# Foundations of Computational Social Systems

## Economic systems

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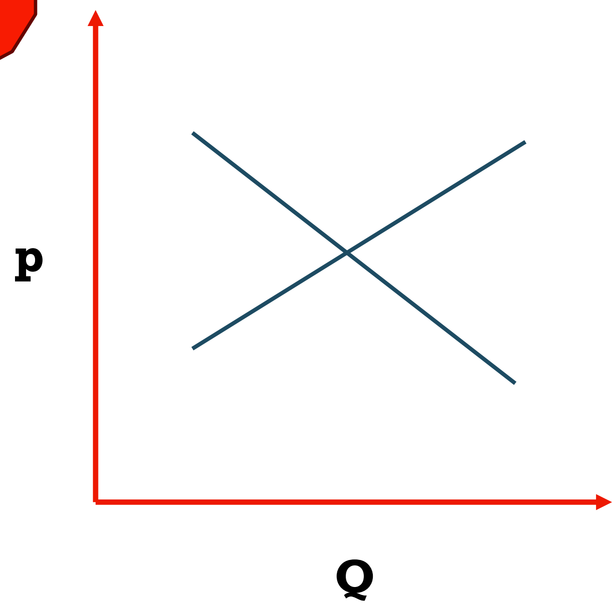
# Agenda

1. Basic Macro
2. Dynamic models (DSGE)
3. Four economic problems
4. A look at basic macro data
5. Big data in economics and finance
6. Outlook

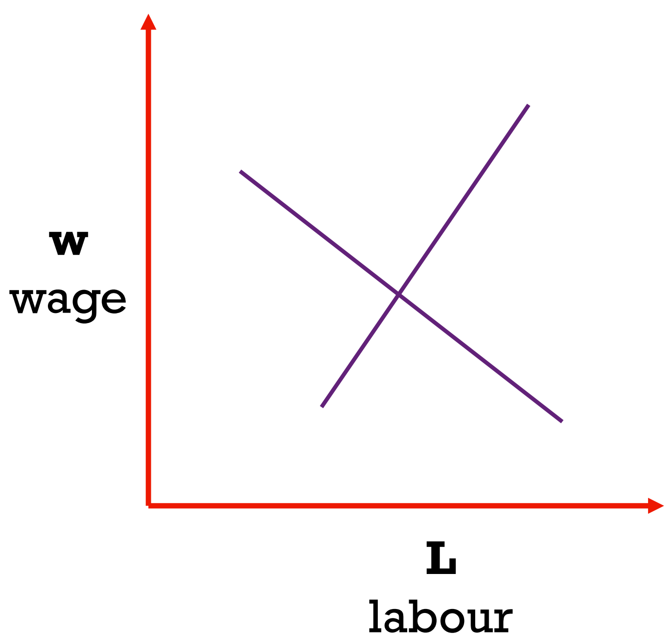
1.

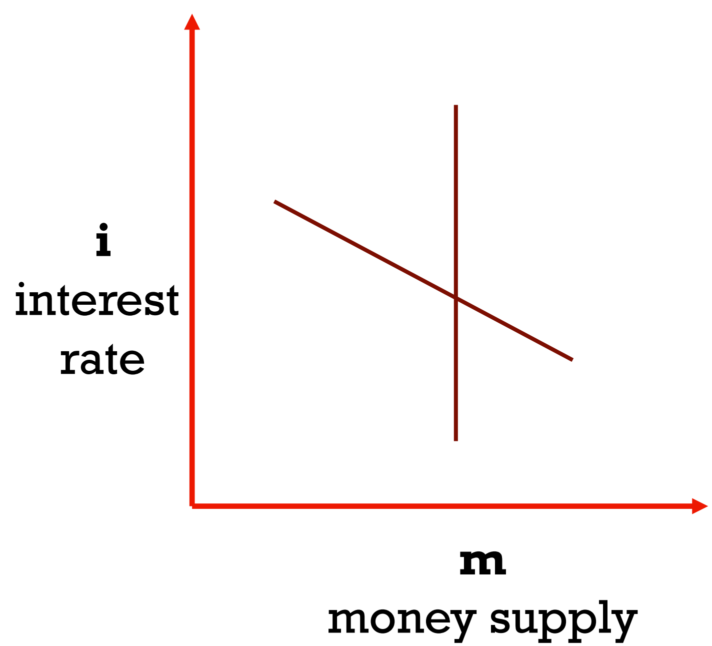
# Basic Maroeconomics




(Macro)economics

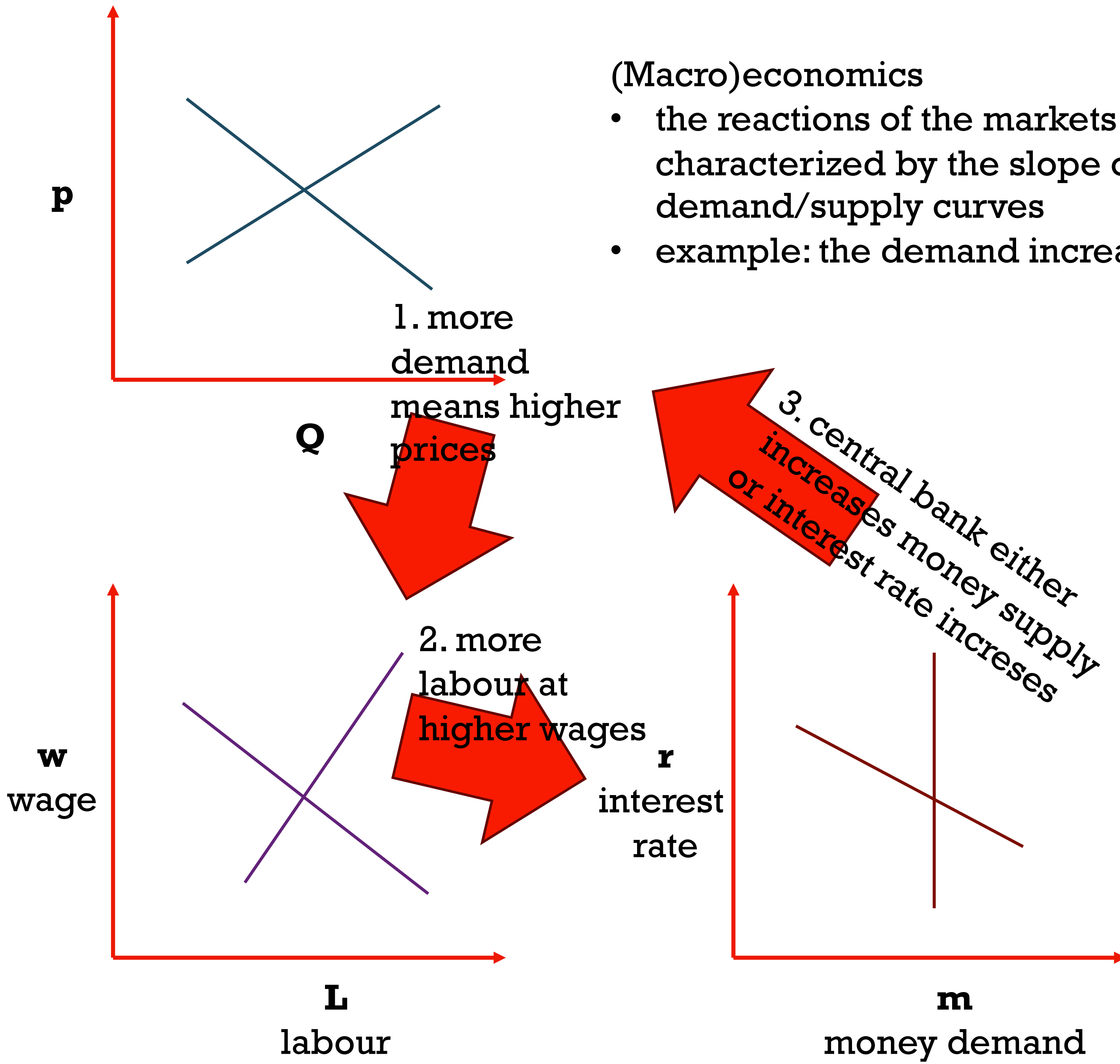
- equilibrium of market price and quantity
- in fact - several markets: goods, money, labor
- which are interdependent

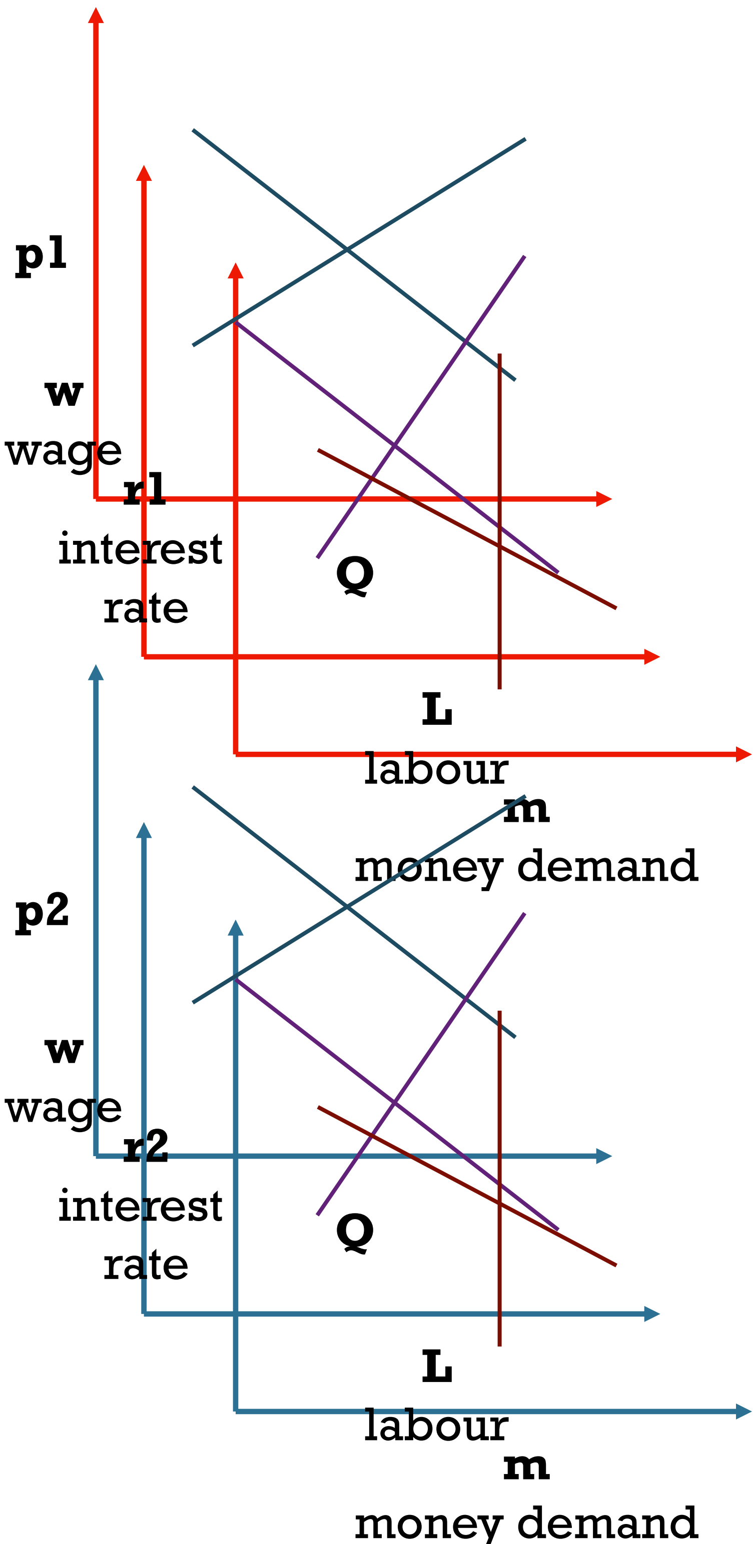


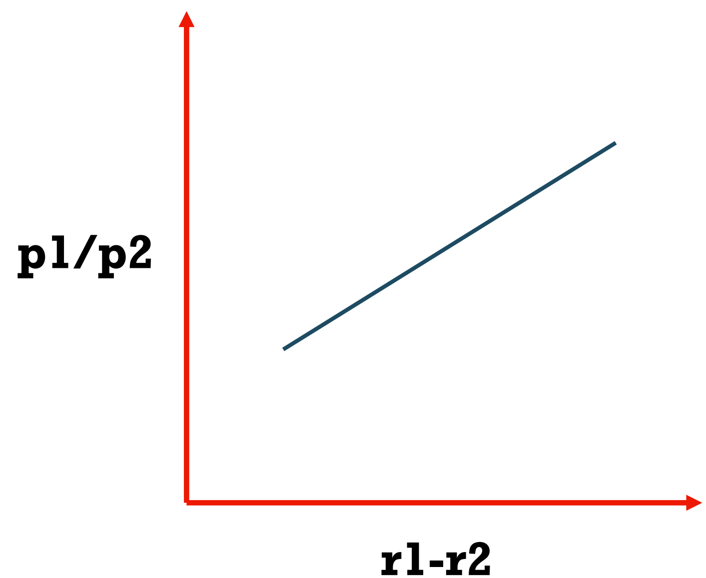
(Macro)economics

- the reactions of the markets are characterized by the slope of the demand/supply curves
- example: the demand increases





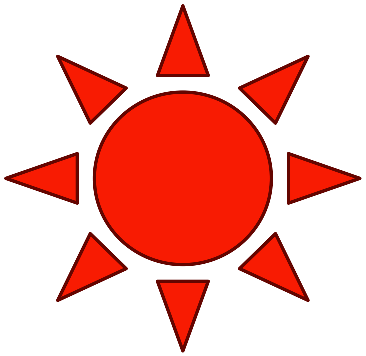

We are not living on an island.. therefore, in the case of an open economy we have capital and goods flows between countries and therefore the model needs an exchange market




How other countries effect the domestic economy depends on size and monetary policy

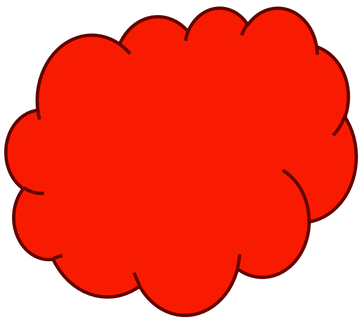
Notes

- these models are used for comparative-static analysis, i.e., the changes from an old to a new market equilibrium after a shock
- The baseline model is referred to as the AS-LM model
- When you discuss an open economy we go the the Mundell-Fleming model



Baseline

- Economic policy cannot be judged by looking at one market/country in isolation!
- We have to consider all reactions until the system is back in equilibrium!
- No free lunch!



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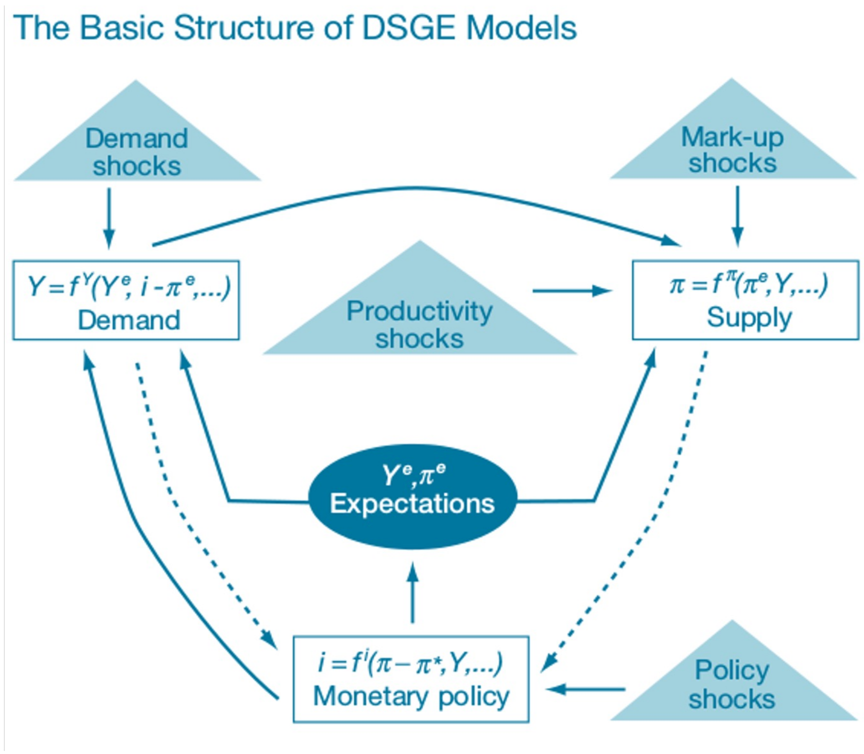
# Dynamic Maroeconomics (DSGE)




Source: FRBNY Economic Policy Review / October 2010

- Dynamic structural general equilibrium models are macroeconomic models that represent
- Labor markets (households)
- goods markets (firms)
- money market (central bank)

# Microfoundations

- Representative household maximizes "lifetime utility"
- ***C*** consumption, ***H*** labor, ***w*** wage, ***P*** price level, ***B*** Bond price, ***R*** gross return

$$\underset{\{B_{t_0+s}, C_{t_0+s}, [H_{t_0+s}(i)]_{i\in[0,1]}\}_{s=0}^{\infty}}{Max} E_{t_0}\sum_{s=0}^{\infty}\beta^s\left\{ b_{t_0+s}\left[\log(C_{t_0+s} - \eta C_{t_0+s-1}) - \int_0^1 v(H_{t_0+s}(i))di\right]\right\}$$

subject to the sequence of budget constraints

$$P_t C_t + \frac{B_t}{R_t} \leq B_{t-1} + \int_0^1 w_t(i) H_t(i) di \, ,$$

- for the equilibrium we can derive a log-linear approximation (Euler equation, simple case without "habit")

$$y_t = E_t y_{t+1} - (i_t - E_t \pi_{t+1}) - \delta_t \, ,$$

- ***y*** output, ***i*** interest rate, ***pi*** inflation, ***delta*** shock+discount factor

# Microfoundations

- (A fraction of) intermediate firms set prices, monopolistic setting with price staggering, standard production fct. assumed, prices are "fixed" until t+s, (final product firms skipped here)
- ***beta*** *discounting,* ***lambda*** *marginal utility,* ***C*** consumption, ***H*** labor, ***W(i)*** wage, ***P*** price level, ***i*** interest rate, ***alpha^s*** probability

$$\underset{P_t(i)}{\text{Max}} \; E_t \sum_{s=0}^{\infty} \alpha^s \frac{\beta^s \Lambda_{t+s}}{\Lambda_t} \{ P_t(i) Y_{t+s}(i) - W_{t+s}(i) H_{t+s}(i) \}$$

- for the equilibrium we can derive a log-linear approximation of a Philips curve

$$\pi_t = \xi s_t + \beta E_t \pi_{t+1} + u_t \; ,$$

- ***pi*** inflation, ***s*** real marginal costs, ***u*** markup shock, ***eta*** sensitivity to cost change

# Central bank

- CB chooses interest rate (and thus inflation)
- ***phi*** → trade-off between inflation and output target

$$i_t = \rho i_{t-1} + (1-\rho)[r_t^e + \pi_t^* + \phi_\pi(\pi_t^{4Q} - \pi_t^*) + \phi_y(y_t - y_t^e)] + \varepsilon_t^i,$$

- ***i*** interest rate, ***r*** real interest (exp.), ***pi*** inflation (optimal/4Q), ***y*** output (actual/exp.), ***eta*** shock
- this means that the model boils down to three differential equations that you can analyze by numerical integration
- A popular way of doing this is the DYNARE toolbox in Matlab (dynare.org)
- ***Application: assume a shock to any of the three main processes and calculate impulse responses (calibrate parameters accordingly)***

Further readings

- Goodfriend, M and R King (1997), The new neoclassical synthesis and the role of monetarypolicy, NBER Macroeconomics Annual 1997.
- SMETS/WOUTERS (2002), AN ESTIMATED STOCHASTIC DYNAMIC GENERAL EQUILIBRIUM MODEL OF THE EURO AREA, ECB WORKING PAPER NO. 171.
- Argia M. Sbordone, Andrea Tambalotti, Krishna Rao, and Kieran Walsh (2010), Policy Analysis Using DSGE Models: An Introduction, FRBNY Economic Policy Review / October 2010

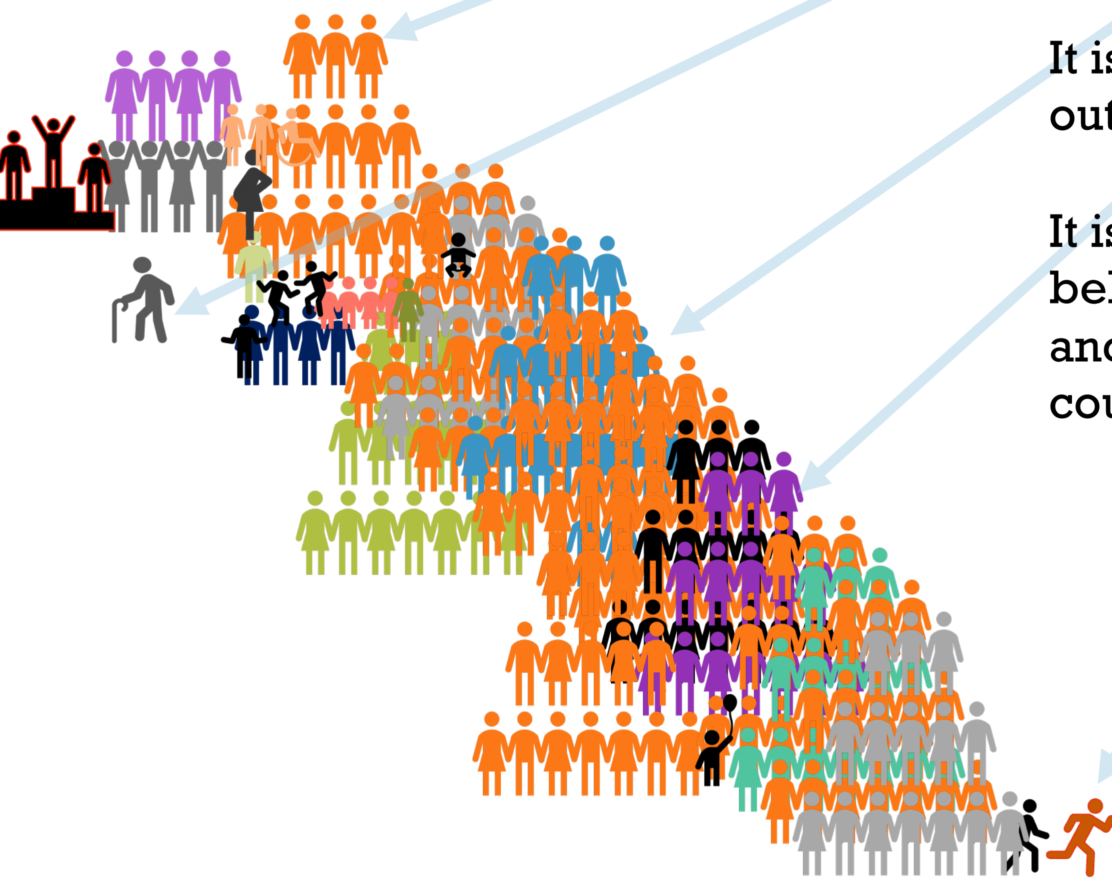
3.

**Problem 1**: Micro vs Macro

It is relatively easy to research on the problems of a household or firm

It is also easy to look at the outcomes for an entire economy

It is difficult to explain how the behavior of a single household and the outcome for the entire country relate!



## **Problem 2**: The representative agent

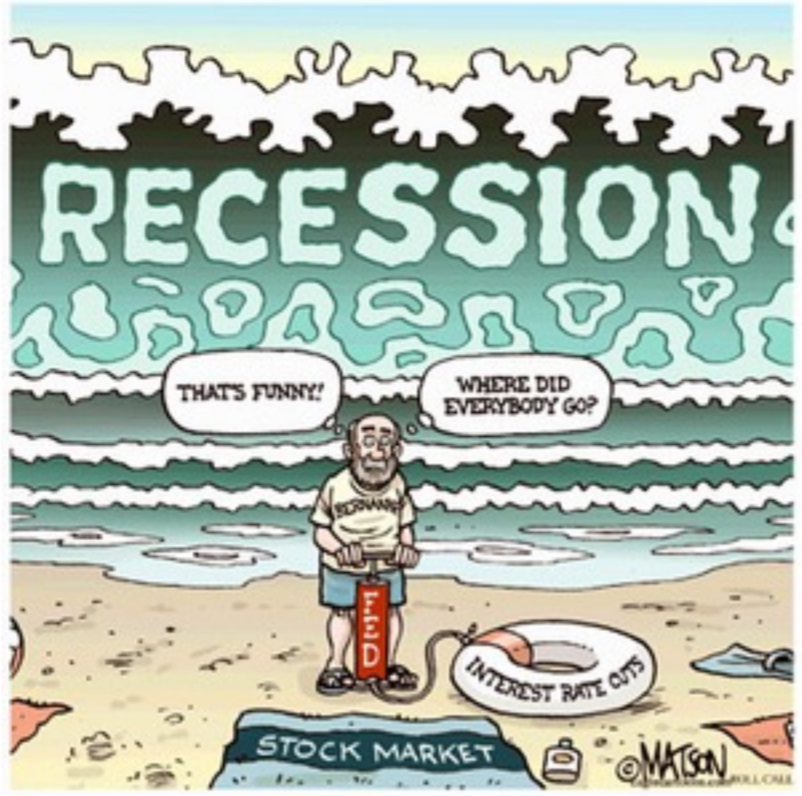
Instead of analyzing every household or firm, we often assume that there is one representative agent who makes choices dependent on his/her utility

While this often makes sense, it can also leave us with paradoxes and problems

- how do we model interactions?
- how do we explain inequality (for example in wealth)?
- how do we deal with differences in information sets or expectation formation
- different levels of rationality and behavior?



**Problem 3**: Equilibrium vs Chaos



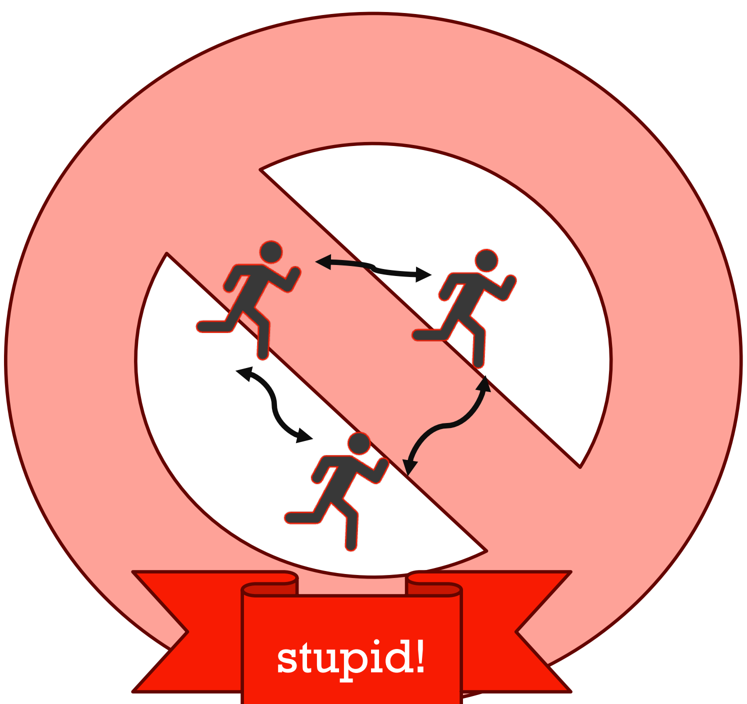

Many economic models rely on the concept of an equilibrium model. The economy/the market is supposed to return back to a (possibly new) equilibrium after a perturbation.
This often goes hand in hand with the assumption of rationality of agents.

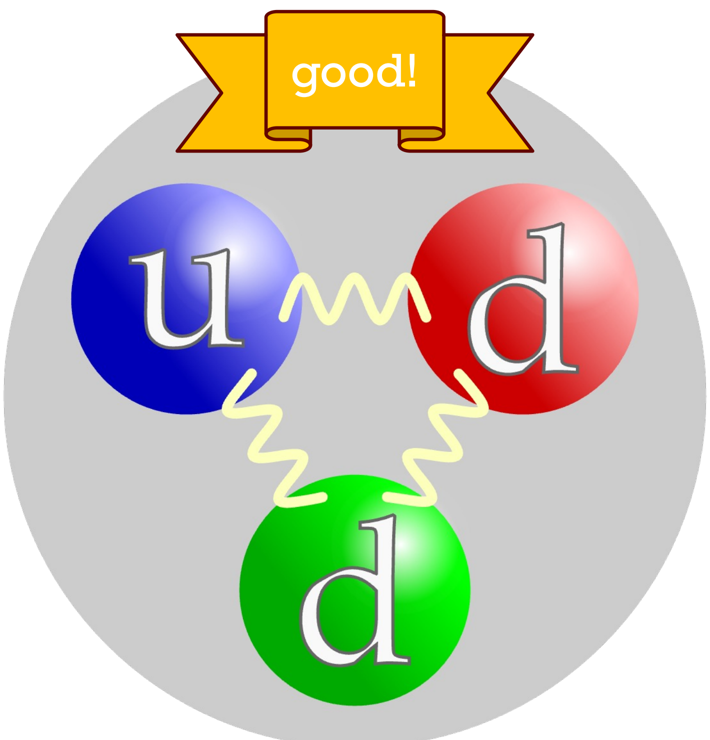
This leads to problems in explaining crisis and recessions.

- How to deal with markets that are not "in equilibrium"?
- How to explain high volatility and risks in financial markets?
- How do we deal with "irrational exuberance"?

**Problem 4**: Behavior vs Laws

The methods in economics are not always the same as in the natural sciences. One can argue that while in the latter we can for many processes uncover actual laws (of physics etc.), many processes in economic (and social) systems are governed by human behavior.
While it is true that we cannot experiment in economic systems as we can in the natural sciences and that we have to deal with a lot more ”latent” data...
Economic and social systems do in fact often show laws or regularities that we can describe as in any other scientific discipline!

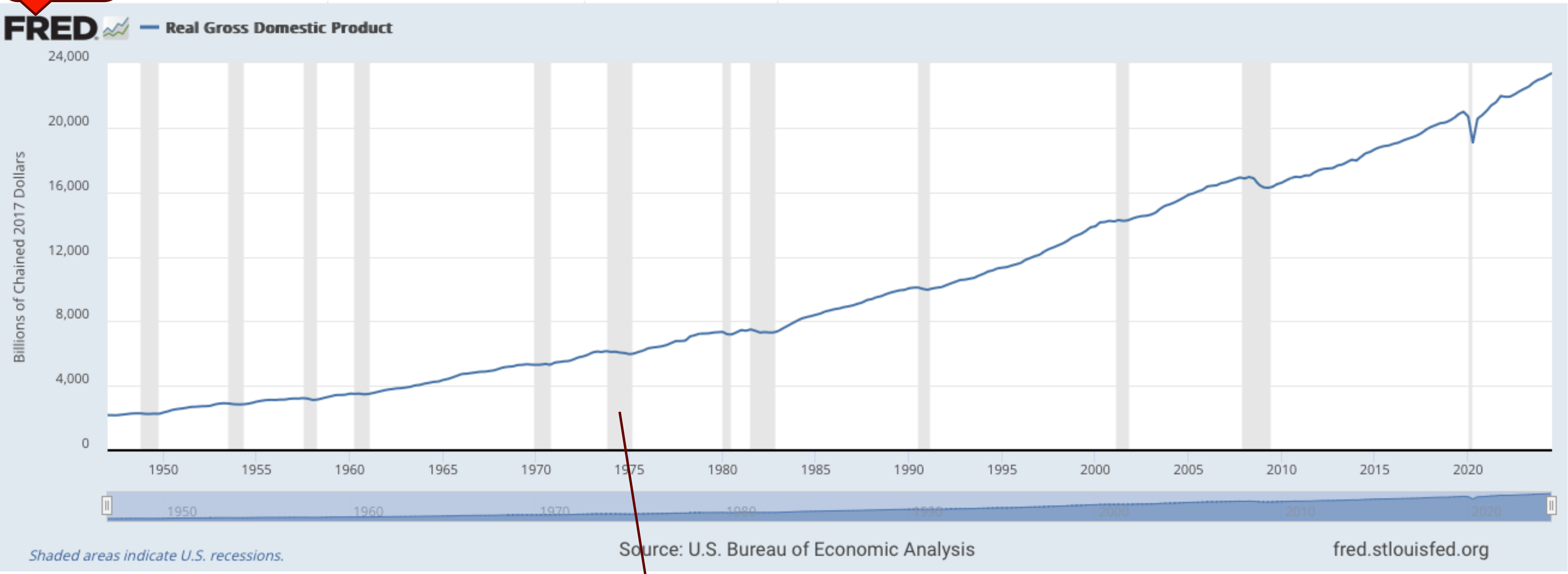


4.

# Data: GDP

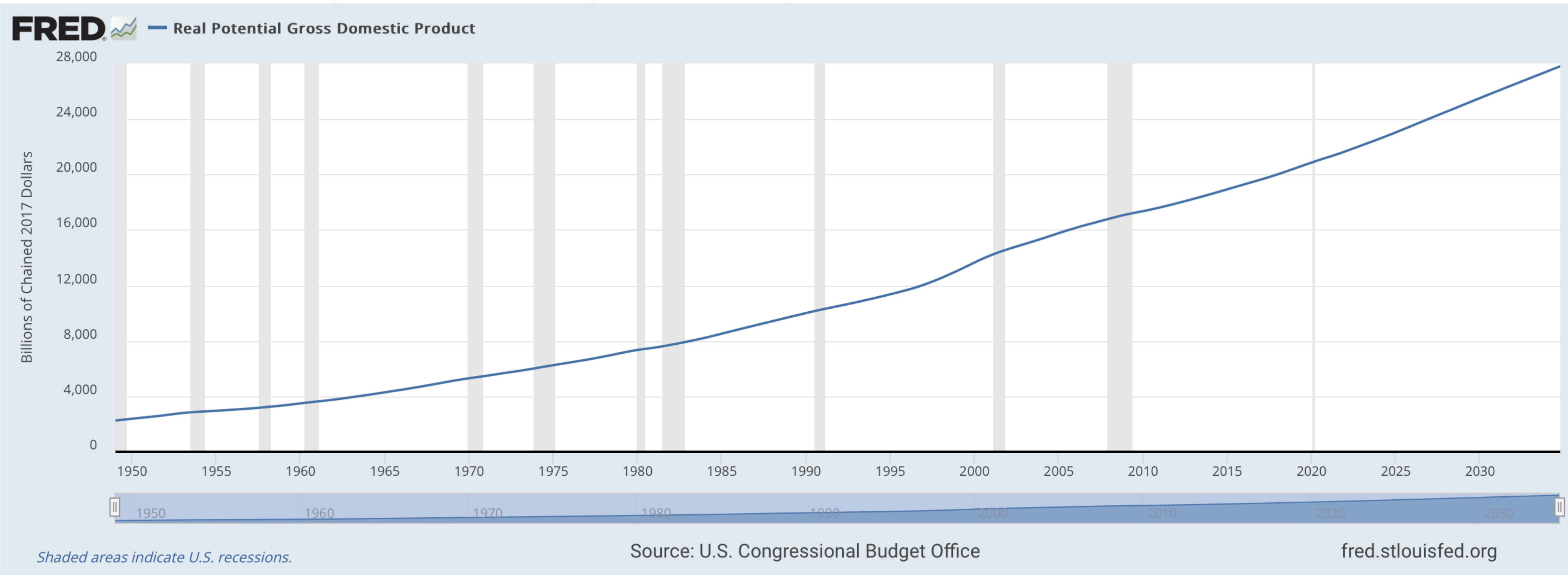
go meet Fred!




quarterly GDP data for the US

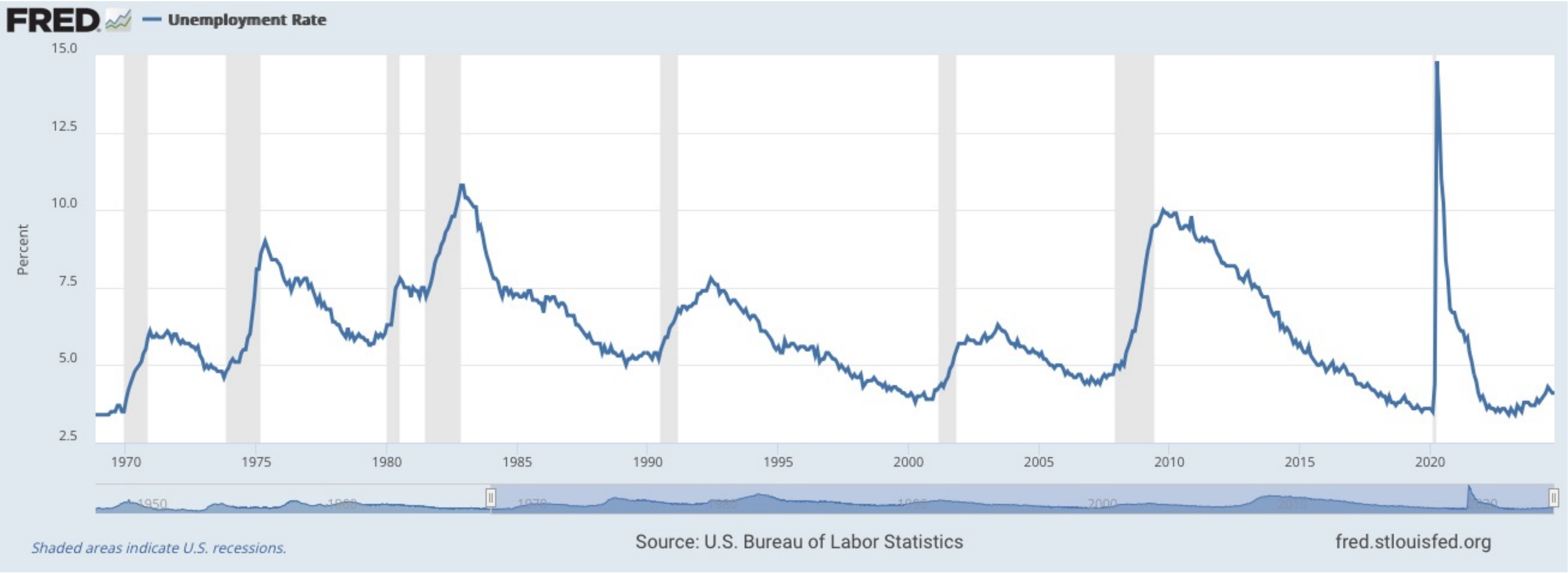
grey: recession

Data: Potential GDP



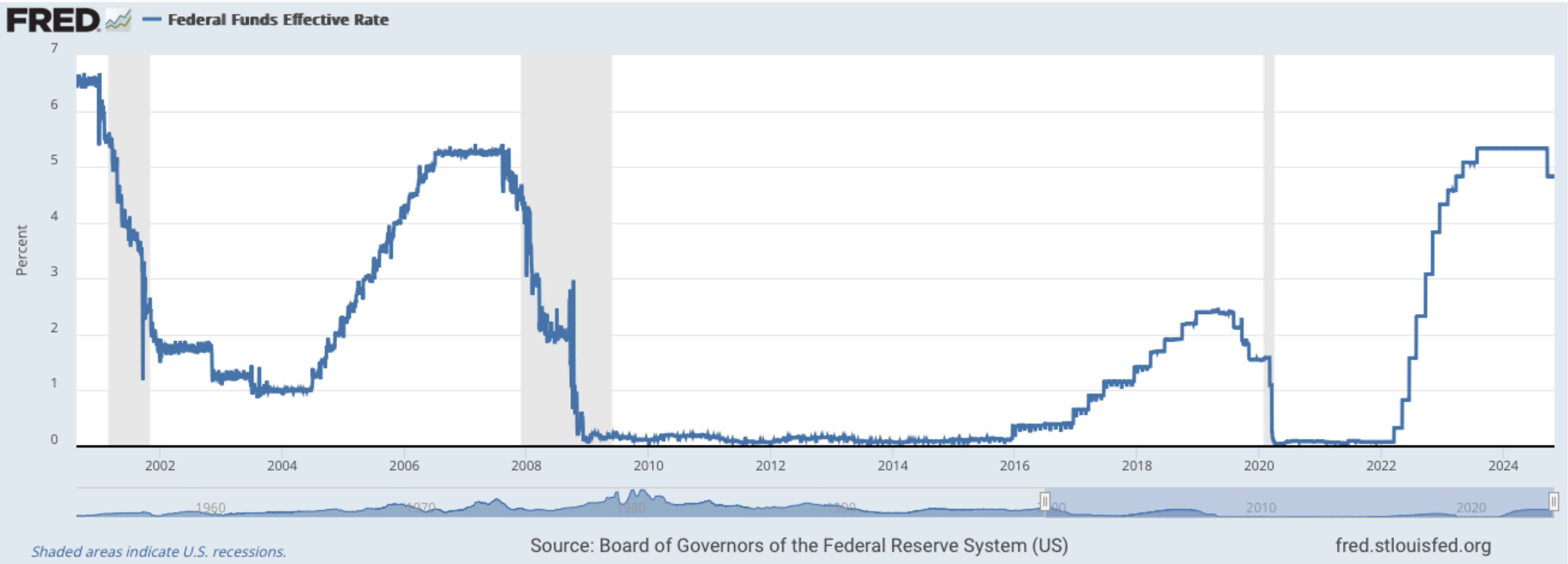

Since the actual output is fluctuating, but the economies capital/capacity has momentum, we estimate the potential output.
The difference between this and the GDP is the (output) gap, which is an important variable for policy makers.

# Data: Unemployment




monthly(!) data for the US

Data: Interest rates




the federal funds rate is set by the central bank… and is (mostly) adjusted in steps in irregular intervals

Notes

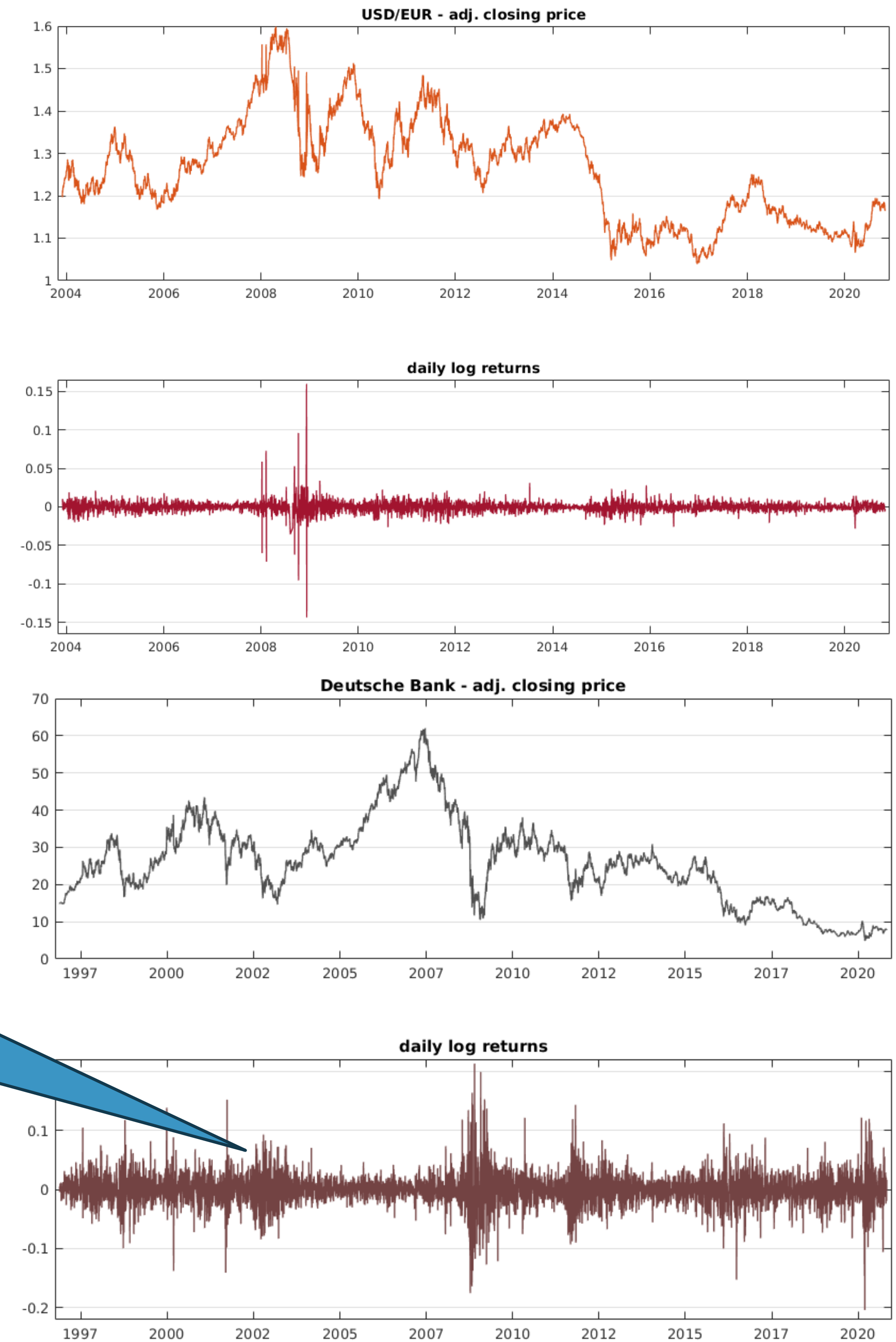
- Macroeconomic data is often available in rather limited frequency
- this makes the estimation of very rich models difficult
- Time series are often not stationary
- Many TS have seasonal patters (often HP filtering or similar is used)
- Often policy changes and/or structural changes are present
- Macroeconomic TS of smaller countries are often influenced by external factors

5.

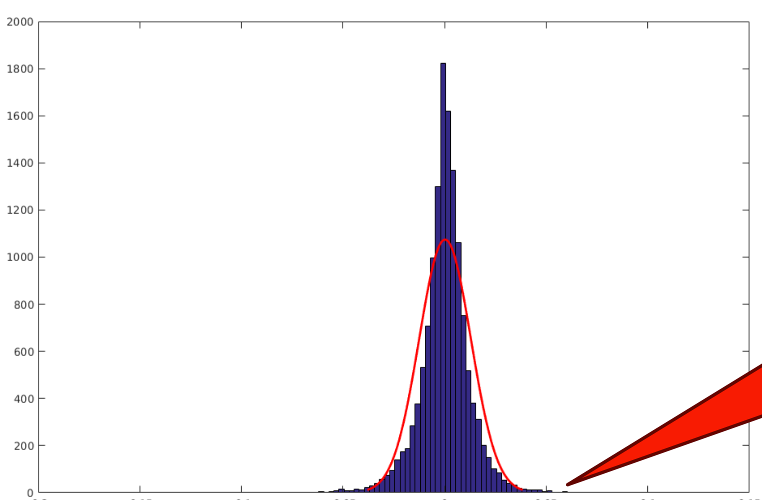
# "Big" data: financial markets

The data situation is completely different in the financial world, example: asset markets

- prices and order volumes on daily level, market participants typically use intra-day data
- this allows for some rather detailed TS analysis
    - forecasting of volatility
    - structural breaks
    - spill-overs
    - risk analysis




volatility clustering



"fat tails"

## "Big" data: financial markets – Problem 1: what is volatility?

The daily price changes in assets markets (returns) appear like some stationary process... but do they follow a random walk?

No! (autocorrelation in absolute returns and non-normal distribution)

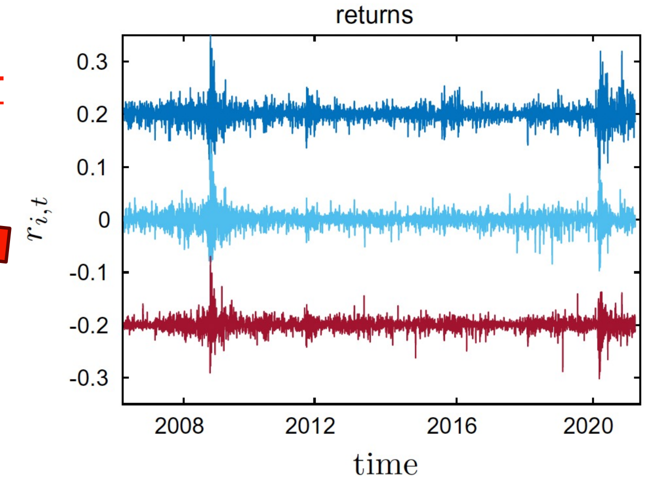
Assume returns follow a random process with $\varepsilon_t = v_t\sqrt{h_t}$ where $v_t$ is white noise and

$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i h_{t-i}$$

Hence: volatility $h$ depends on the lagged values of the returns and its own lagged values!

This is called a GARCH(p,q) process
*(generalized autoregressive conditional heteroskedasticity)*

# "Big" data: financial markets – estimated volitility



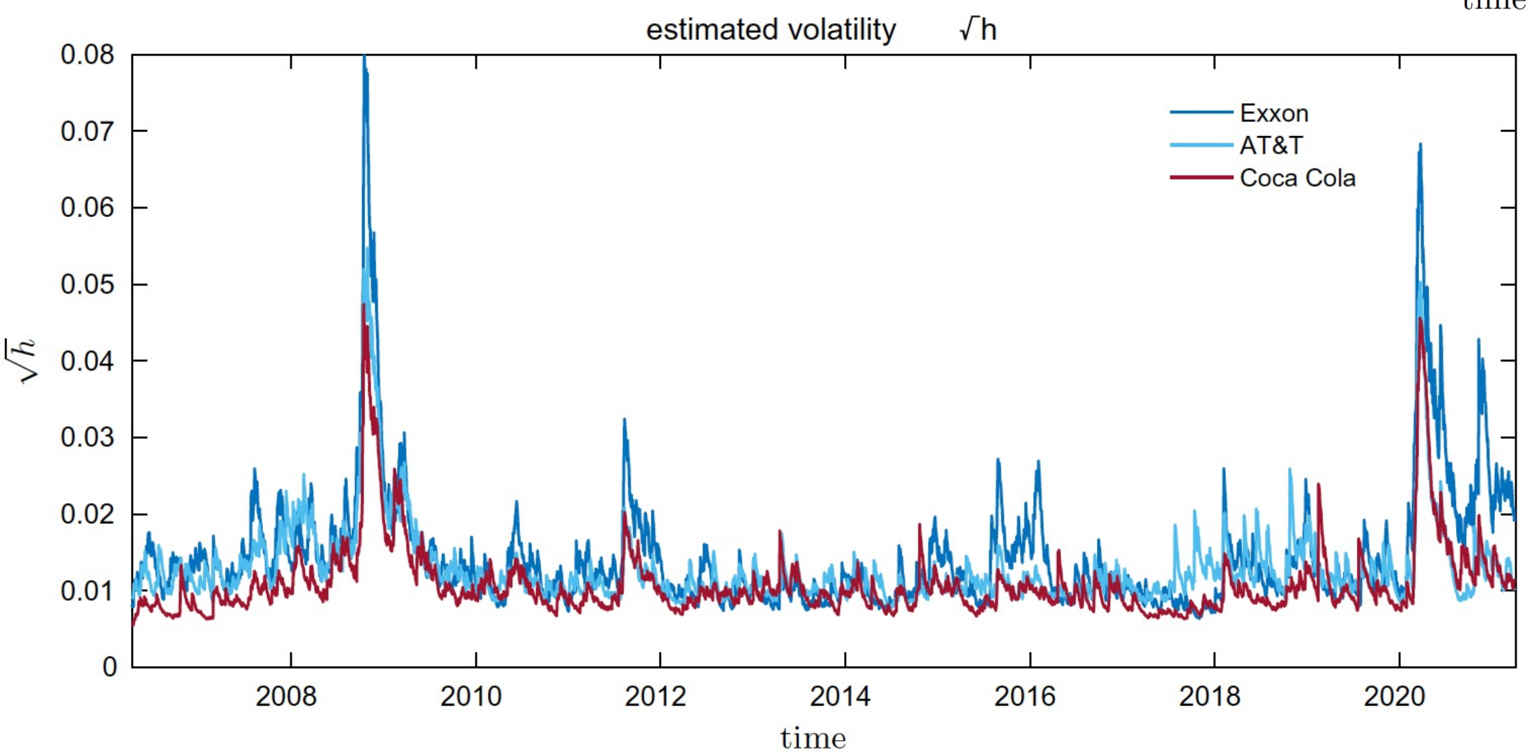




**Fig. 9** Estimated volatility from a GARCH(1,1) model for three stocks. These three time series of volatility show typical qualitative features, including pronounced peaks and decay. Nevertheless there are significant differences between the stocks that are relevant for the evaluation of stock comovement

# ”Big” data: financial markets – Problem 2: dimensional reduction

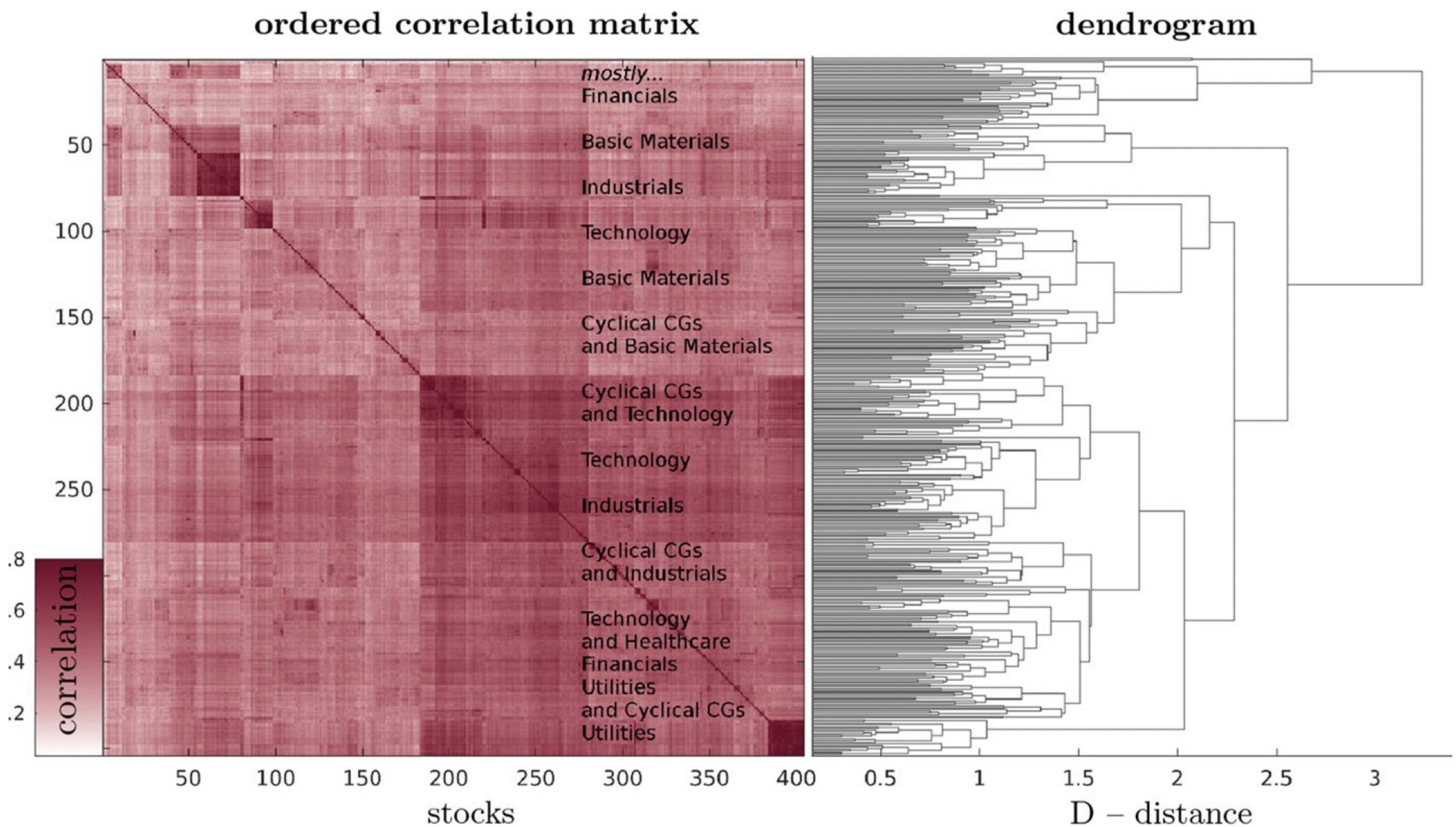



**Fig. 6** Color-coded correlation matrix and dendrogram of the hierarchical clustering for the constituents of the S &P 500. The rows and columns in the left panel are ordered according to the dendrogram in the right panel. Sector classifications for the clusters are superimposed based on the most frequent label within a cluster

## "Big" data: financial markets – Problem 2: dimensional reduction

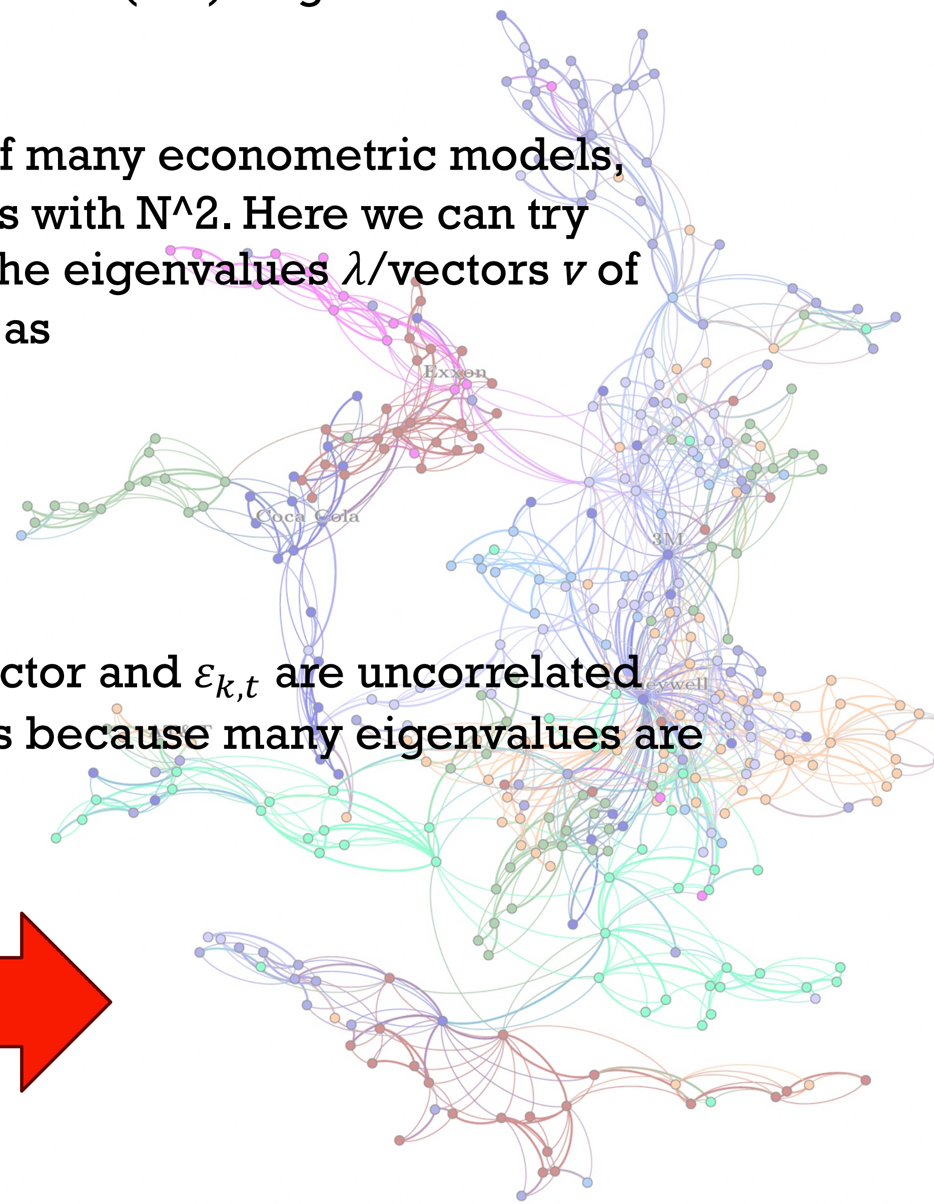
When we look at large sets of assets we end up with (too) large covariance matrices. A way out is clustering (last slide).

This can also be a problem for the estimation of many econometric models, since the number of parameters typically grows with N^2. Here we can try dimensional reduction, for example based on the eigenvalues $\lambda$/vectors $v$ of the covariance matrix we can write the returns as

$$r_{i,t} = \sum_{k=1}^{N} \sqrt{\lambda_k} v_{k,i}\, \varepsilon_{k,t}$$

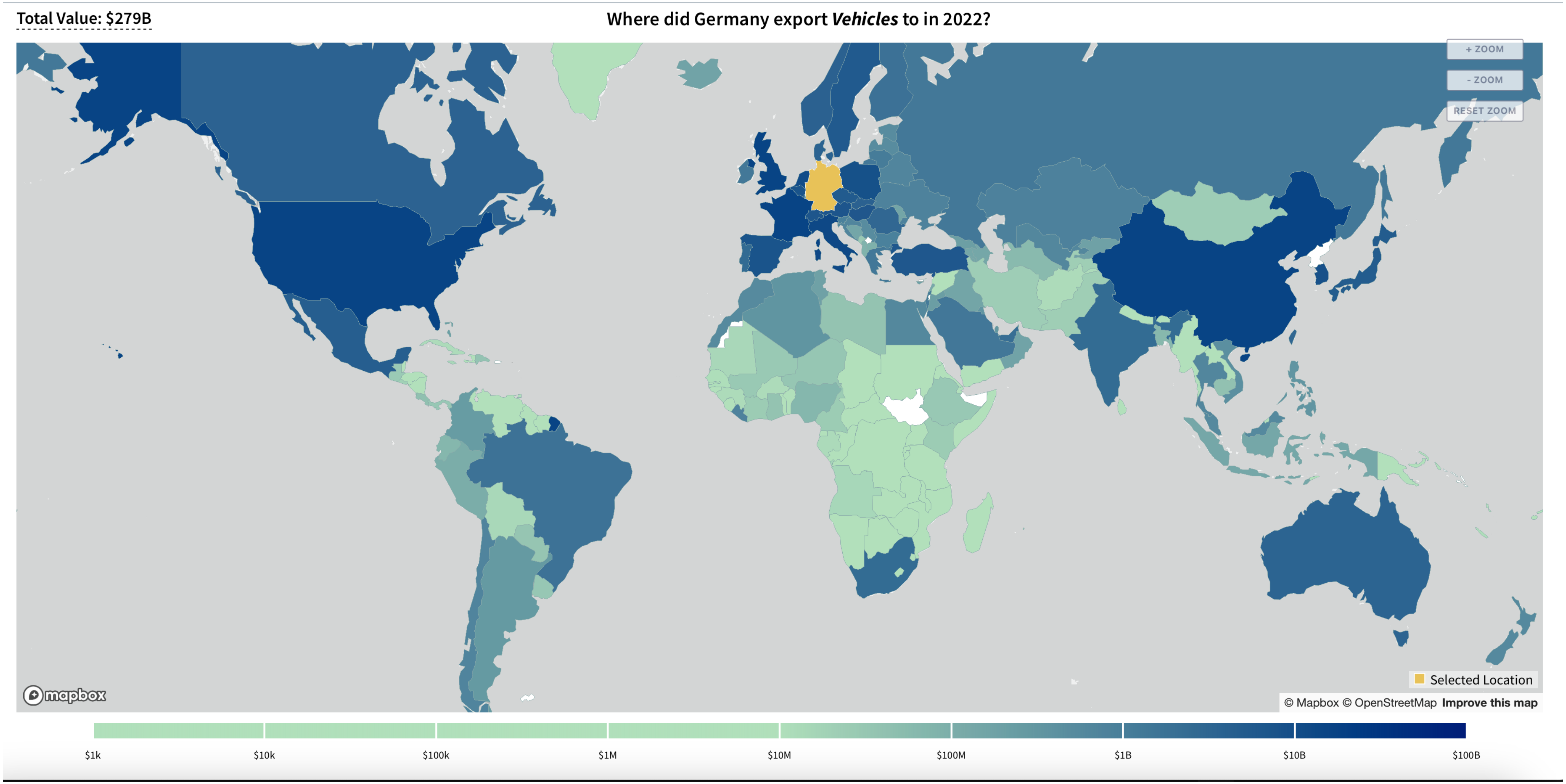
where $v_{k,i}$ denotes element $i$ in the $k$th eigenvector and $\varepsilon_{k,t}$ are uncorrelated random variables with unit variance (this works because many eigenvalues are small).

Note: we can also interpret the covariance matrix as an adjacency matrix and derive network representations of asset market correlations… see the lecture on computational finance.



## "Big" data: trade

Trade is an important aspect of economic activity. It shows the degree of cooperation as well as competitiveness of an economy and its potential vulnerabilities.




source: Atlas of economic complexity, Harvard Growth Lab

Why trade?
- comparative advantages
- resources

(Net) Exports of certain products often mean
- that a country is competitive

No exports of a certain product often mean
- that a country is not capable to produce them

Reciprocal flows can mean
- that equally developed countries compete and exchange specializations
- that their economies are integrated

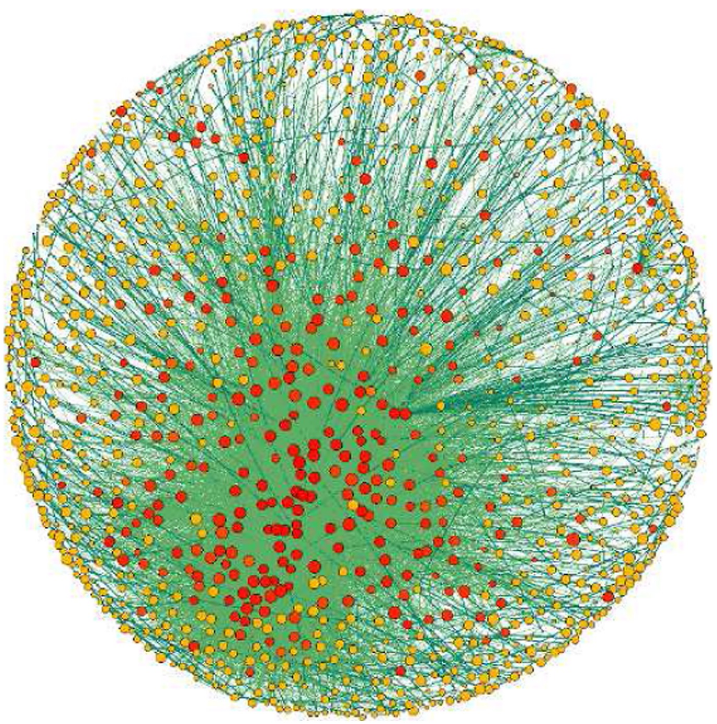
Trade data

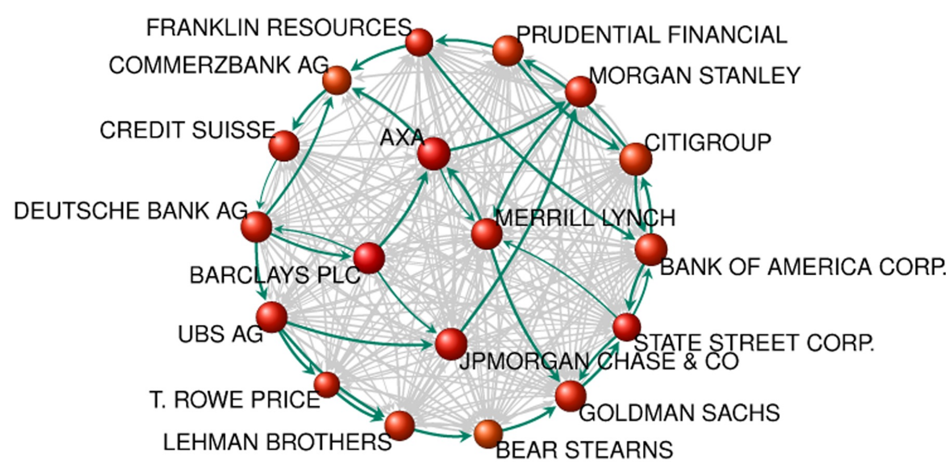
- countries report most of their trade data in an aggregated manner
- bilateral data is compiled based on customs declarations that are processed by the UN's comtrade database
- this data is available in different forms, either (relatively) raw, or cleaned up to years flows in the about 6000 product categories

## "Big" data: firm networks

A relatively new approach is to look at economic activity in terms of firm networks from different perspectives

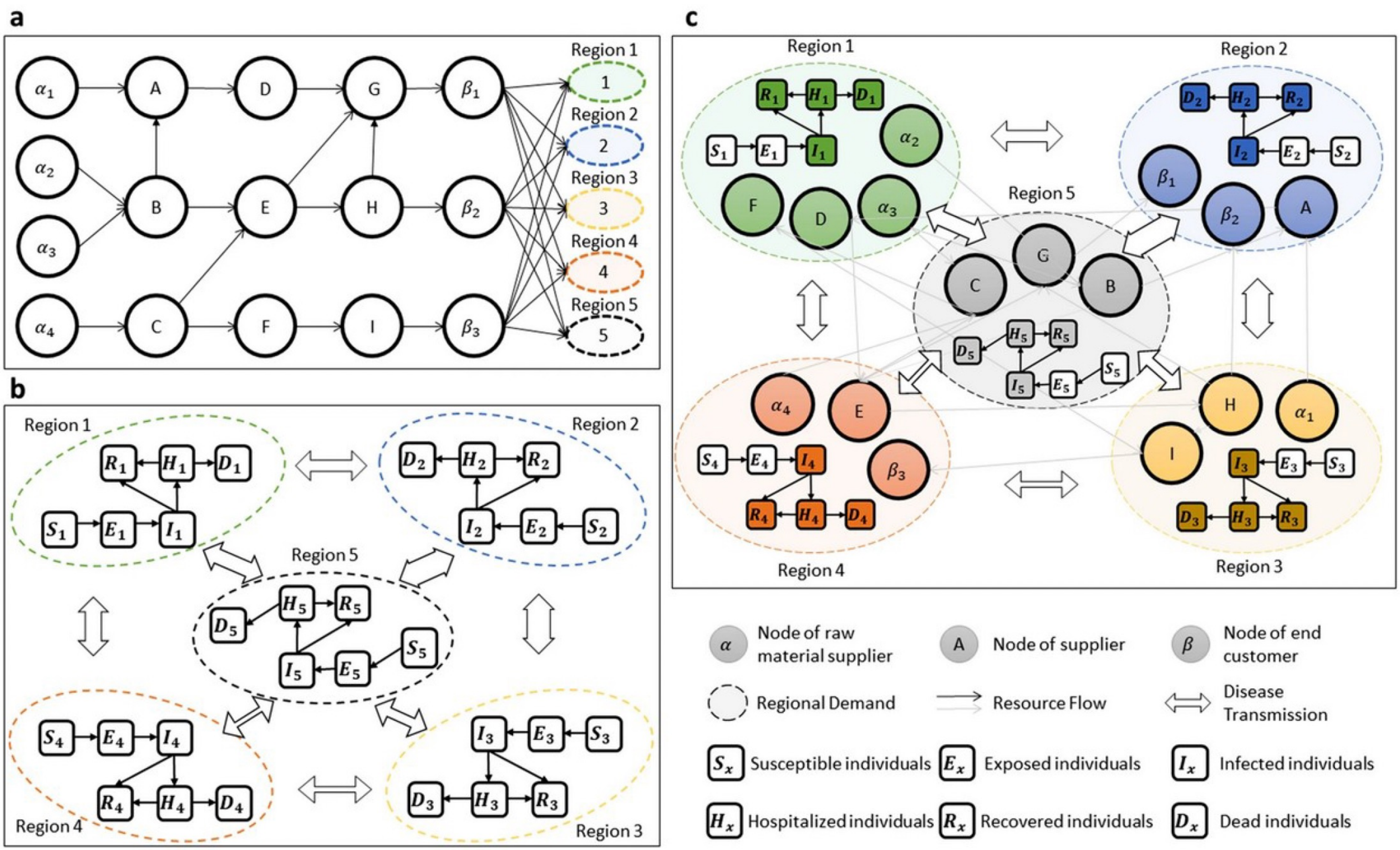
- for (economy-wide) supply chain analysis
- to analyze ownership structure
- for environmental accounting
- for stress testing and analysis of resilience






Vitali S, Glattfelder JB, Battiston S (2011) The Network of Global Corporate Control. PLoS ONE 6(10): e25995. https://doi.org/10.1371/journal.pone.0025995

# "Big" data: example for research on global supply chains




System Model of supply chain and disease dynamics: **(a)** a classic supply chain network with three types of products; **(b)** a classic multi-patch disease network for COVID-19; **(c)** the model of multi-patch disease and the production and supply chain.

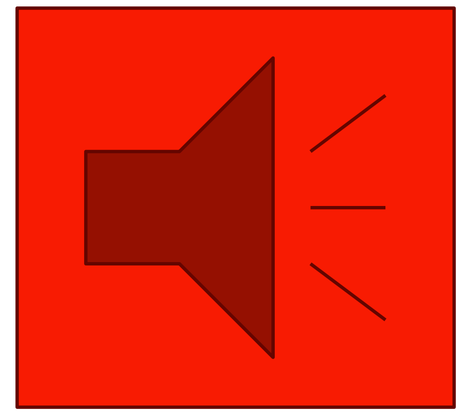
Li, X., Ghadami, A., Drake, J.M. et al. Mathematical model of the feedback between global supply chain disruption and COVID-19 dynamics. Sci Rep 11, 15450 (2021)

6.

## "Big" data: caveats

### Big data vs classical modeling

- big data analysis of economic systems often comes with an availability bias
- parts that are transparent and developed are analyzed, other parts of the economy/world are ignored
- data availability is not random but follows economic and political interests!
- understanding a system means to be able to condense it to key mechanisms and to make predictions
- this requires domain knowledge from economics and the social sciences
- modeling the entire economy is about as useful as a map in a 1:1 scale



# courses in CSS

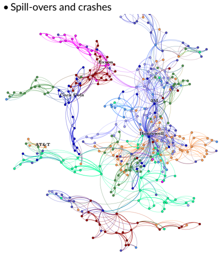
**New course** on **Computational Finance**. Learn about **financial market data**, models and applications.

## Computational Finance

Matthias Raddant, Institute of Software Technology

### Topics

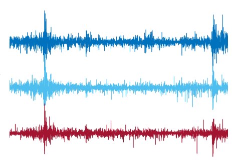
- Statistical regularities of asset markets
- Fundamental value, efficient markets, risk
- Models of information transmission
- Models with chartists and fundamentalists
- Univariate time series analysis and models
- Multivariate models and data analysis
- Random matrix theory, spectral decomposition
- Portfolio selection
- Network approaches to asset markets
- Spill-overs and crashes




Filtered graph for constituents of the S&P 500

### Course content

This course offers an introduction to topics in (computational) finance and financial econometrics. We start with an exploratory overview about the characteristics of asset markets, in particular time series of returns. We continue by defining basics concepts in finance, like efficiency, risk, and the fundamental value of an asset. We then have a look at market microstructure, with a focus on models about the transmission of information and the interaction between different agent types. For the rest of the course, we deal with several aspects of time series modeling and its application. These are the modeling of returns in uni- and multivariate settings, the applications to portfolio selection, as well as interdisciplinary approaches to spill-overs and interdependencies in financial markets. This includes methods from network science and complex systems analysis.



Daily returns of three stocks, 3775 days

### Target group

This course is aimed at master students with some background in data science (including students from the CSS program), physics or engineering who are interested in applications to financial markets. The course can however also serve as a relatively self-contained introduction to financial markets for students from other study programs.

course name: Computational Finance
number: 716.245
when: Wintersemester 24/25
starts: 3 October
room: Seminar room IST, IC02062
contact: raddant@tugraz.at

Scan QR code to go to course catalogue and register

TU Graz

from summer semester 2025

## Economic systems

1. Introduction: Economic concepts and computational economics
2. Socio-economic household data
3. Behavioral aspects and agent heuristics
4. Agent-based modelling of economic systems (I/II)
5. Data from financial and capital markets
6. Dynamics in macroeconomic models
7. GDP Data and forecasting
8. Interorganizational networks
9. Supply chain data
10. Data analysis of international trade
11. Flow of resources and supply security
12. Complex systems and resilience
13. Complexity and sustainability