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Risk bubbles and market instability

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Abstract

We discuss a simple model of correlated assets capturing the feedback effects induced by portfolio investment in the covariance dynamics. This model predicts an instability when the volume of investment exceeds a critical value. Close to the critical point the model exhibits dynamical correlations very similar to those observed in real markets. Maximum likelihood estimates of the model's parameter for empirical data indeed confirms this conclusion. We show that this picture is confirmed by the empirical analysis for different choices of the time horizon.

Globalization and the informatics revolution have expanded the reach and density of financial interactions to an unprecedented extent. At the same time, the complexity of financial instruments has increased in complexity at a much faster pace than our understanding of their consequences on the collective behavior. Somewhat at odds with this, most financial instruments are designed under the assumption that market prices are exogenous processes, i.e. that individuals have no impact at all on the market. Such a price taking assumption might be a good approximation for the individual investor. But, if a particular strategy is used by many traders it will likely have a sizeable impact on the market.

Actually, the Minority Game shows that the global behavior of interacting systems such as a financial markets may change dramatically by the addition of a single agent (see 4.5.3 [1]). It also shows that the properties of financial markets would drastically change if agents accounted, even approximately, for their impact on it (see 5.2.3 in [1]). This occurs because, in the schematic picture of Minority Games, markets have a tendency to react to trading strategies in such a way as to reduce their profitability: The more speculators enter the market, the less this is predictable and the more its state is susceptible to perturbations. The point where the market becomes information-efficient is also

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the point where its susceptibility diverges, implying that the market reacts with a finite response even to infinitesimal perturbations. Interestingly, close to this point Minority Game models exhibit anomalous fluctuations phenomena [2] which bear some resemblance with the stylized facts observed in real markets[3].

We have recently shown [4] that this picture extends, qualitatively, to multi-asset markets described by a very simple model. Considerations about risk are essential in this extension [2] . One of the key functions of financial markets is indeed that of allowing companies to "trade" their risk for return, by spreading it across financial investors. Investors on their side, diversify (i.e. spread) their strategies across stocks so as to minimize risk, as postulated by portfolio optimization theory [5]. Ref. [4] discusses how the market is affected, when many agents spread their risk on the market following portfolio theory.

From the point of view of risk, the key quantity of interest is the covariance matrix of asset returns. Much attention has been recently put into the characterization of the statistical properties of the covariance matrix $\hat{C}$ (at the daily scale in most cases): The key findings are that

- The bulk of the eigenvalue distribution of $\hat{C}$ is dominated by noise and it is well described by random matrix theory [6].
- The largest eigenvalue Λ – the so-called *market mode* – is very well separated from the other eigenvalues.
- The few large eigenvalues smaller than Λ, which leak out of the noise background contain significant economic information. Indeed the taxonomy of assets built [7–10] from financial correlations alone bears remarkable similarity with a classification in economic sectors.
- market correlations also exhibit highly non-trivial dynamics: correlations "build up" as the time scale on which returns are measured increases, and they saturate for returns on the scale of some days [11,12]. Furthermore, financial correlations are persistent over time [13] and they follow recurrent patterns [10].

Fig. 1a shows the time dependence of the largest eigenvalue of (the exponentially averaged) correlation matrix of daily returns for Toronto Stock Exchange [14]. Similar behaviour has been reported earlier [15] for different markets. A closer look [4] at the data in Fig. 1 shows that fluctuations in the largest eigenvalue $\Lambda(t+1) - \Lambda(t)$ are broadly distributed, suggesting that Fig. 1a can hardly be explained entirely as the effect of few exogenous shocks.

Ref. [4] formulates the hypothesis that such non-trivial dynamics arises as a

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[2] Most models of single asset markets focus on speculation and expected return. Their generalization to many assets induces no nontrivial dynamics of correlation across assets.

consequence of the internal market dynamics. The efficiency of portfolio optimization depends on the cross correlations among the stocks the financial market is composed of. But if such optimal portfolio strategies are used by many investors, this will have a sizeable impact on the market. This affects not only price dynamics, but also the very correlations on which these strategies depend. Hence financial correlations enter into a feedback loop because they determine in part those trading strategies which contribute to the price dynamics, i.e. to the financial correlations themselves.

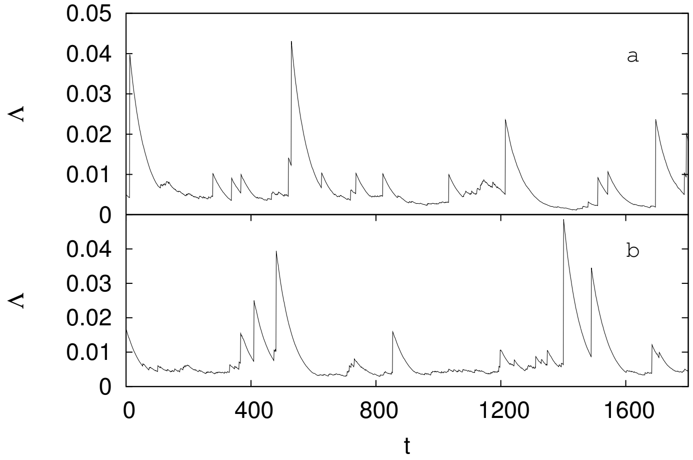

Fig. 1. Maximum eigenvalue of the correlation matrix as a function of time for $\tau = 50$. a) Toronto Stock exchange [14]. Here the correlation matrix is obtained using Eqs.(3) and (4) with $|\delta x_t\rangle$ taken from historical data. b) simulation of Eq.(1) with $N = 20$, $R = 10^{-2}$, $B = 10^{-6}$,$\Delta = 0.04$, $\epsilon = 10^{-1}$,$W = 1.4$. Components of $|b\rangle$ were generated uniformly in the interval $[0, 2 \cdot 10^{-3}]$, resulting in $W^* \approx 1.41$.

The above chain of considerations is captured by a simple phenomenological model [4] aimed at reproducing in a simple yet plausible way the interaction among assets, and the resulting correlations induced by portfolio investment. We consider a market of N assets and we denote by $|x_t\rangle$ the vector of log-prices[16] in day t. This undergoes the dynamics

$$|x_{t+1}\rangle = |x_t\rangle + |\beta_t\rangle + \xi_t|z_t\rangle. \tag{1}$$

where $|\beta_t\rangle$ is the vector of *bare* returns, i.e. it describes the fundamental economic processes which drive the prices. This is assumed to be a Gaussian random vector with $E[|\beta_t\rangle] = |b\rangle$, $E[|\beta_t\rangle\langle\beta_{t'}|] = |b\rangle\langle b| + \hat{B}\delta_{t,t'}$, where $|b\rangle$ and $\hat{B}$ are parameters describing the “bare” economic correlations. The last term in Eq. (1) describes the component of trading activity along Markovitz's optimal portfolio. ξ_t is an independent Gaussian variable with mean ϵ and variance Δ and $|z_t\rangle$ is the optimal portfolio with fixed return R and total wealth $\langle z|1\rangle = W$. In other words, $|z_t\rangle$ is the solution of

$$\min_{|z\rangle,\nu,\sigma}\left[\frac{1}{2}\langle z|\hat{C}_t|z\rangle - \nu\left(\langle z|r_t\rangle - R\right) - \sigma\left(\langle z|1\rangle - W\right)\right] \quad (2)$$

where $\hat{C}_t$ is the correlation matrix at time t. Both the expected returns $|r_t\rangle$ and the correlation matrix $\hat{C}_t$, which enter Eq. (2), are computed from historical data over a characteristic time τ:

$$|r_t\rangle = (e^{\frac{1}{\tau}} - 1)\sum_{t'<t} e^{-\frac{t-t'}{\tau}}|\delta x_t\rangle \quad (3)$$

$$\hat{C}_t = (e^{\frac{1}{\tau}} - 1)\sum_{t'<t} e^{-\frac{t-t'}{\tau}}|\delta x_t\rangle\langle\delta x_t| - |r_t\rangle\langle r_t| \quad (4)$$

where $|\delta x_t\rangle \equiv |x_t\rangle - |x_t - 1\rangle$. This makes the set of equations above a self-contained dynamical stochastic system. In a nutshell, it describes in a simple way how the economic bare correlated fluctuations $|\beta_t\rangle$ are *dressed* by financial investment. Note that:

- the optimal portfolio is usually computed from the *expected* covariance and returns. The model assumes that one can use historical covariance and returns as a proxy for expected ones
- traders have different time horizons in the market whereas the model assumes that all investors have the same trading horizon τ
- a simple linear impact function for the price dynamics is assumed
- a dependence on $|\delta z_t\rangle = |z_t\rangle - |z_{t-1}\rangle$ can also be envisaged. Indeed, one may think that Eq. (1) contains just the first term in an expansion in time derivatives of $|z_t\rangle$. The rationale for neglecting these terms is that they are less relevant with respect to the $|z_t\rangle$ term, as far as the low frequency behavior of the model is concerned
- the structure of economic correlations is neglected, i.e. $B_{i,j} = B\delta_{i,j}$. The idea behind this is that economic correlations contribute to eigenvalues which are much smaller than the market mode, and hence, to a first approximation are indistinguishable from the noise band. At any rate, economic correlations are expected to change over time scales much longer than those over which the market mode fluctuates. This means that it is unlikely that they contribute in any appreciable way to the dynamics observed in Fig. 1.
- one can consider several component $|z_t^k\rangle$ of portfolio investors, each with a different parameters R^k, ϵ^k and Δ^k. This model can be reduced to the one above, with effective parameters $\tilde{R}$, $\tilde{\epsilon}$ and $\tilde{\Delta}$
- $|z_t\rangle$ is a quantity, not a percentage as in portfolio theory [5].

Numerical simulations of the model show a very interesting behaviour. In Fig 1b we plot the temporal evolution of the maximum eigenvalue Λ of the correlation matrix for a particular choice of parameters. The dynamics is highly non-trivial, with the appearance of instabilities resembling those observed in real markets (Fig. 1a). In addition, the statistics of the day-to-day differences in Λ show a clear power-law behaviour, again very similar to the one we get for real markets.

In the limit $\tau \to \infty$, where correlations and returns are computed averaging over an infinite time period, the model can be solved analytically [4]. One finds a singular behavior of Λ when the volume W of investment in portfolio strategies reaches a critical value W^*. Indeed as $W \to W^*$ the solution develops a singularity with infinite slope $\frac{\partial \Lambda}{\partial W} \to \infty$. This is reminiscent of the divergence of susceptibility χ close to a phase transition, signalling that the response $\delta\Lambda = \chi \delta W$ to a small perturbation δW diverges as $W \to W^*$. A static solution ceases to exist in the $\tau \to \infty$ limit for $W > W^*$. This can be seen from a simple geometric argument: For $\epsilon = 0$ the two constraints $\langle z|1\rangle = W$ and $\langle z|r\rangle = R$ are hyper-planes in the $|z\rangle$ space, hence a solution exists for all W and R. With $\epsilon \neq 0$, the constraint $\langle z|r\rangle = R$ becomes a hyper-sphere hence, solutions are possible only for $W < W^*$.

Numerical simulations show that W^* represents a threshold to the amount of wealth that can be invested by risk-minimization into a market without destabilizing it. This is clearly seen in Fig. 2 where we report Λ_t as a function of time for values of W approaching W^*. Within the picture offered by the this simple model, Fig. 1 suggests that real markets might be close to the critical point W^*. This has been checked [4] by fitting real market data [14] with a maximum likelihood method. The whole method was checked to reproduce the correct parameters on synthetic data set generated from the model itself.

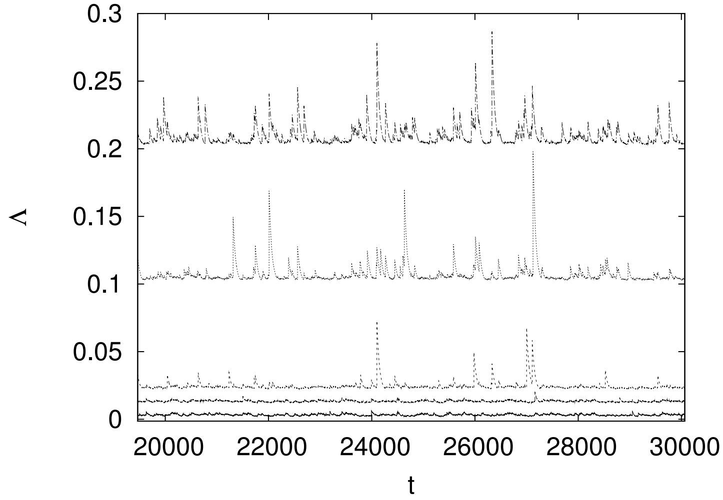

Fig. 2. Maximum eigenvalue of $\hat{C}$ as a function of time for different values of W ($W = 1.2,\ 1.32,\ 1.42$ and 1.48 from bottom to top) and the same parameters as in Fig. 1 ($W^* \approx 1.42$). Curves are shifted upwards for clarity.

Here we focus on the stability of the results as a function of the time scales used. Indeed, Ref. [4] assumes that the parameters of the model vary slowly on time scales of order τ. We repeated the fitting procedure for different values of

τ on different time windows of $T = 500$ days. Fig. 3 shows the results for the Dow Jones and the Toronto stock exchange indices. Each window is shifted by 50 days with respect to the previous one, so the data covers approximately 4 years (in order to compute the initial condition for $\hat{C}_t$, we used data for 1000 more days). In this time period (1997-2005), no major crashes or structural changes occurred in these markets. The same cannot be said of European markets, because of the introduction of the Euro.

The main figure shows that parameters exhibit some fluctuations but are roughly constant over a long time horizon (the longer time series of the Dow Jones actually displays a very slow convergence to W^* in time). The parameters are also stable with respect to changes in τ. The inset shows the location of the fitted parameters with respect to critical point. Results for the same market cluster in the same region for different values of τ.

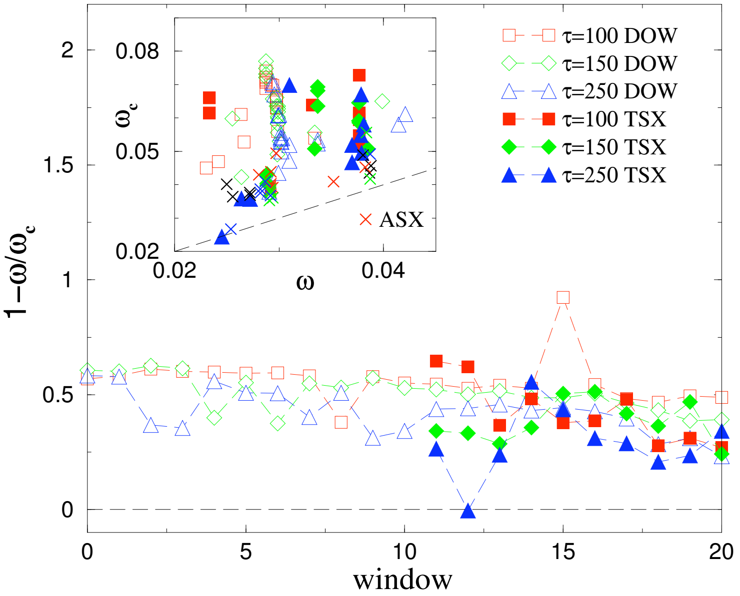

Fig. 3. Fitted values of the parameters $\omega = \epsilon W$ and $\omega_c = \epsilon W^*$ for successive time windows of $T = 500$ points $\tau = 100, 150$ and 250 and different markets (DJ, TSX, ASX). The main figure shows the distance from the critical point as a function of time. The time window is shifted by 50 days for each point. Inset: ω_c vs ω for the same data sets.

Our model is very stylized and it fails to capture many important aspects. For example, it is undeniable that external factors and global events have an effect on financial markets. Still it reproduces key empirical features of real financial markets thus suggesting that it captures essential dynamical features of markets. This suggests that the impact of optimal portfolio investment is a potential cause of instability. Non-stationary correlations close to the instability can be considered as an additional component of risk resulting from the enhanced susceptibility of the market. Such "market impact" risk arises because investment according to an optimal portfolio strategy changes the structure of correlations with which that strategy was computed. This component of risk diverges as the market approaches the critical point W^*, thus discouraging further investment. This provides a simple rationale for why markets "self-organize" close to the critical point, which is somewhat reminiscent of the picture which Minority Games [1] provide of single asset markets. The idea is that the market attracts investors as long as it provides efficient ways of diversifying risk. This increases the volume (W) of investment up to the point where the risk measure changes thus turning optimal portfolio strategies into sub-optimal ones.

This is a further case where, when the density of interactions increases, the system approaches a critical state where individual actions might propagate through the system in an unpredictable manner [17]. In such systems, actions might be so remotely related to their ultimate consequences to make even the most sophisticated optimizing behavior or design chimerical.

References

[1] Challet D., Marsili M. and Zhang Y-C. *Minority Games. Interacting agents in financial markets* Oxford University Press (Oxford, 2004)

[2] Challet D. and Marsili M. Phys. Rev. E **68** (3) 036132 (2003)

[3] J.-P. Bouchaud and M. Potters *Theory of financial risk and derivative pricing: from statistical physics to risk management* (Cambridge University Press, Cambridge, 2003); R. Mantegna and E. Stanley, *Introduction to Econophysics* (Cambridge University Press, 1999).

[4] G. Raffaelli and M. Marsili, eprint `physics/0508159`.

[5] Elton E.J. and Gruber M.J., *Modern Portfolio theory and investment analysis* (J. Wiley & sons, New York, 1995).

[6] Laloux L, Cizeau P, Bouchaud JP, Potters M Phys. Rev. Lett. **83** (7) 1467-1470 (1999) and Plerou V, Gopikrishnan P, Rosenow B, Amaral LAN, Stanley HE Phys. Rev. Lett. **83** (7) 1471-1474 (1999)

[7] Bonanno G, Caldarelli G, Lillo F, Mantegna RN, Phys. Rev. E **68** 4, 046130 (2003)

[8] Plerou V, Gopikrishnan P, Rosenow B, Amaral N.A.N. and Stanley H.E., Phys. Rev. Lett. **83** (7) 1471-1474 (1999).

[9] Giada L. and Marsili M. Phys. Rev. E **63** (6) 061101 (2001)

[10] Marsili M. Quant. Fin. **2** 297-302 (2002)

[11] Kwapien J, Drodz S. and Speth J, Phys. A **330** (3-4) 605-621 (2003)

[12] Potters M. , Bouchaud J.P. and Laloux L., cond-mat/0507111

[13] Onnela JP, Chakraborti A, Kaski K, Kertesz J, Kanto A, Phys. Rev. E **68** (5) 056110 (2003)

[14] Data was taken form `finance.yahoo.com` in the time period June 16th 1997 to May 25th 2005 for all assets except for the Dow Jones, for which we used May 2nd 1995 to May 23rd 2005. Correlations were measured on the set of assets composing the index at the final date.

[15] Drodz S, Kwapien J, Grummer F, Ruf F and Speth J, Phys. A **299** (1-2), 144-153 (2001) and Drodz S, Grummer F, Ruf F and Speth J, Phys. A **294** (1-2), 226-234 (2001).

[16] We use Bra-ket notation: $|x\rangle$ should be considered as a column vector, whereas $\langle x|$ is a row vector. Hence $\langle x|y\rangle$ is the scalar product and $|x\rangle\langle y|$ is the direct product, i.e. the matrix with entries $a_{i,j} = x_i y_j$.

[17] G. Bianconi and M. Marsili, Phys. Rev. E **70**, 035105 (2004).

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