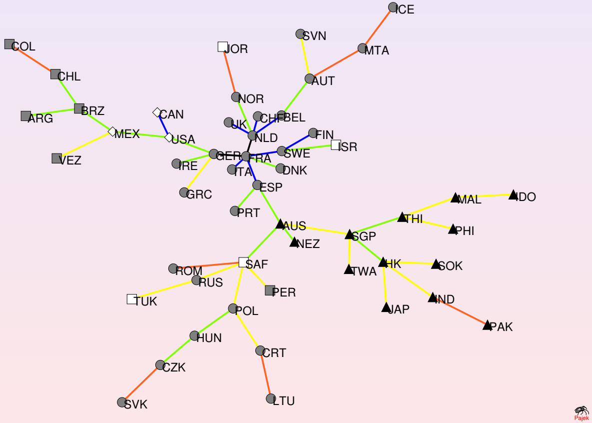


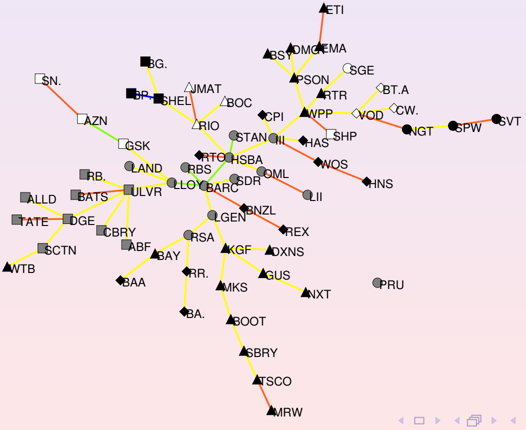
Markets organized by geographical location

Full time series, $T = 475$ weeks, for the 53 World Indices.



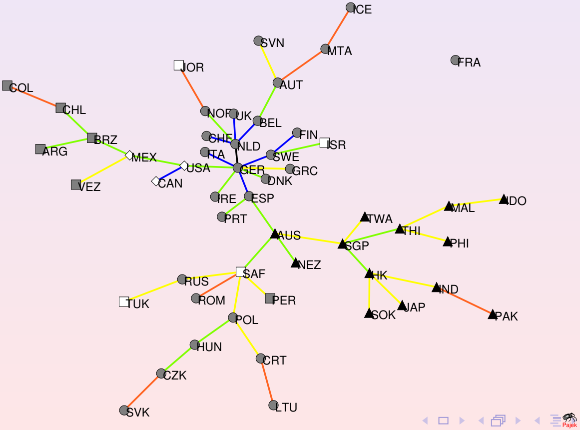
And if we take one stock out?

Full time series, $T = 2322$ days, for the FTSE100 stocks (without PRU).

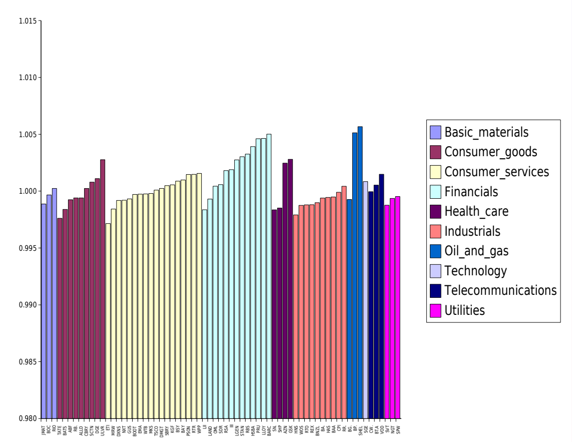


And if we take one country out?

Full time series, $T = 475$ weeks, for the 53 World Indices (without France).



Change in the Mean Length of the MST



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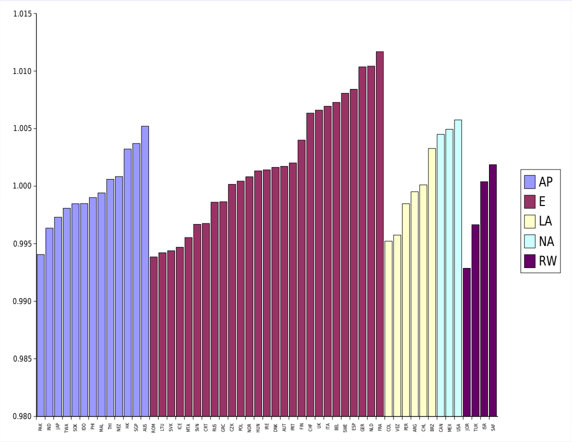

Outline

Can we mimic real MST from random data?

- Returns as random variables from a Gaussian distribution

$$r_i(t) = \epsilon_i(t) \tag{15}$$

- Returns as random variables from a T-student distribution

$$r_i(t) = \gamma_i(t) \tag{16}$$

- Returns from a *Market Model* with Gaussian noise

$$r_i(t) = \alpha_i + \beta_i R_m(t) + \epsilon_i(t) \tag{17}$$

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$$r_i(t) = \alpha_i + \beta_i R_m(t) + \epsilon_i(t) \tag{17}$$

- Returns from a *Market Model* with T-student noise

$$r_i(t) = \alpha_i + \beta_i R_m(t) + \gamma_i(t) \tag{18}$$

Can we mimic real MST from random data?

- Returns as random variables from a Gaussian distribution

$$r_i(t) = \epsilon_i(t) \tag{15}$$

- Returns as random variables from a T-student distribution

$$r_i(t) = \gamma_i(t) \tag{16}$$

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How to fit the Gaussian and T-student distributions?

- Gaussian Distribution

$$p(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{x^2}{2\sigma^2}\right) \quad (19)$$

- T-student Distribution

$$p_k(x) = \frac{\Gamma(k)}{\Gamma\left(k-\frac{1}{2}\right)} \frac{1}{\sqrt{\pi(2k-3)}\sigma} \left[1 + \frac{x^2}{\sigma^2(2k-3)}\right]^{-k} \quad (20)$$

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Parameters for the T-student, from the fractional moments

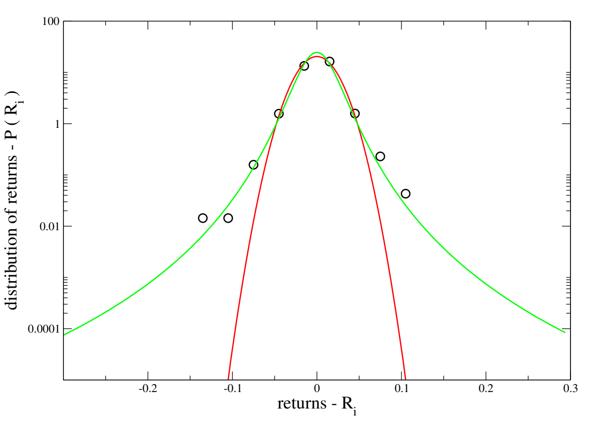
$$\frac{< S^{\frac{P}{N}-1} >}{< S^{\frac{P}{N}+1} >} = \frac{1}{(2k-3)\sigma^2}\left[(k-1)\frac{2N}{P}\right] - \frac{1}{(2k-3)\sigma^2} \tag{21}$$

- $\frac{2}{3} < \frac{P}{N} < 1$
- Linear regression give us k and σ^2:

$$k = \frac{2a-b}{2a} \tag{22}$$

$$\sigma^2 = \frac{1}{a+b} \tag{23}$$

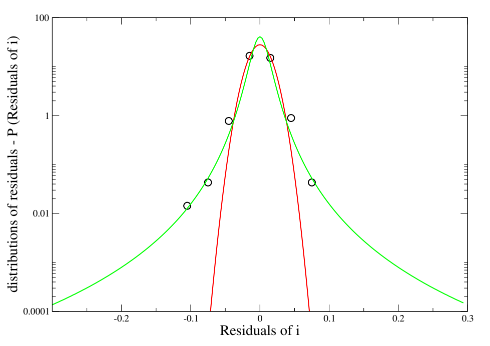
Distribution of the Log-return (HSBC)



Distribution of the Residuals (HSBC)

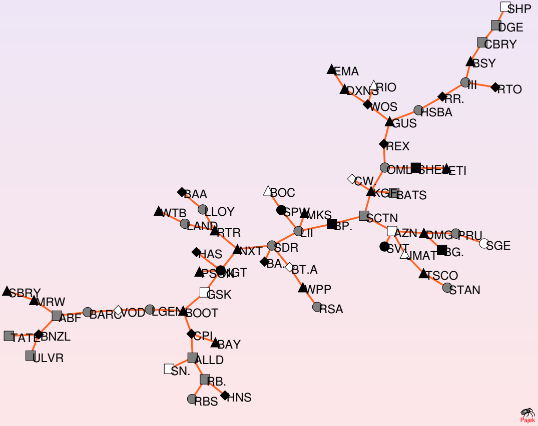
Residuals of a stock is the difference between the returns and the values estimated using the *Market Model*:

$$Res_i(t) = R_i(t) - \alpha_i - \beta_i R_M(t) \quad (24)$$



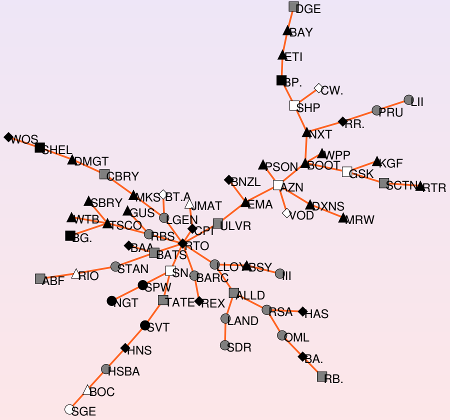
Random Model - Gaussian

Full time series, $T = 2322$ days (pseudo-FTSE100 stocks).



Random Model - T-student

Full time series, $T = 2322$ days (pseudo-FTSE100 stocks).



Market Model - Gaussian

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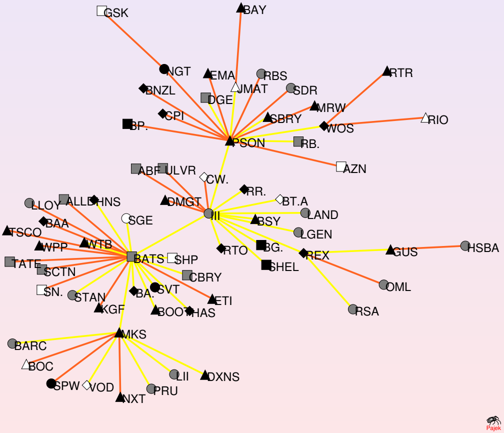

Market Model - T-student

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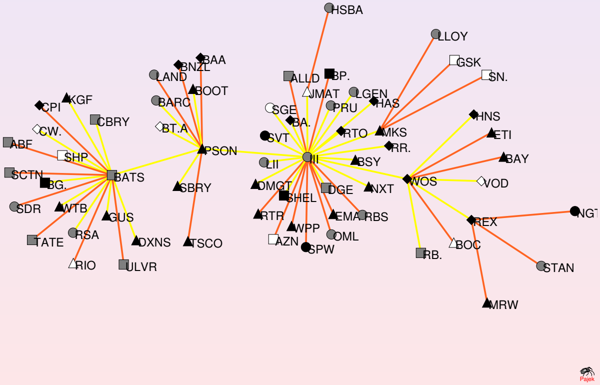
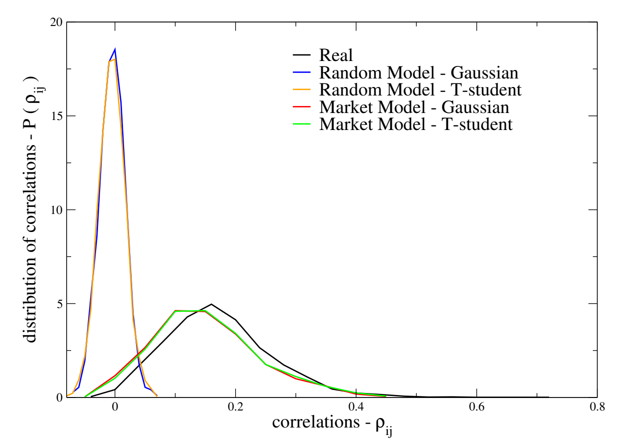
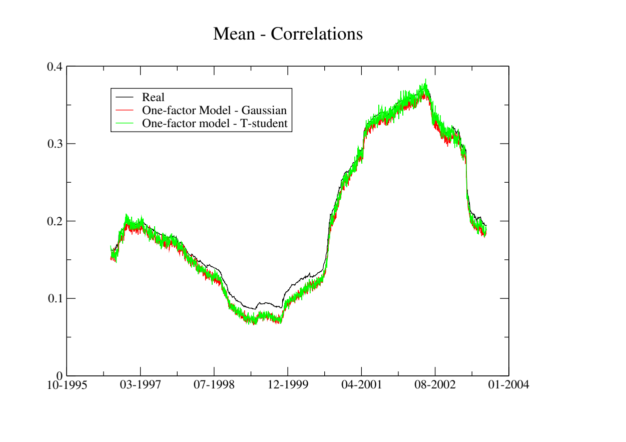


Outline

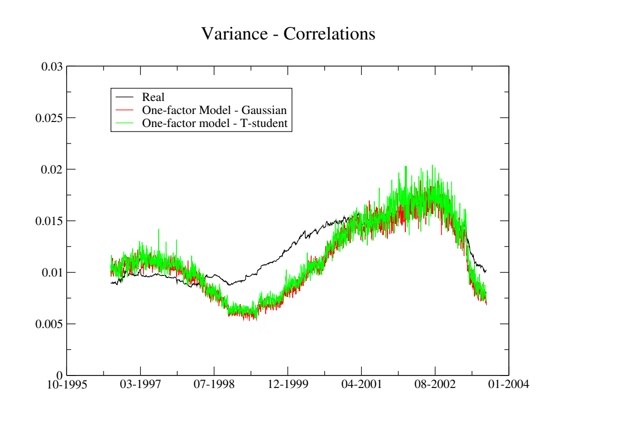
Distribution of correlations



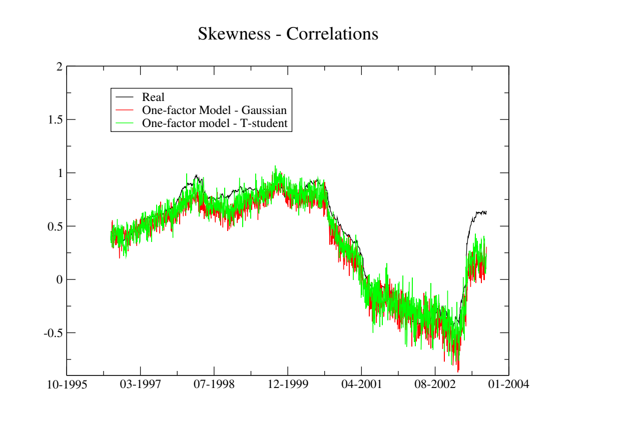
Mean correlation in time



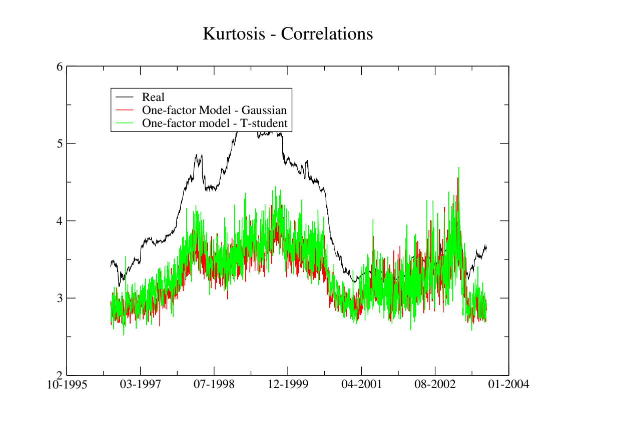
Variance of correlations in time



Skewness of correlations in time

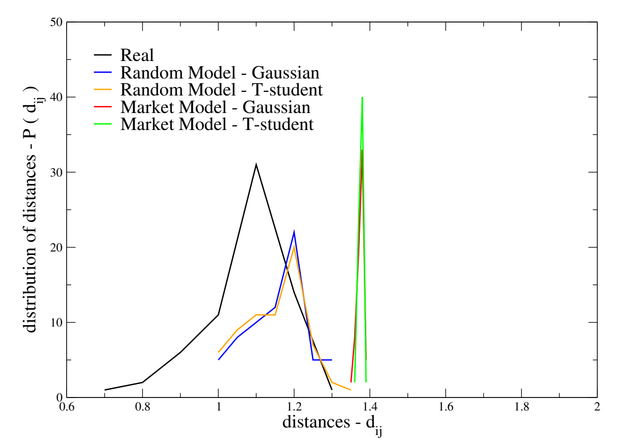


Kurtosis of correlations in time

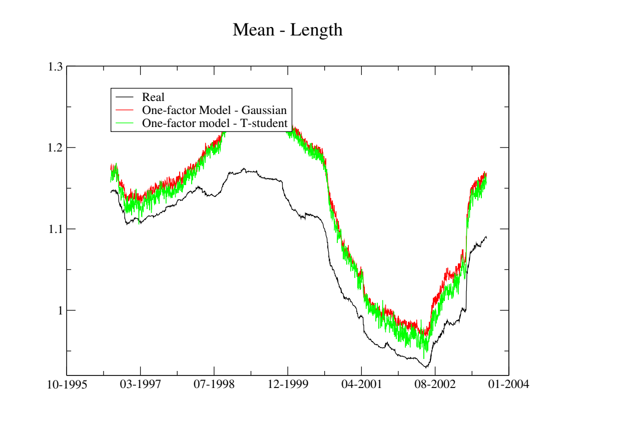


Outline

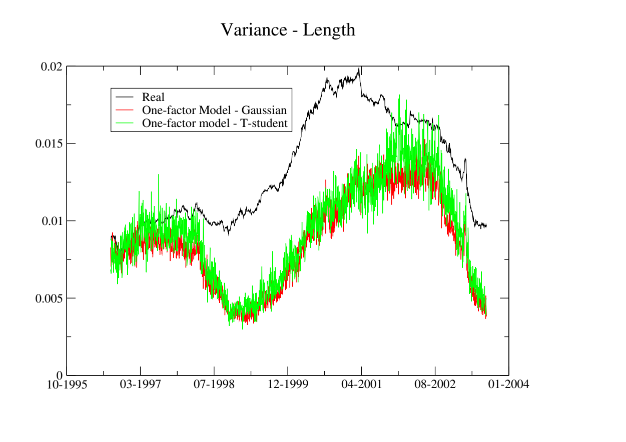
Distribution of distances



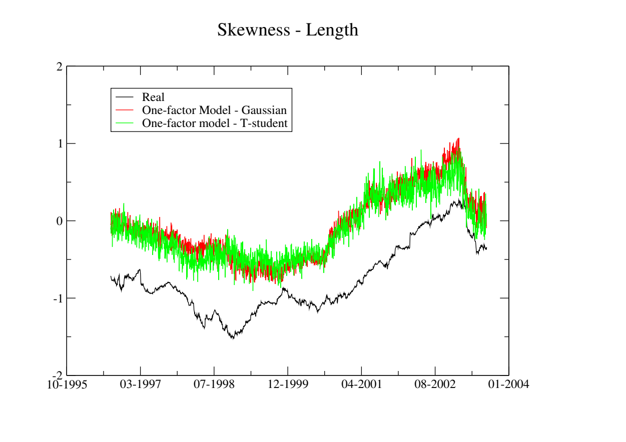
Mean distance in time



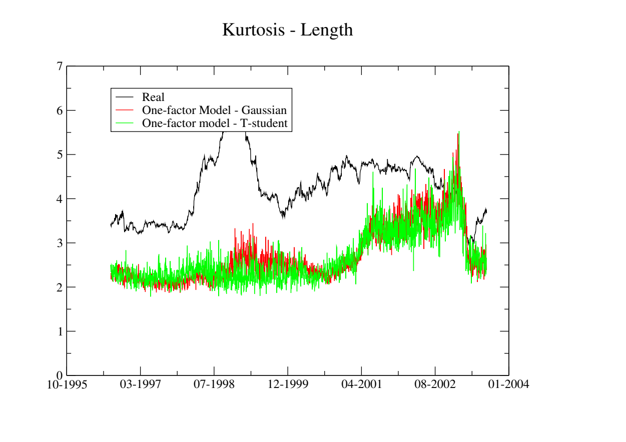
Variance of distances in time



Skewness of distances in time



Kurtosis of distances in time



Conclusions

- Similar behaviour for both the FTSE100 stocks and the World Indices:
  - Mean and variance of correlations are correlated
  - Mean and variance of distances are anti-correlated
  - MST show different clusters (Industrial sectors / Geography)
- We can mimic the moments of correlations from random time series (*Market Model*), compared with the real one.
- The moments of distances and degree (related with the MST) cannot be mimicked with these simple models.
- There is more information in these trees that we should study ...

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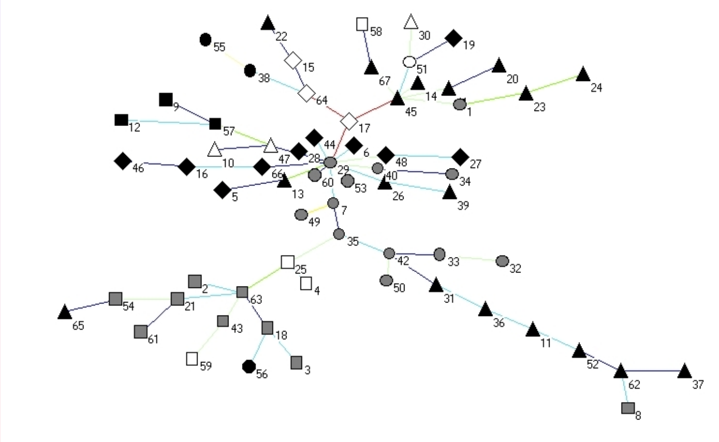
Future work ... (Earnings per share)



Acknowledgements

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