Do markets exhibit critical slowing down at minute-frequency?

Econophysics PY 538, Spring 2017
George A. Pantelopulos

Outline of topics

What is the Question?

- Do high frequency price jumps/crashes show Critical Slowing Down?
- Concept of Critical Slowing Down in 2D Ising Model
- Critical Slowing Down outside physics

Why is it important?

- Intra-day scale critical slowing down may be an early warning sign
- As an early warning sign, it might be acted upon

What I have done to address the question

- Identification of jumps/crashes at minute-frequency with AR(1)
- Increased standard deviations prior to jumps/crashes

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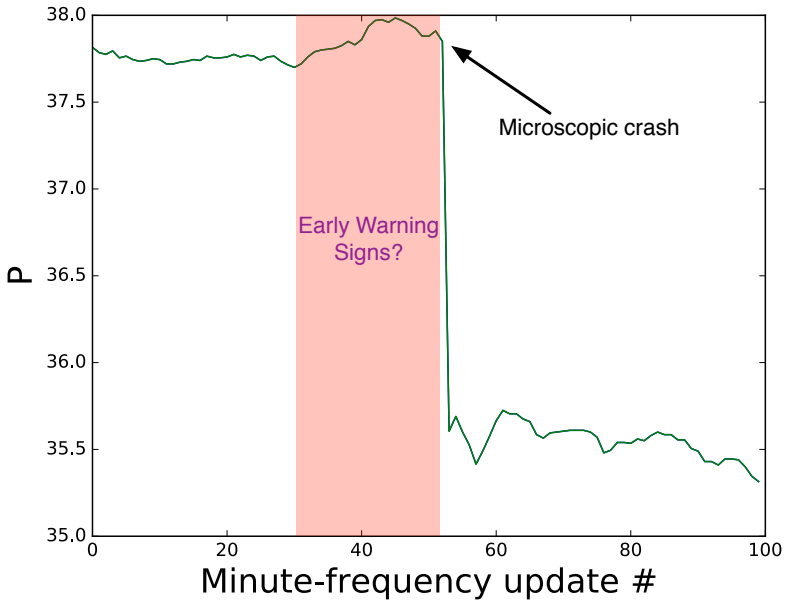
Do high frequency price jumps/crashes show Critical Slowing Down?



ProSeiben (PSM, German Market) Nov 3, 2016 11:37 - Nov 4, 2016 4:48

Concept of Critical Slowing Down in 2D Ising Model

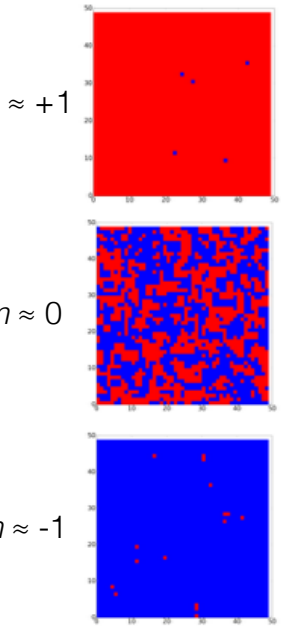
Time-dependent behavior near phase transitions were first studied in the context of physical systems, such as the 2D Ising Ferromagnet simulated using Nearest Neighbor Metropolis Monte Carlo method

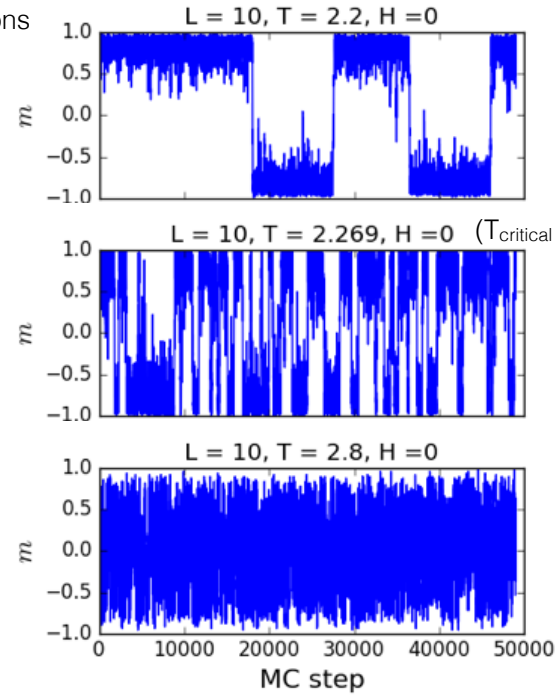
L = 50 state visualisations

$m \approx +1$

$m \approx 0$

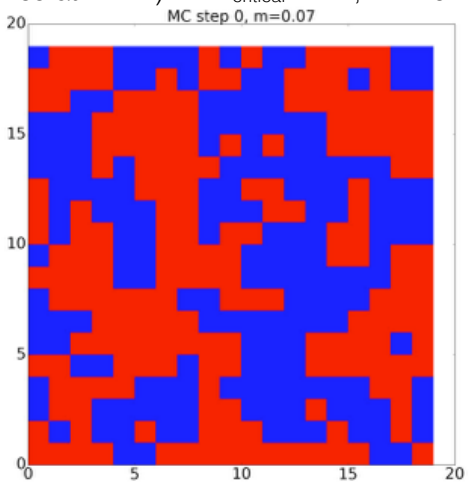
$m \approx -1$





($T_{critical} \approx 2.269$ at L = ∞)

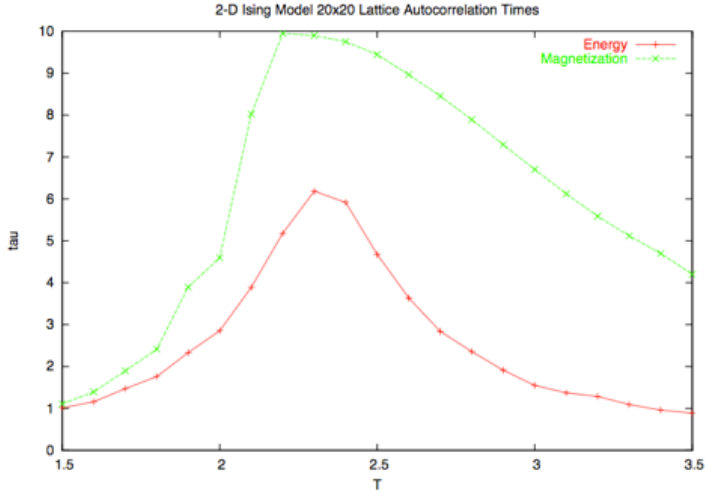
$T_{critical} \approx 2.2$, L = 20



Slowing down, simply put, is the lengthening of time it takes to relax to a sample mean.

The “slowing down” of return times to the mean near the critical point in the Metropolis MC 2D Ising Model is traditionally quantified using the integrated autocorrelation time (tau)

$$\tau = \sum_{k=0} \frac{< O_t O_{t+k} >_t - < O_t >_t^2}{< O_t^2 >_t - < O_t >_t^2}$$



http://www.physics.buffalo.edu/phy410-505/2011/topic5/app2/

This behavior in 2D Ising Model simulation can simply be captured in Lag-1 Autocorrelations!

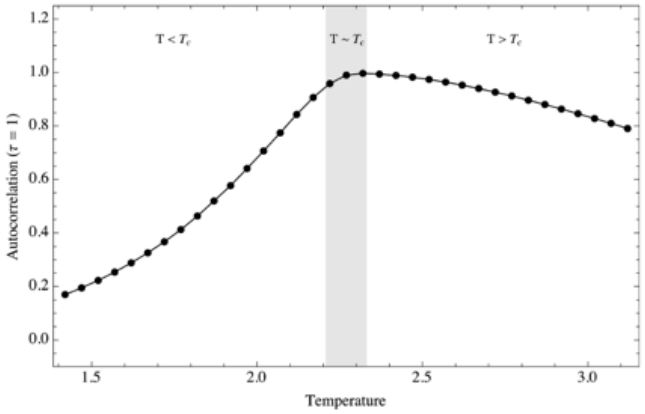


Fig: Lag-1 autocorrelation of Ising model magnetization.

O. Morales et al., Behavior of early warnings near the critical temperature in the two-dimensional Ising model. PLoS One. 10 (2015), doi:10.1371/journal.pone.0130751.

In recent years Ecology, Climate, and Medicine have observed critical slowing down in real data!

In physical models, we very often think of phase transitions dependence on temperature.

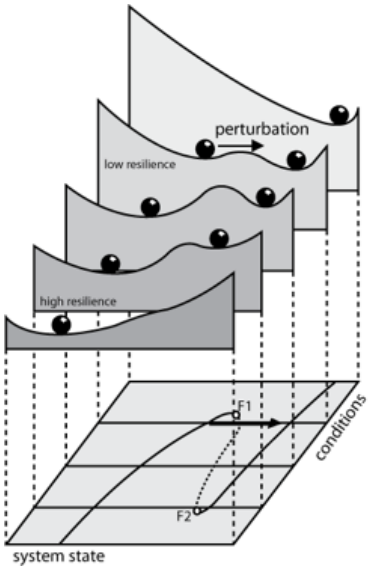
In other fields, often phase transitions are thought to be due to changes to composition of the system — these can be changes in things like size of populations (like changing density), and even changes to the composition of the system Hamiltonian!

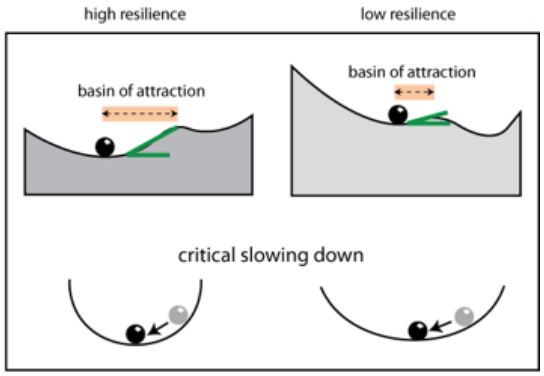
In ecology:
- Algal blooms
- Extinction

In climate:
- Ice age transitions
- Desertification

In Medicine:
- Depression
- Migraines

Very notably, experiments have demonstrated the ability to use critical slowing down to *control* the transition between states!





R. D. Batt et. al., Changes in ecosystem resilience detected in automated measures of ecosystem metabolism during a whole-lake manipulation. Proc. Natl. Acad. Sci. 110, 17398–17403 (2013).

Two simple, general tools for evaluating critical slowing down: Standard Deviation and AR(1) coefficient measured in a rolling window.

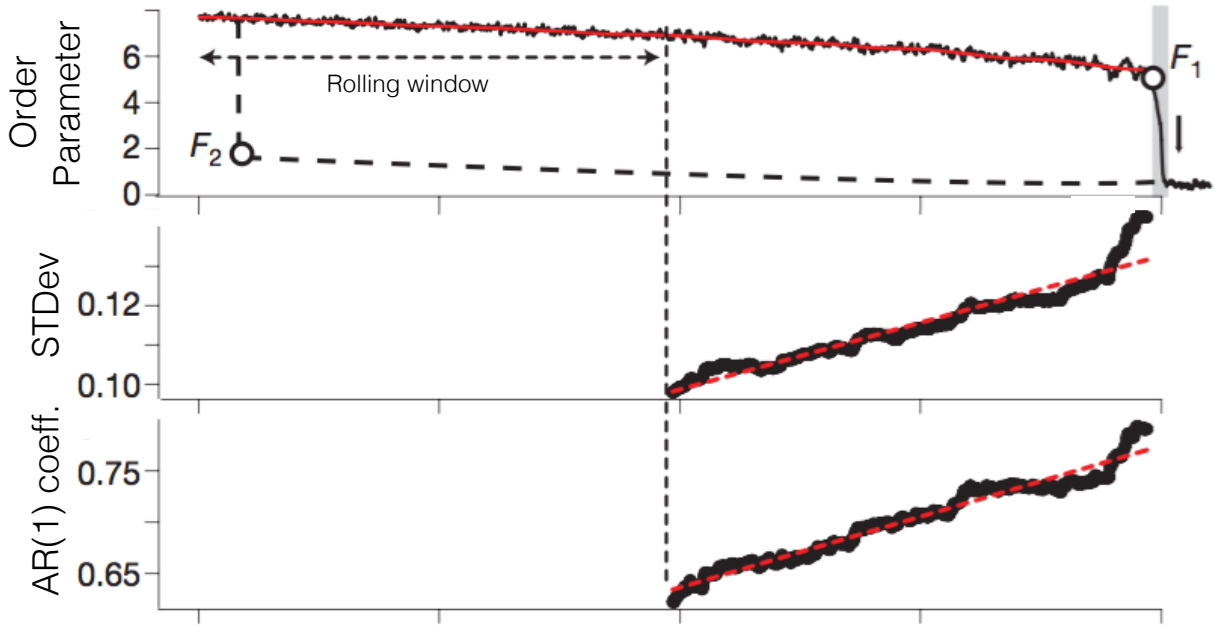


Fig: F_1 and F_2 represent bifurcation points between two states

M. Scheffer et al., Early-warning signals for critical transitions. Nature. 461, 53–59 (2009).

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Intra-day frequency critical slowing down may be an early warning sign

Very recently, work on day-frequency market prices not exhibit critical slowing down prior to market crashes… but massive crashes like this are quite possibly the result of major outside perturbations on the system, and thus may not be features of a nominally functioning, “healthy” market.

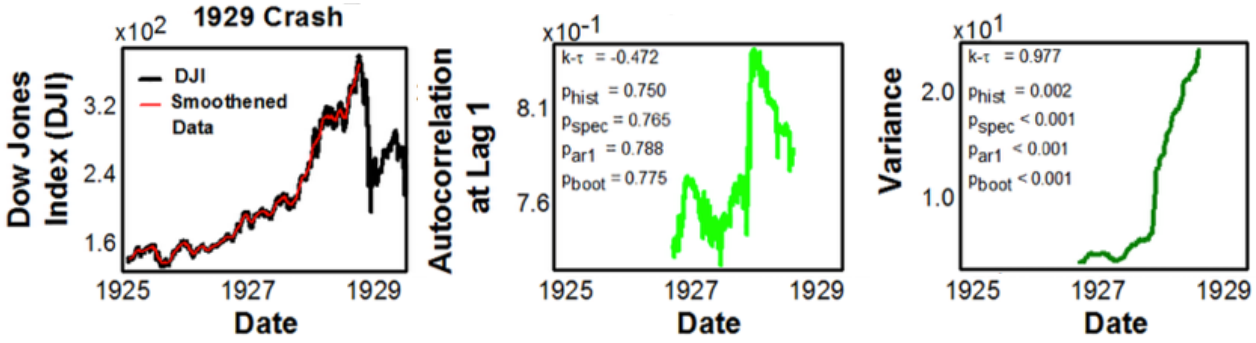


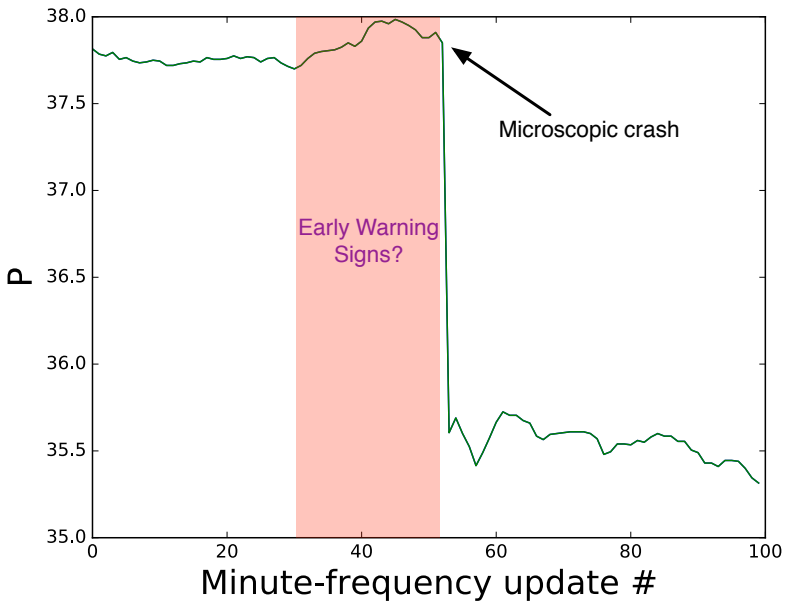
Fig: Lag-1 Autocorrelation and Variances measured using a rolling window.

Higher-frequency prices may show this behavior — a healthy market may very well be critical when examined at high frequency.

V. Guttal, S. Raghavendra, N. Goel, Q. Hoarau, Lack of critical slowing down suggests that financial meltdowns are not critical transitions, yet rising variability could signal systemic risk. PLoS One. 11, 1–20 (2016).

If critical slowing down can at minute-frequency can be identified, it may be actionable.

If the behavior of the market is constantly evaluated in a rolling window, we might see the onset of a transition and act in response.



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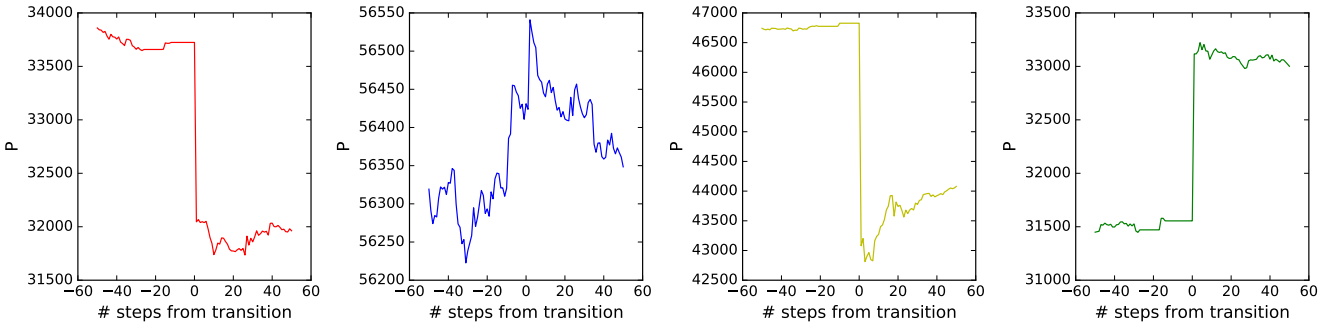
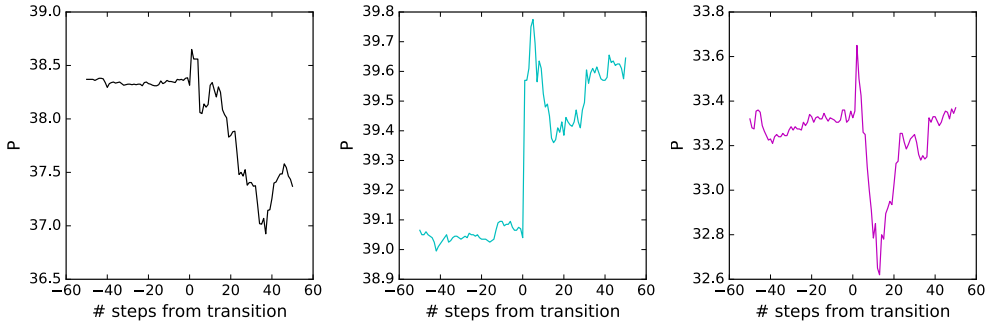
Seven clear jumps/crashes at minute-frequency are selected to test for signature of critical slowing down

Samples from the Warsaw Stock Exchange (WIG)



Samples from ProSeiben (PSM)



AR(1) coefficients of Prices prior to transitions show linear increase over several minutes prior to jumps/crashes

Lag-0 and Lag-1 prices seem to be strongly linearly related, so AR(1) models may be sufficient for fitting.

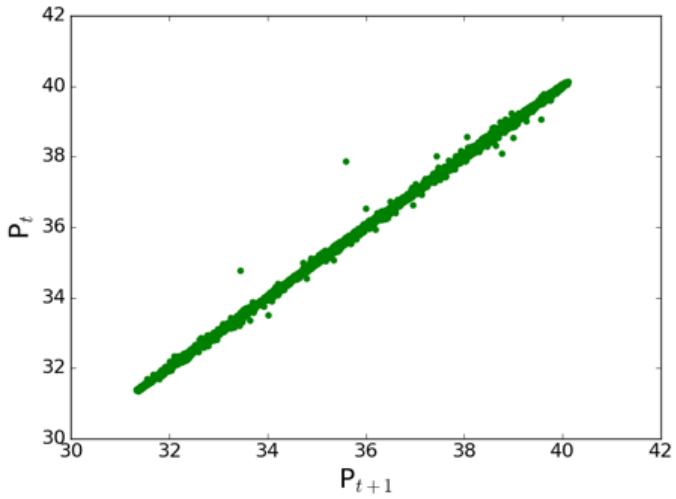


Fig: Lag-0 and Lag-1 PSM prices at minute frequency.

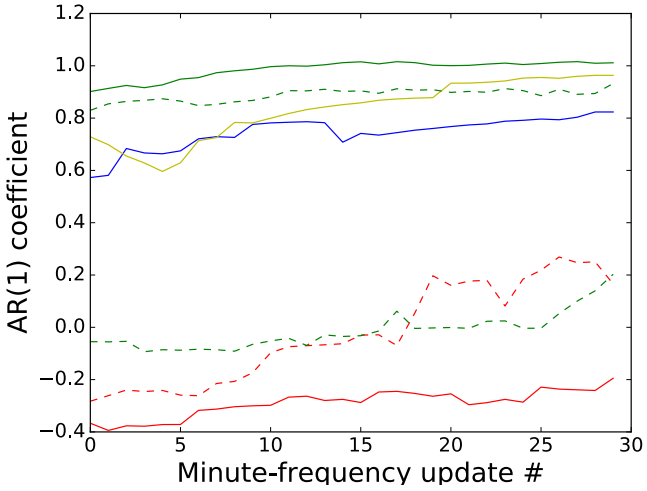


Fig: AR(1) coefficients from 50-point model fits up to the transition point.

Minute-frequency samples exhibit “slowing down” over several minutes prior to jumps/crashes

The “slowing down” of price fluctuations is quantified using a 50-point sliding window measurement of price standard deviations.

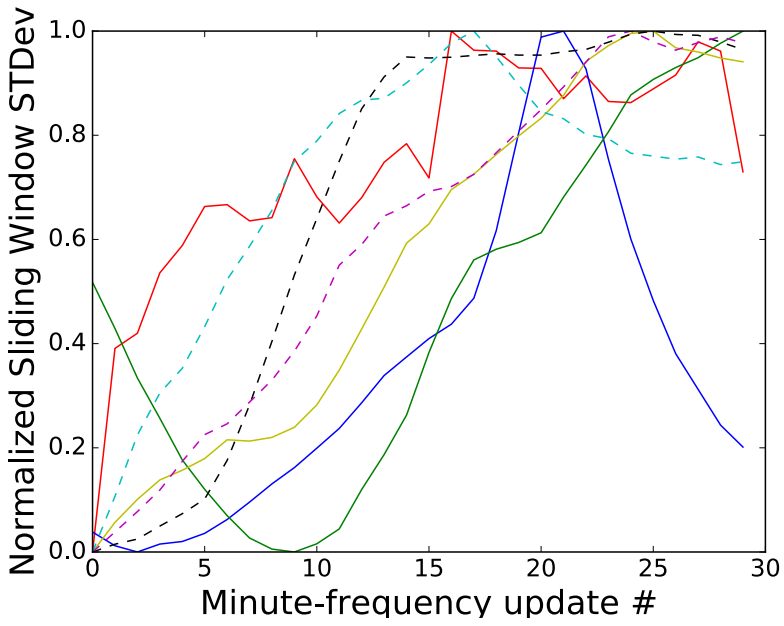


Fig: Solid (dashed) lines are from WIG (PSM) data

Tentative Conclusions

- Results suggest markets may exhibit critical slowing down at intra-day frequencies
- Substantial narrowing of a windowed distribution in real-time may serve as a critical warning sign for jumps/crashes… How to use such a tool is up for debate!

Future Work

- Systematic identification of critical points
- Careful validation of window function widths
- Get more data
- Examine data at higher frequencies