Séminare de la Chaire
Energie et Prospérité

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Dynamical Systems, Business Cycles and the Impact of Major Natural Hazards

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Please visit these sites for more info.

https://dept.atmos.ucla.edu/tcd/, http://www.environnement.ens.fr/
& https://www.researchgate.net/profile/Michael_Ghil

Motivation

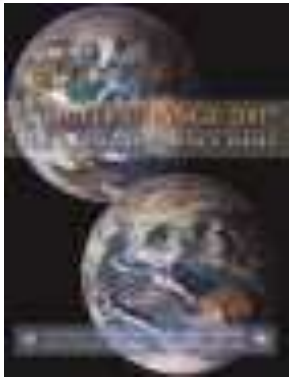
- Coupled climate and socio-economic modeling
- Coordinating EU project on extreme events
  - in the geosciences and the socio-economic sciences
- Novel tools for both data analysis and modeling
  - SSA-MTM Toolkit for time series analysis
  - key tools for nonlinear and random dynamics
  - combined modeling and data studies

Motivation – I

- Major cost in lives & goods of floods & other extremes
- Cost of reconstruction & infrastructure renewal

Motivation – II

- The IPCC process: Assessment Reports (AR1–AR5)
- 3 working groups: various sources of uncertainties
  - Physical Science Basis
  - Impacts, Adaptation and Vulnerability
  - Mitigation of Climate Change



- Physical and socio-economic modeling
  - separate vs. coupled
- Ethics and policy issues

What is macroeconomics?

- **Economic subdisciplines**
  - macroeconomics: national or regional economy as a whole
  - microeconomics: individual households and firms
  - econometrics: methodology of both macro- & microeconomics
- **Macroeconomic variables and indicators**
  - gross domestic product (GDP) – produit intérieur brut (PIB)
  - production, demand
  - capital, profits (gross, net)
  - price level, wages
  - unemployment rate, number of employed workers
  - liquid assets (of banks, companies)
  - consumption, investment, stock

N. B. Some of these are in physical units, others are monetary;
some are observable (time series), some are not

Outline

A. Endogenous business cycle (EnBC) model

- sawtooth-shaped business cycles, 5–6-year period
- impact of natural hazards
- vulnerability paradox ➔ fluctuation-dissipation relation

B. U.S. macroeconomic indicators

- methodology: singular-spectrum analysis (SSA) + multi-channel SSA (M-SSA)
- BEA data confirm the vulnerability paradox

C. EU & World data – work in progress

- Italy, Netherlands and UK data, correlations with USA
- 100 countries representing all economic regions
- commonalities and differences

D. Concluding remarks & bibliography

The need for models with endogenous dynamics

"The currently prevailing paradigm, namely that financial markets tend towards equilibrium, is both false and misleading; our current troubles can be largely attributed to the fact that the international financial system has been developed on the basis of that paradigm."

George Soros,
The New Paradigm for Financial Markets:
The Credit Crisis of 2008 and What It Means,
BBS, PublicAffairs, New York, 2008

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A tale of two theories: the "real" cycle and the endogenous cycle theories

- ***In the real cycle theory, business cycles and economic fluctuations arise from exogenous "real" (i.e. not monetary) shocks, like changes in productivity or in energy prices, or from fiscal shocks.***

  Aside from these exogenous shocks, the economic system is stable:
  all markets are at equilibrium, and there is no involuntary unemployment.
  Deviations from equilibrium are damped more or less rapidly.
  Acting on the economy, therefore (e.g., recovery policies), is not useful.

- ***In endogenous business cycle (EBC) models, cyclical behavior originates from endogenous instabilities in the economic system.***

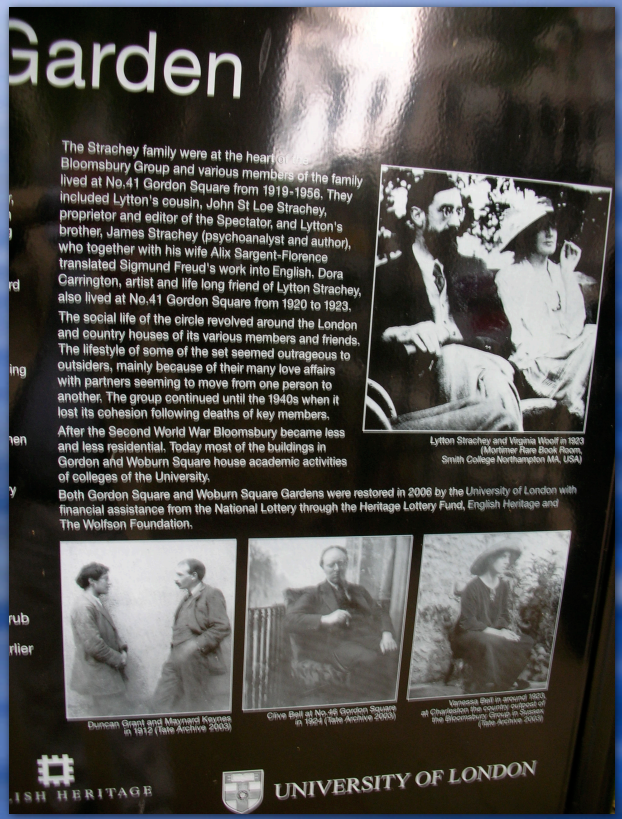
  Several instabilities have been proposed:
  - profitability-investment instability
  - delays in investment
  - income distribution

  Acting on the economy can, therefore, have positive effects,
  by stabilizing it or by shifting its mean state.

The blessings of interdisciplinarity

♥ *John M. Keynes's home in Bloomsbury*

♥ *Photo with lover Duncan Grant*



photos M.G., May 2008

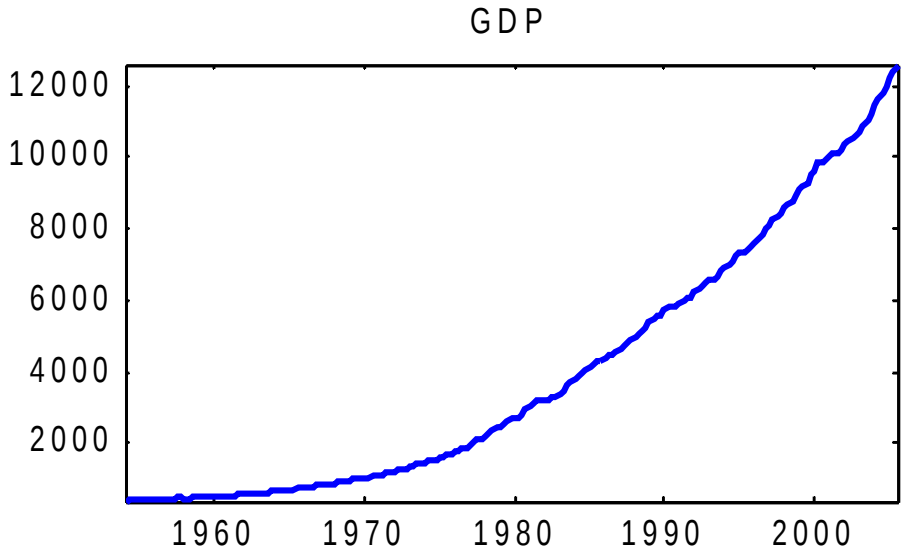
NEDyM (Non-equilibrium Dynamic Model)

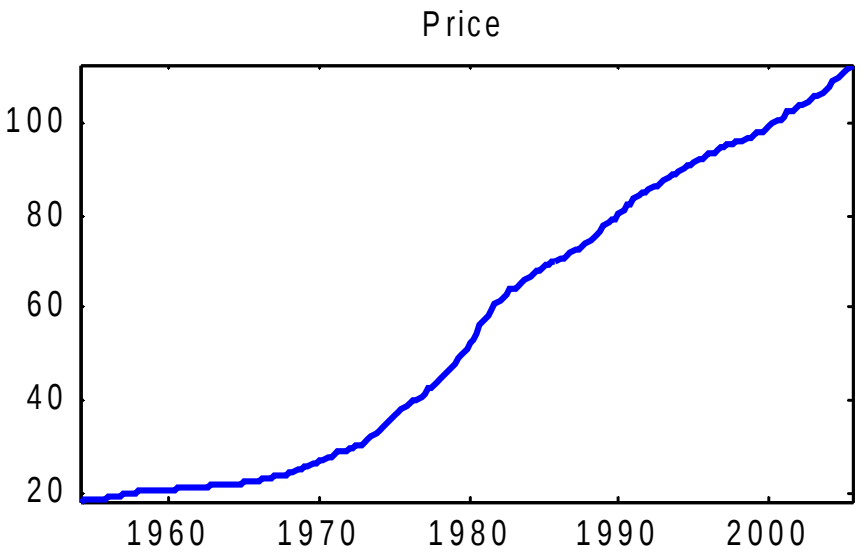
- Represents an economy with one producer, one consumer, one goods that is used both to consume and invest.
- Based on the Solow (1956) model, in which all equilibrium constraints are replaced by dynamic relationships that involve adjustment delays.
- The NEDyM equilibrium is neo-classical and identical to that in the original Solow model. If the parameters are changing slowly, NEDyM has the same trajectories as the Solow model.
- Because of market adjustment delays, NEDyM model dynamics exhibits Keynesian features, with transient trajectory segments, in response to shocks.
- NEDyM possesses endogenous business cycles!

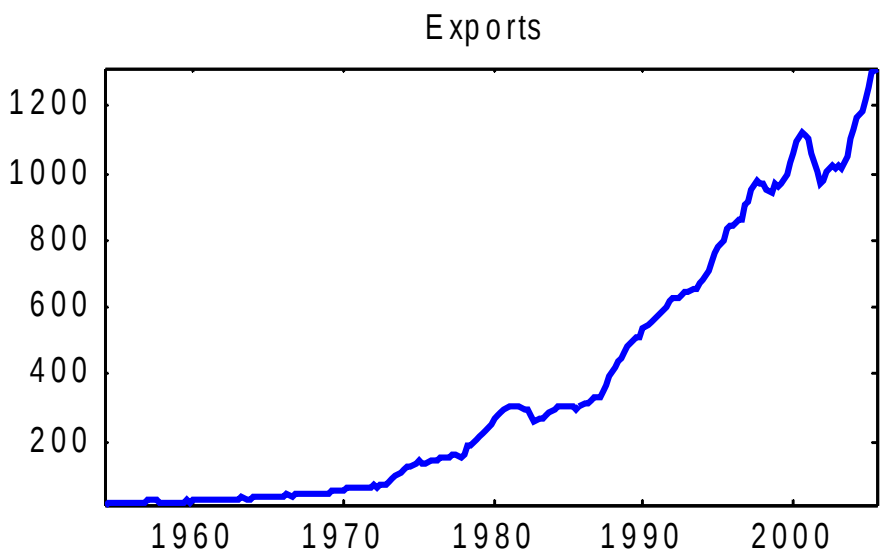
Hallegatte, Ghil, Dumas & Hourcade (*J. Econ. Behavior & Org*., 2008)

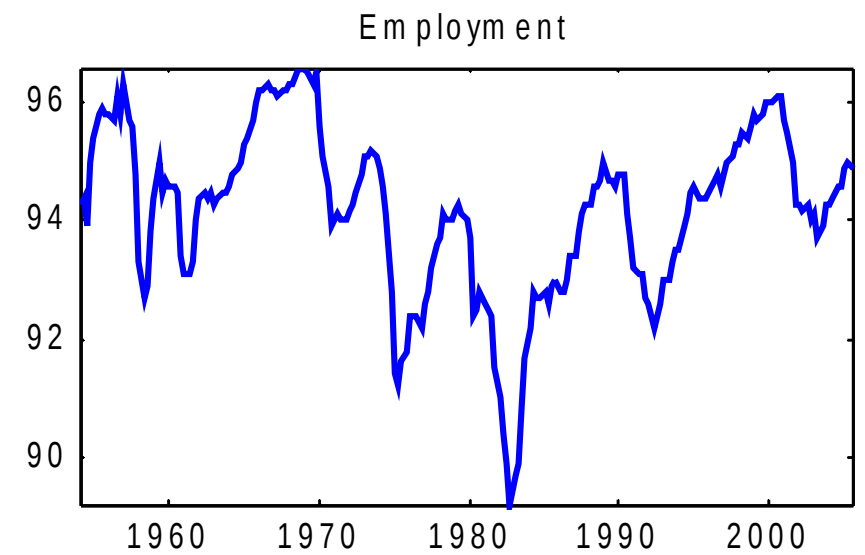
Macroeconomic time series

Macroeconomic indicators of the U.S.



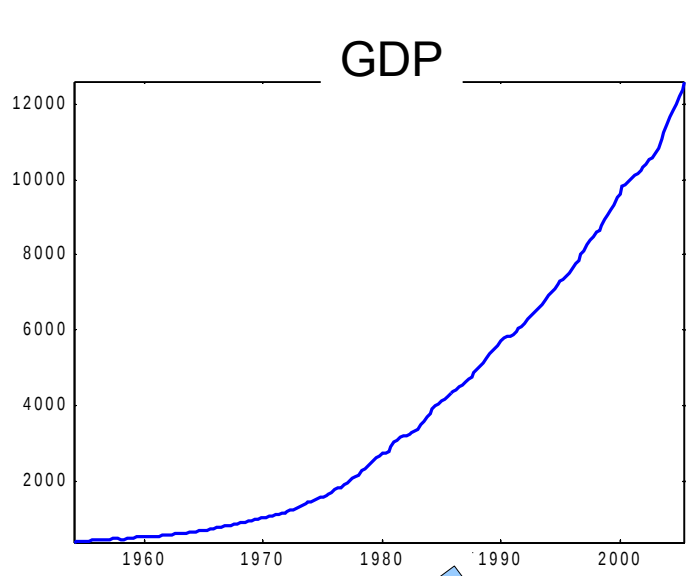


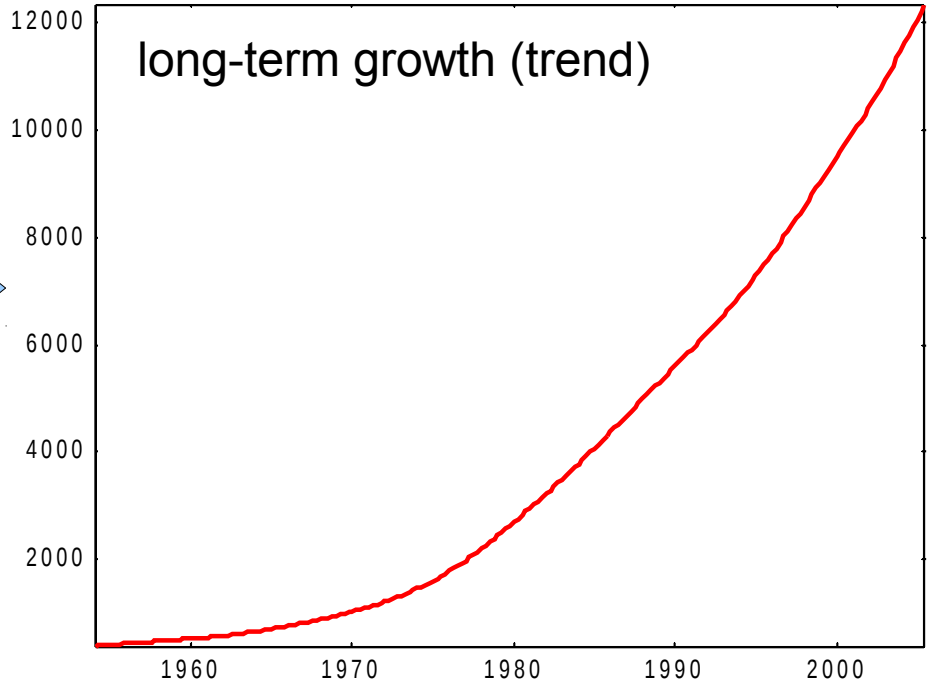


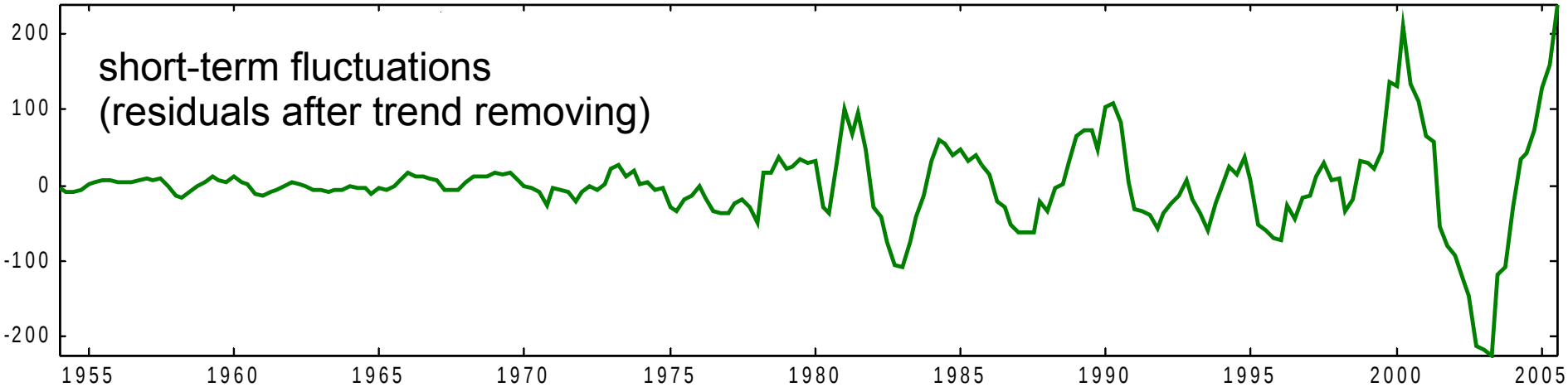


Macroeconomic modeling

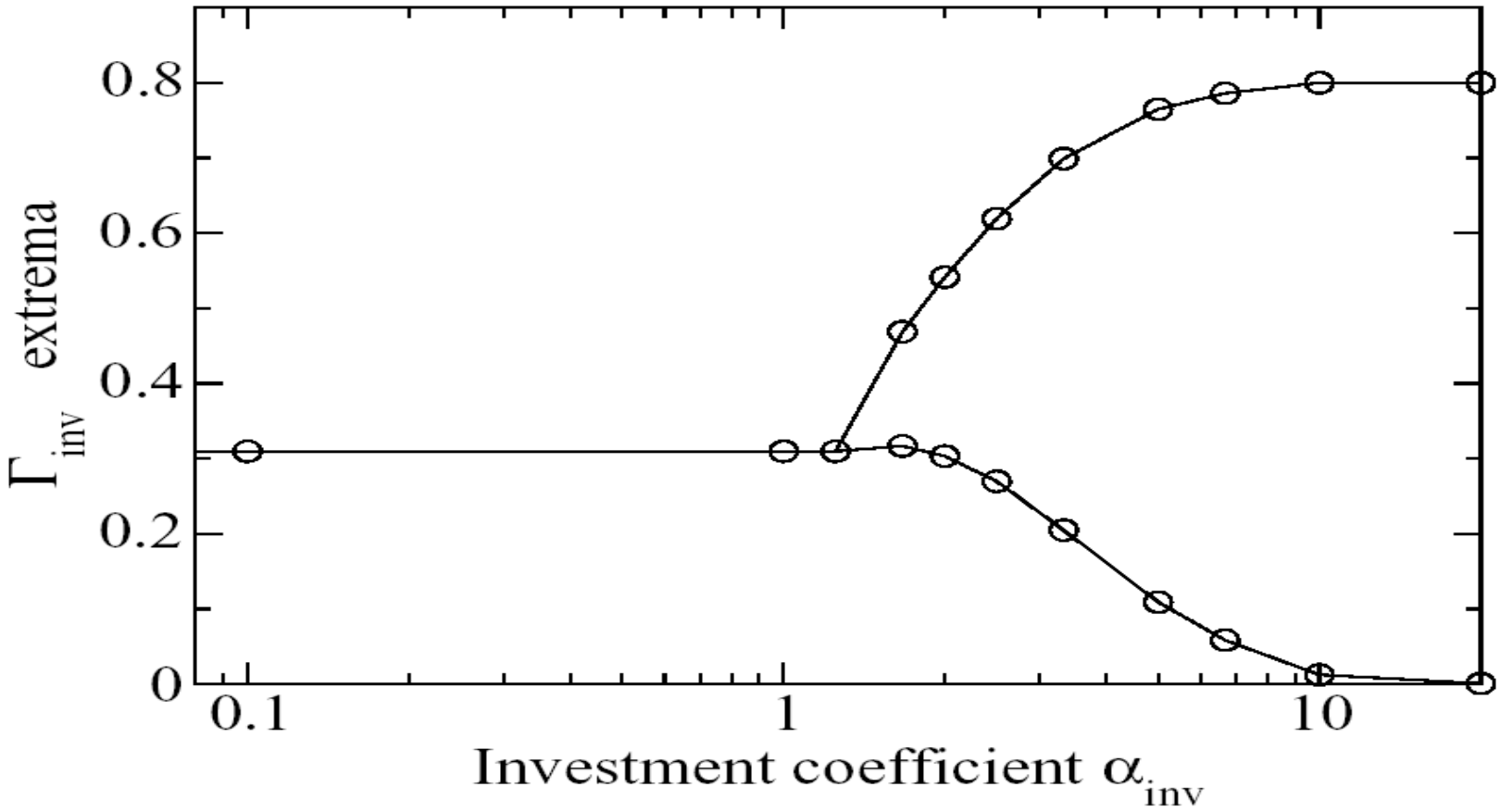
Two main areas of research



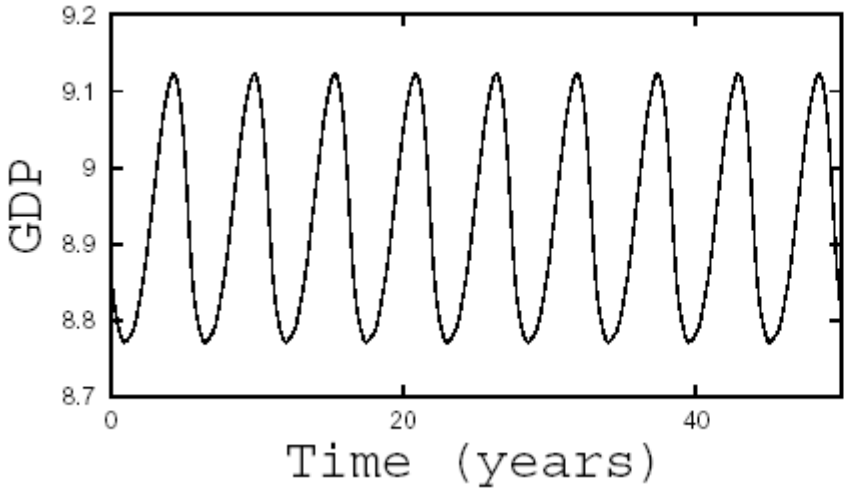


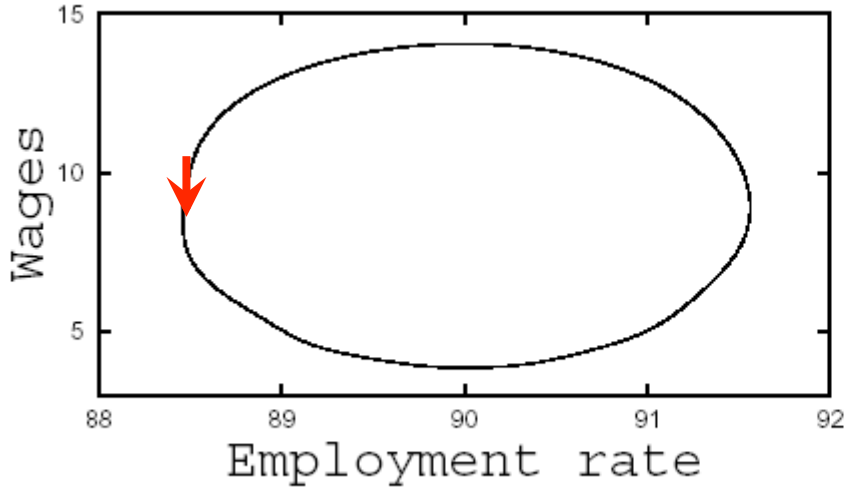


Hopf bifurcation from stable equilibrium to a limit cycle ("business cycle")

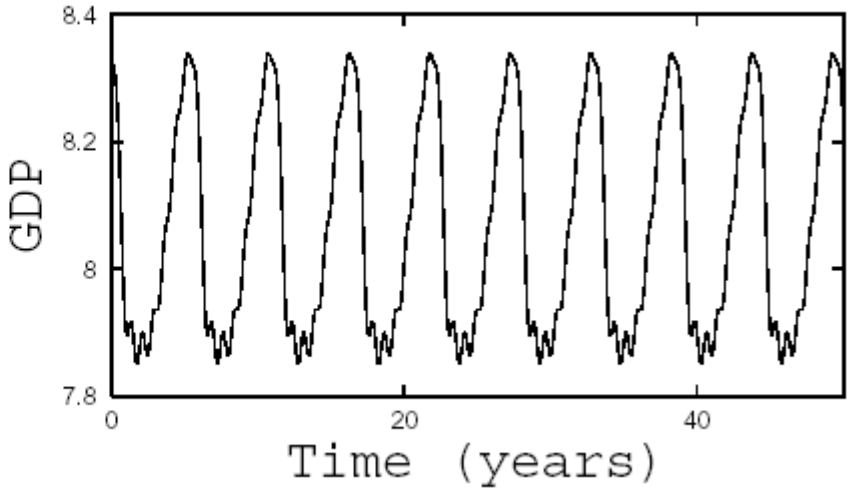


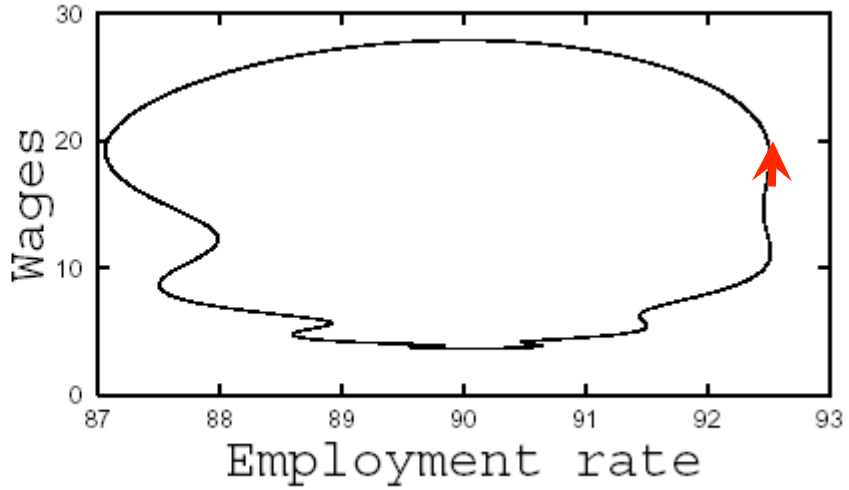
α_{inv} = 1.7: purely periodic behavior (limit cycle)



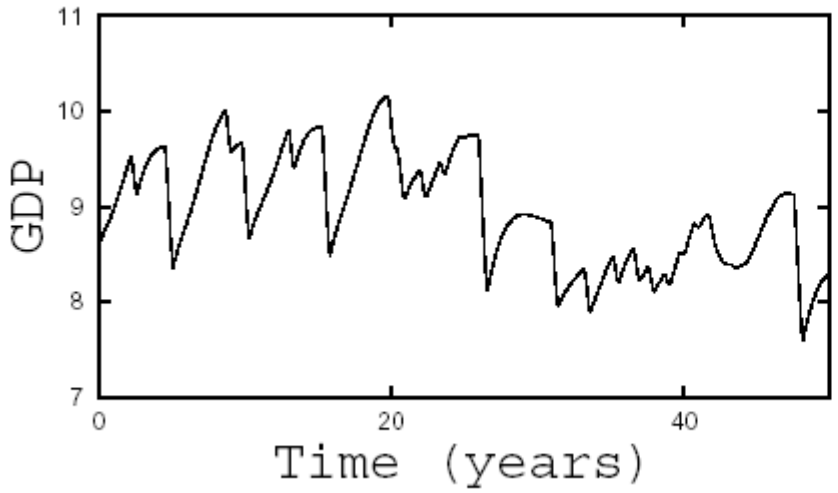


α_{inv} = 2.5: transition to chaos (irregular behavior)

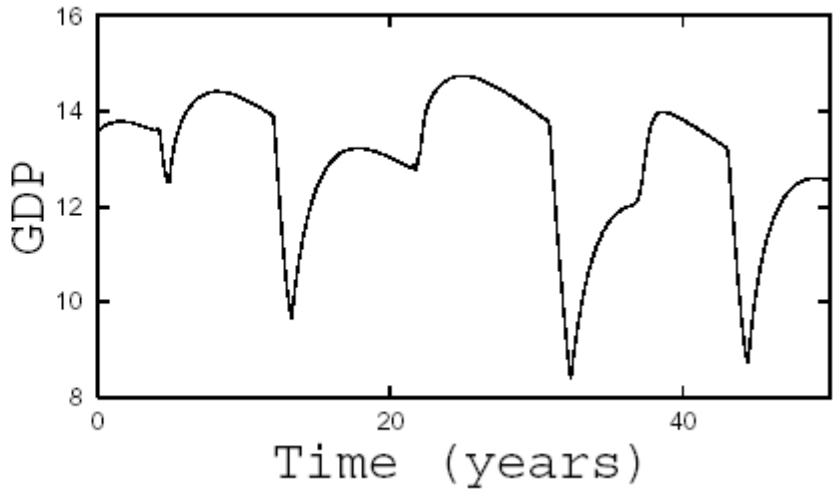




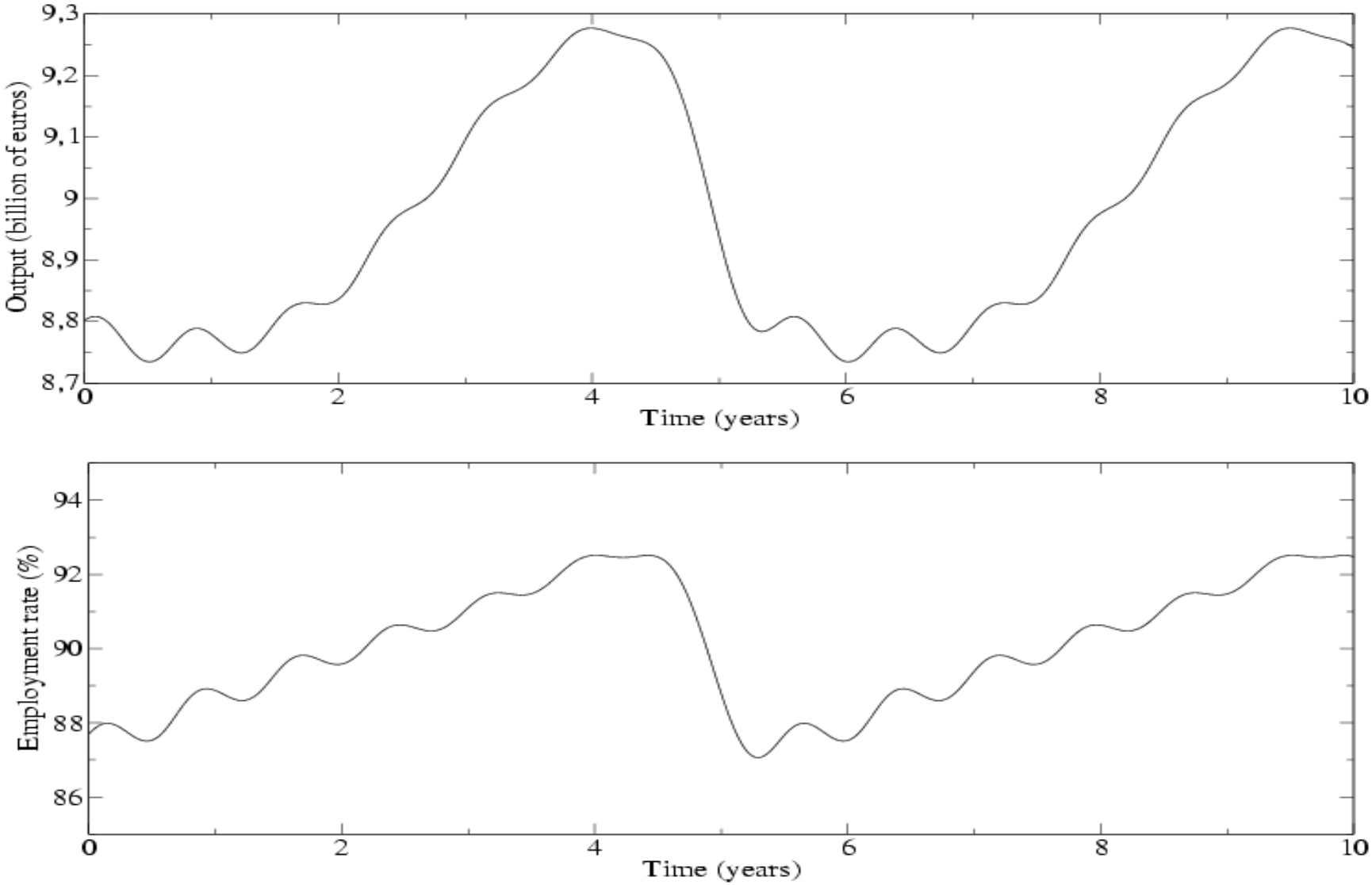
α_{inv} = 10: irregular orbit
(kinky torus)



α_{inv} = 20: very asymmetric
business cycle
(relaxation oscillation)



Endogenous dynamics: an alternative explanation for business cycles



Endogenous business cycles (EnBCs) in NEDyM

- Business cycles originate from the profit–investment relationship
  (oscillations with a 5–6-year period) – Fukuyama (1989–92)?!

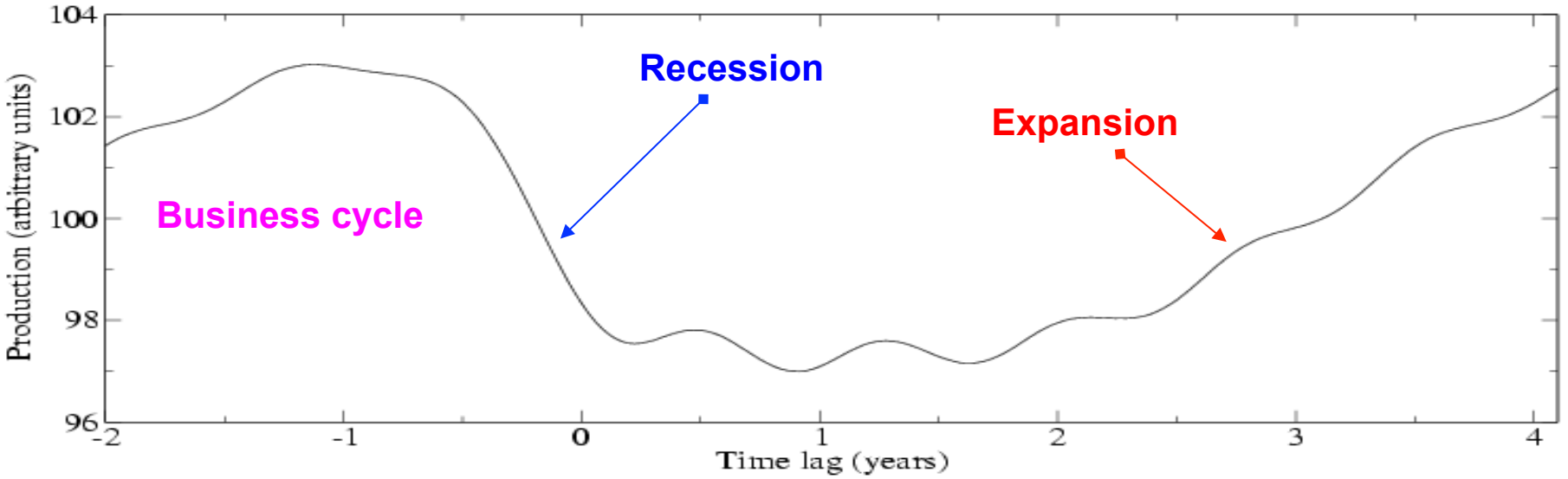
  higher profits => more investments => larger demand => higher profits

- Business cycles are limited in amplitude by three processes:
  - increase in labor costs when employment is high;
  - constraints in production and the consequent inflation in goods prices when demand increases too rapidly;
  - financial constraints on investment.

- EnBC models need to be calibrated and validated
  - harder than for real business cycle models (RBCs):
    fast and slow processes =>
    need a better definition of the business cycles =>
    study of BEA & NBER data!

Catastrophes and the state of the economy – I

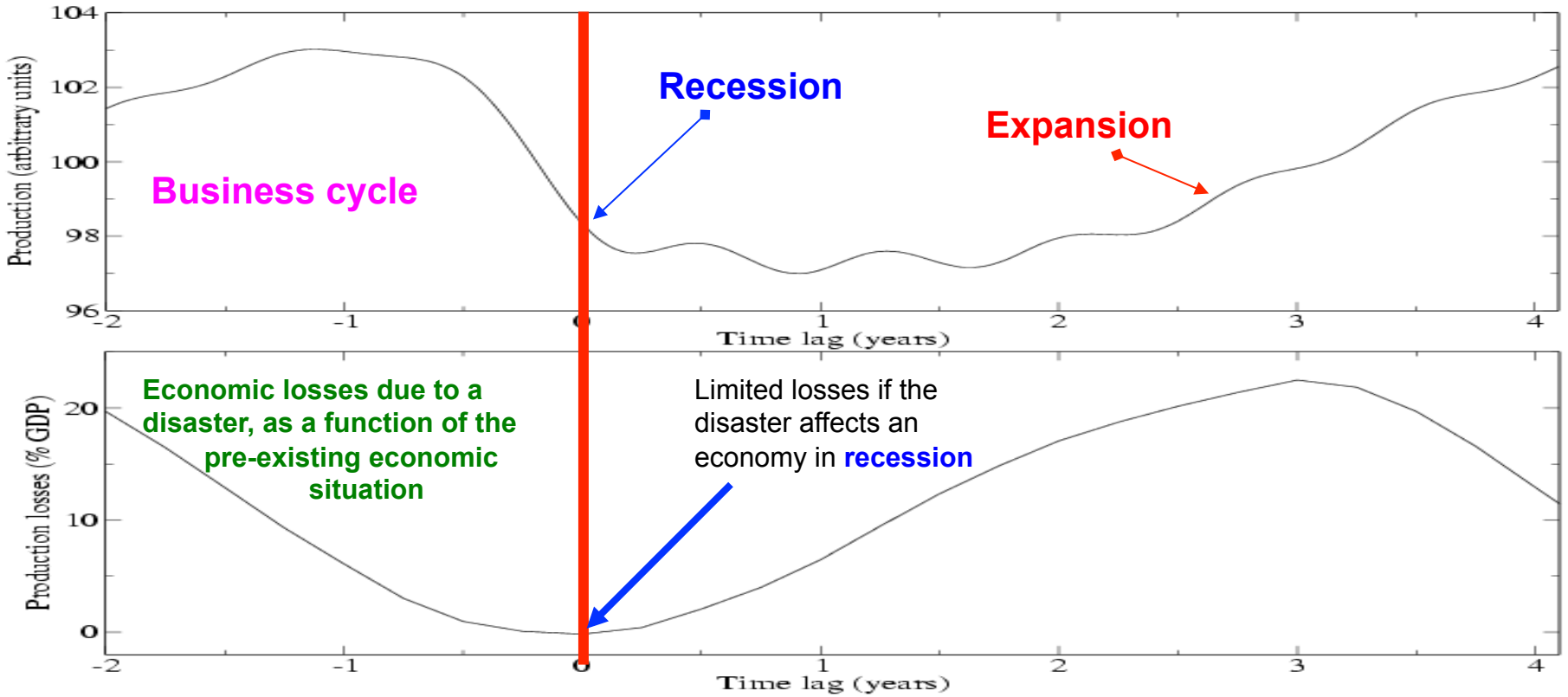
A vulnerability paradox: When does a disaster cause greater **long-term damage** to an economy, during its **expansion phase** or during a **recession**?



Hallegatte & Ghil, 2008, *Ecol. Econ.*, **68**, 582–592, doi:10.1016/j.ecolecon.2008.05.022

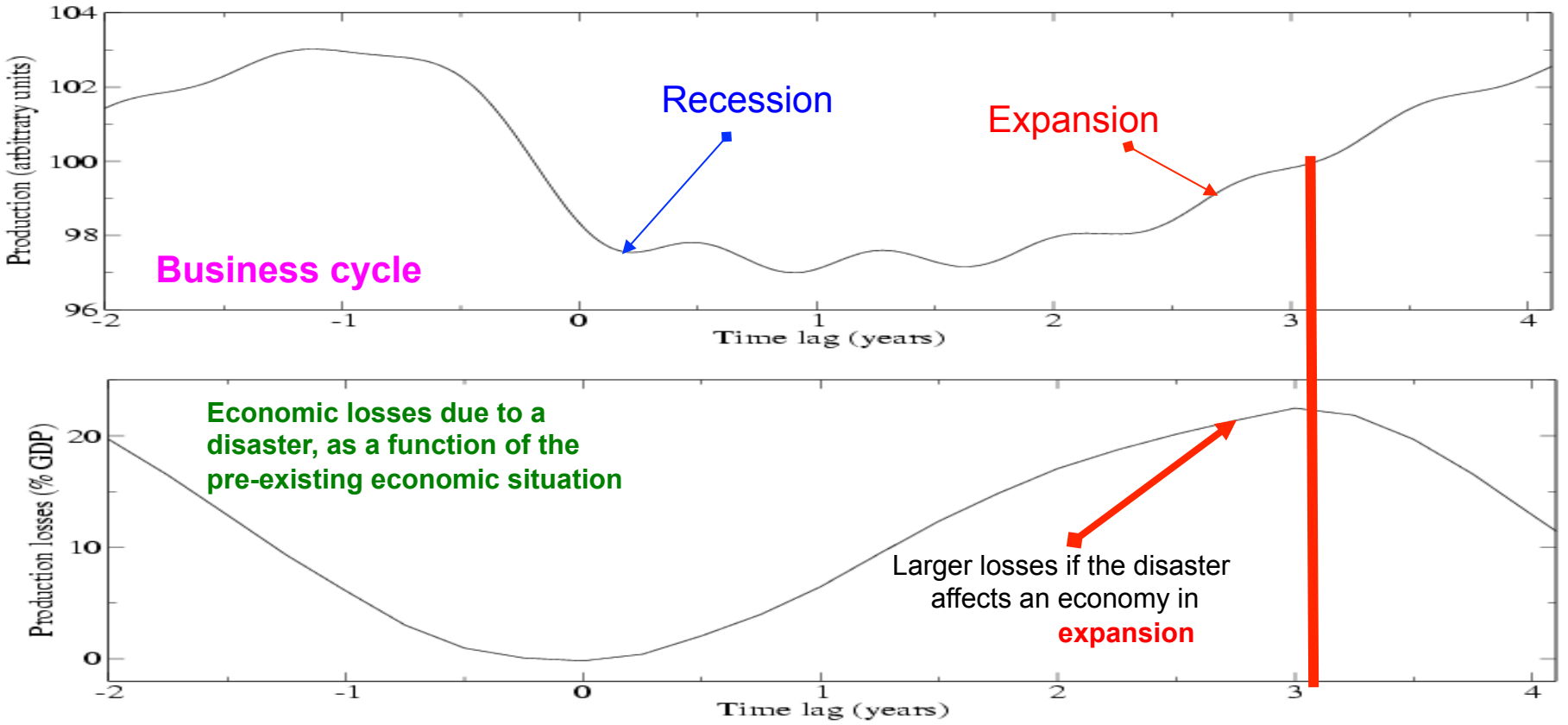
Catastrophes and the state of the economy – II

A vulnerability paradox:
A disaster that affects an economy during its **recession phase**…



Catastrophes and the state of the economy – III

… causes **fewer** long-term damages
than if it occurs during an **expansion!**



Hallegatte & Ghil, 2008, *Ecol. Econ.*, **68**, 582–592, doi:10.1016/j.ecolecon.2008.05.022

Long-term averaged GDP losses due to natural disasters(*)

Calibration	Economic dynamics	Mean GDP losses (% of baseline GDP)
No investment flexibility $\alpha_{inv} = 0$	Stable equilibrium	0.15%
Low investment flexibility $\alpha_{inv} = 1.0$	Stable equilibrium	0.01%
High investment flexibility $\alpha_{inv} = 2.5$	Endogenous business cycle	0.12%

(*) calibrated on the disasters that impacted the EU in the last 30 years (Hallegatte, Hourcade & Dumas, 2007; Munich-Re, 2004)

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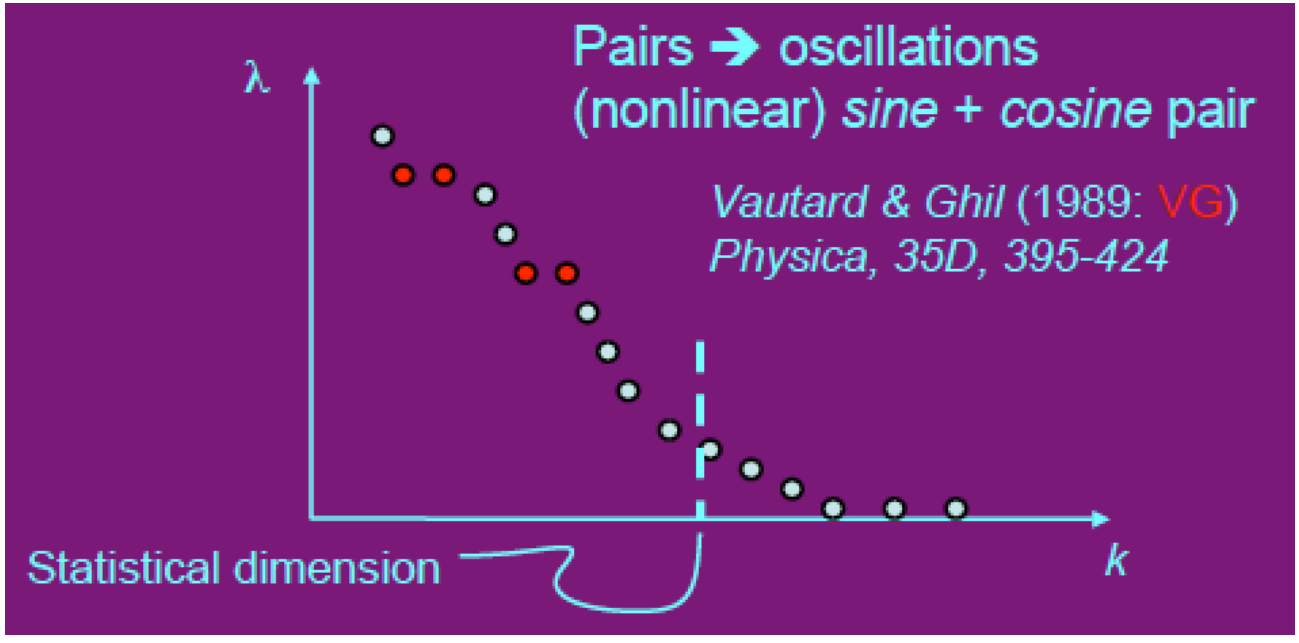
Singular Spectrum Analysis (SSA) – I

Spatial EOFs (PCA)	Temporal EOFs (SSA)
Expansion	
$\mathbf{\Phi}(t,x) = \sum_k \mathbf{a}_k(t)\,\mathbf{e}_k(x)$	$\mathbf{X}(t,s) = \sum_k \mathbf{a}_k(t)\,\mathbf{e}_k(s)$
Covariance	
$\mathbf{C}_\Phi(x,y) = \left\langle \mathbf{\Phi}(t,x)\mathbf{\Phi}(t,y)\right\rangle_t$	$\mathbf{C}_X(s,u) = \left\langle \mathbf{X}(t)\mathbf{X}(t+\lvert s-u\rvert)\right\rangle_t$
Eigendecomposition	
$\mathbf{C}_\Phi\,\mathbf{e}_k = \lambda_k\,\mathbf{e}_k$	$\mathbf{C}_X\,\mathbf{e}_k = \lambda_k\,\mathbf{e}_k$
Eigenelements	
$\mathbf{e}_k(x)$ $\quad x$ – space	$\mathbf{e}_k(s)$ $\quad s$ – time lag
	λ_k pairs $\rightarrow$ oscillations
	(nonlinear) sine + cosine pair

- Colebrook (1978); Weare & Nasstrom (1982); Broomhead & King (1986; BK); Fraedrich (1986); Vautard & Ghil (1989; VG).
- BK + VG: Analogy between Mañé-Takens embedding and the Wiener-Khinchin theorem.

Singular Spectrum Analysis (SSA) – II



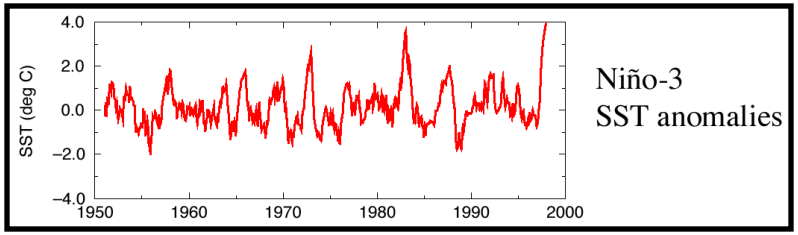
- Truncation of the expansion to the S leading EOFs
  $\Rightarrow$ data-adaptive filter.
- Nearly equal eigenvalues $\Rightarrow$ nonlinear, anharmonic oscillation.

Singular Spectrum Analysis (SSA)

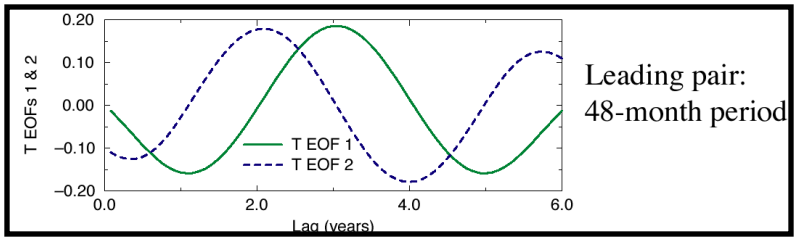
SSA decomposes (geophysical & other) time series into ***Temporal EOFs*** (T-EOFs) and ***Temporal Principal Components*** (T-PCs), based on the series' lag-covariance matrix

Selected parts of the series can be reconstructed, via ***Reconstructed Components*** (RCs)

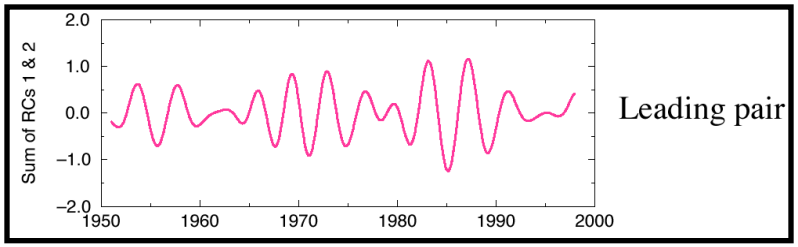
Time series



T-EOFs



RCs



- SSA is good at isolating oscillatory behavior via paired eigenelements.
- SSA tends to lump signals that are longer-term than the window into
  - one or two trend components.

Selected References:

Vautard & Ghil (1989, *Physica* D);
Ghil *et al.* (2002, *Rev. Geophys.)*

Stylized Facts of a Business Cycle – I

Need a more objective, quantitative description of the "typical business cycle." To do so we use two complementary approaches:

1. synchronization methods from dynamical systems ("chaos"); and
2. Advanced methods of time series analysis (SSA and M-SSA)

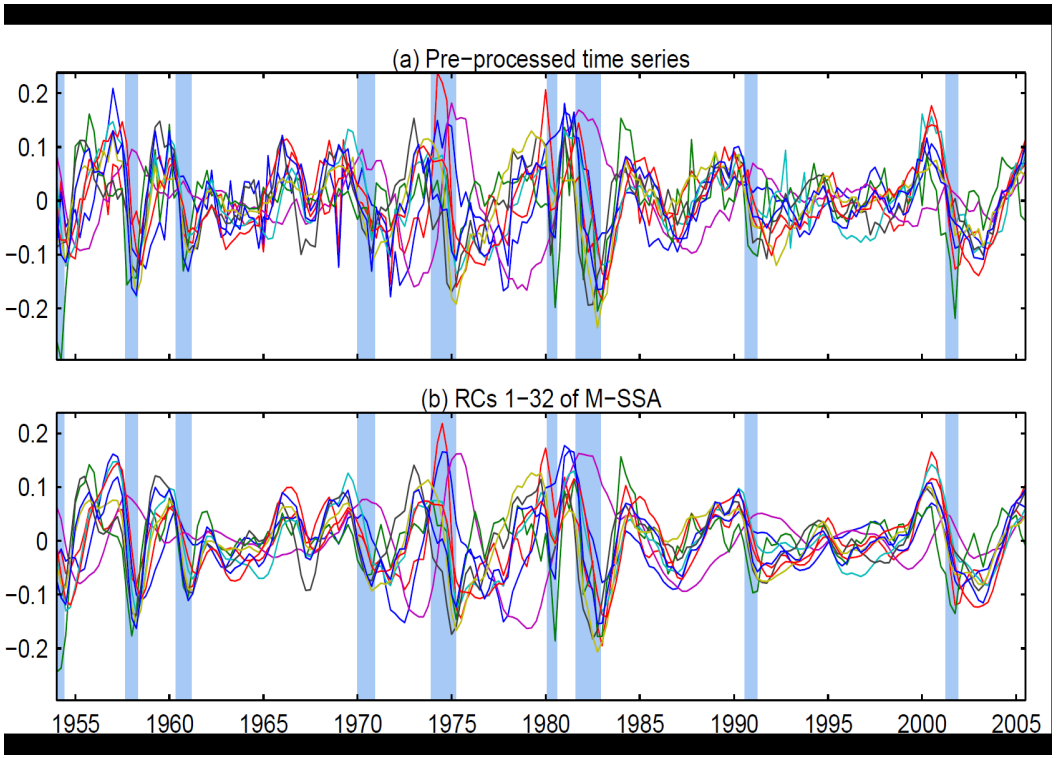
Bureau of Economic Analysis, www.bea.gov; 1947–2005.

9 variables:

gross domestic product (GDP), investment, consumption, employment rate (in %), price, total wage, imports, exports, and change in private inventories.

Groth, Ghil, Hallegatte and Dumas, submitted

Raw data, detrended and standardized



9-channel SSA ($D = 9$, $M = 24$ quarters)

Adaptive filtering, via multichannel singular-spectrum analysis (M-SSA);
vertical shaded bars are NBER-defined recessions

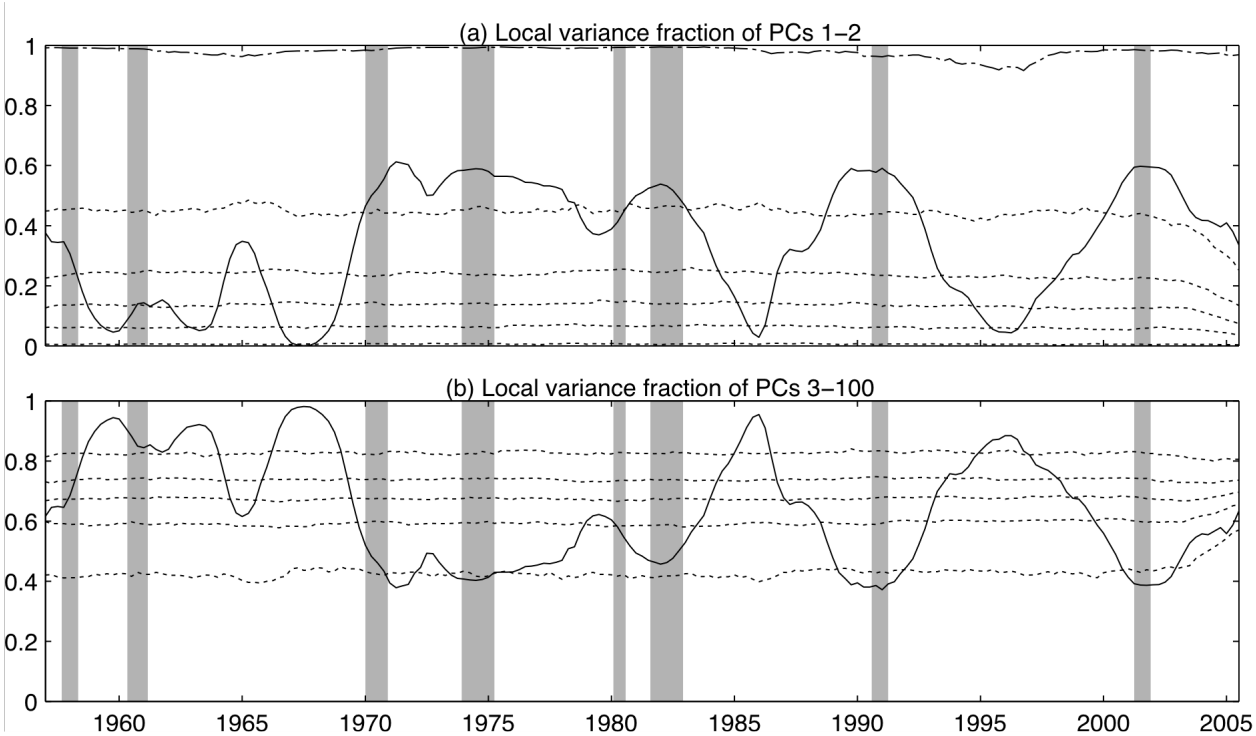
Stylized Facts of a Business Cycle – III

Consider the local variance fraction $V_{\mathcal{K}}(t)$ with $D = 9$, $M = 100$, and $A_k(t)$ the PCs:

$$V_{\mathcal{K}}(t) = \frac{\sum_{k\in\mathcal{K}} A_k(t)^2}{\sum_{k=1}^{DM} A_k(t)^2}$$

The "signal" fraction is largest during the recessions

The "noise" fraction is largest during the expansions



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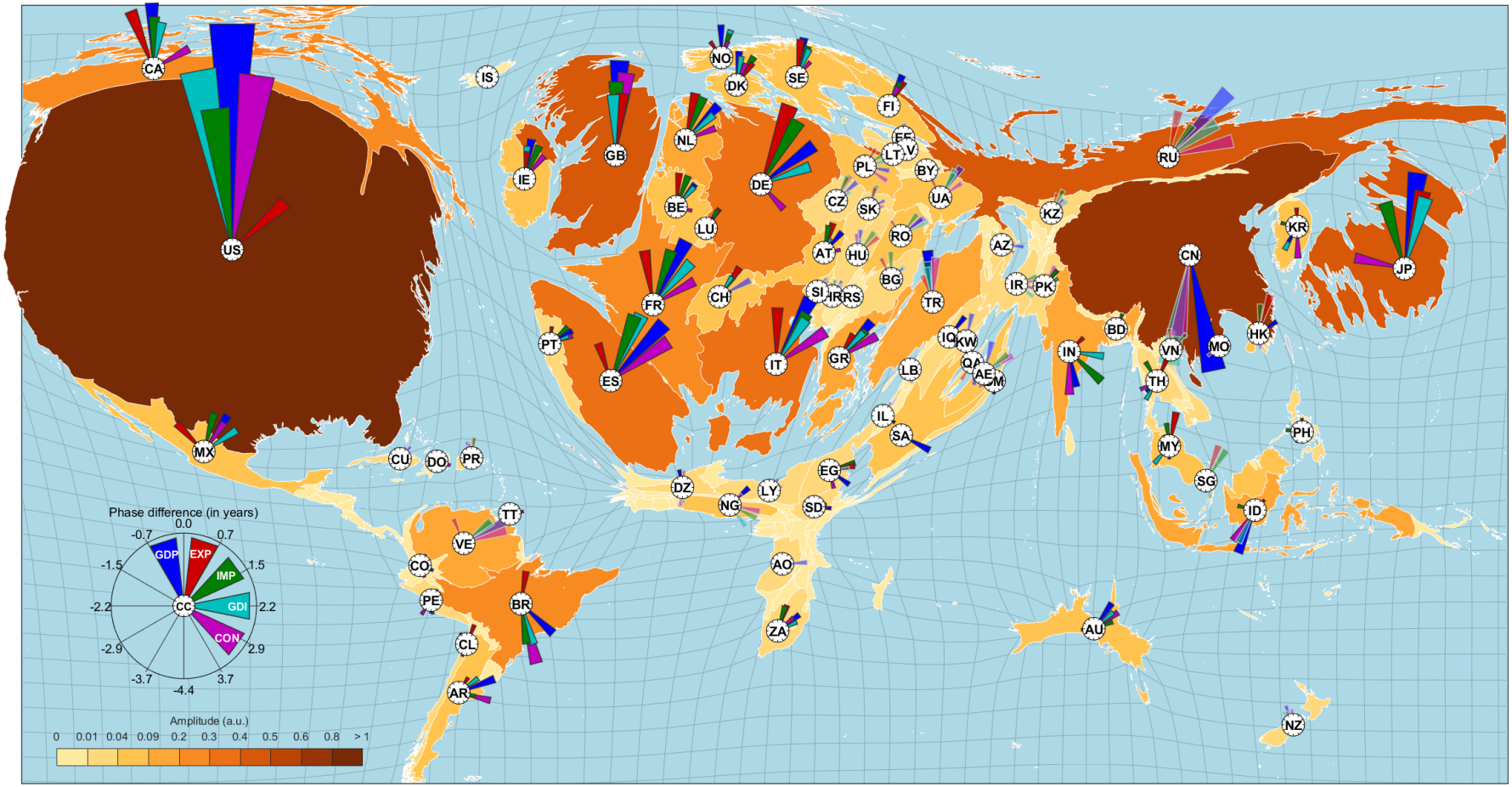
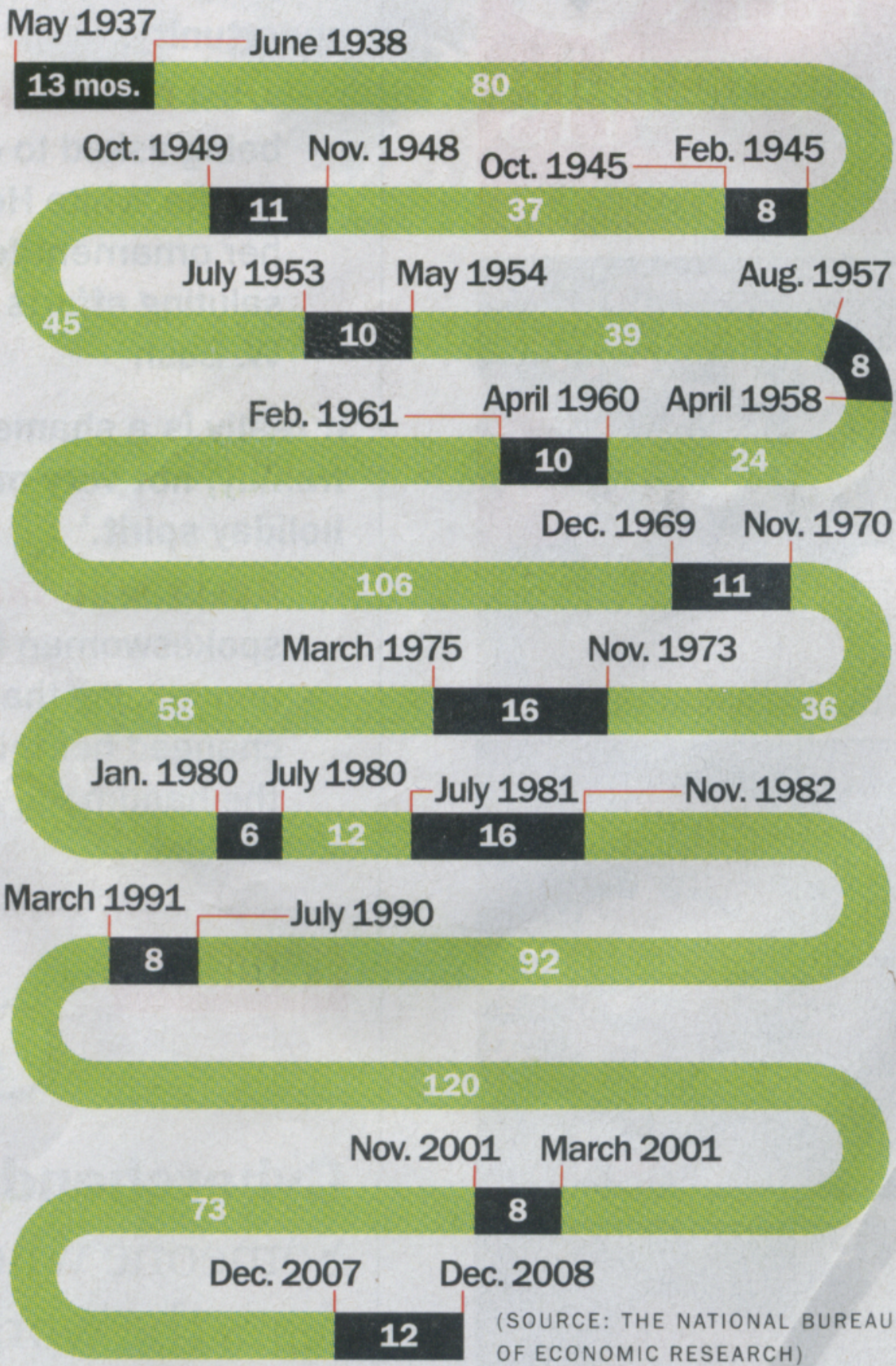
World Business Cycle



Synchronization of macroeconomic indicators from over 100 countries; mean period = 7–11 years

Recessions and Expansions from the Great Depression to Today

Recession Expansion



(SOURCE: THE NATIONAL BUREAU OF ECONOMIC RESEARCH)

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Conclusions and Outlook

1. **Non-equilibrium models** are alive and well: they exhibit fairly realistic, **endogenous business cycles (EBCs):** period = 5–6 years, seasaw shape, good phasing of indices.
1. They also display a **vulnerability paradox**:
   - extreme-event consequences depend on the state of the economy;
   - they are more severe during an expansion than a recession.
3. This paradox is supported by
   - consequences of **Izmit (Marmara) earthquake, 1999**;
   - reconstruction process after the **2004 and 2005 hurricane seasons in Florida**.
4. **U.S. economic data** (BEA, 1947–2005) tentatively support **a nonlinear fluctuation-dissipation theorem (FDT)** à la Ruelle.
5. Need **a better, quantitative characterization of business cycles**: U.S. + Euro-data, synchronization and spectral methods (A. Groth, L. Sella, G. Vivaldo)
6. Need more detailed, regional and sectorial models: B. Coluzzi, M. G., S.H., and G. Weisbuch are using simplified, **Boolean models to study the economy as a network of businesses** (suppliers and clients, etc.).
7. **Unanticipated consequences** – check! **Further opportunities** – check & check!!

A few references

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The deeper motivations of economic modeling

"Really, Karl! Can't I mention the high price of kohlrabi without getting a manifesto?"