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From Physics to Finance

41st Heidelberg Physics Graduate Days

excerpt for publication

For publication, slides and images have been partially removed. Sources and references are shown using light blue boxes with red text.

Heidelberg, October 08th, 2018

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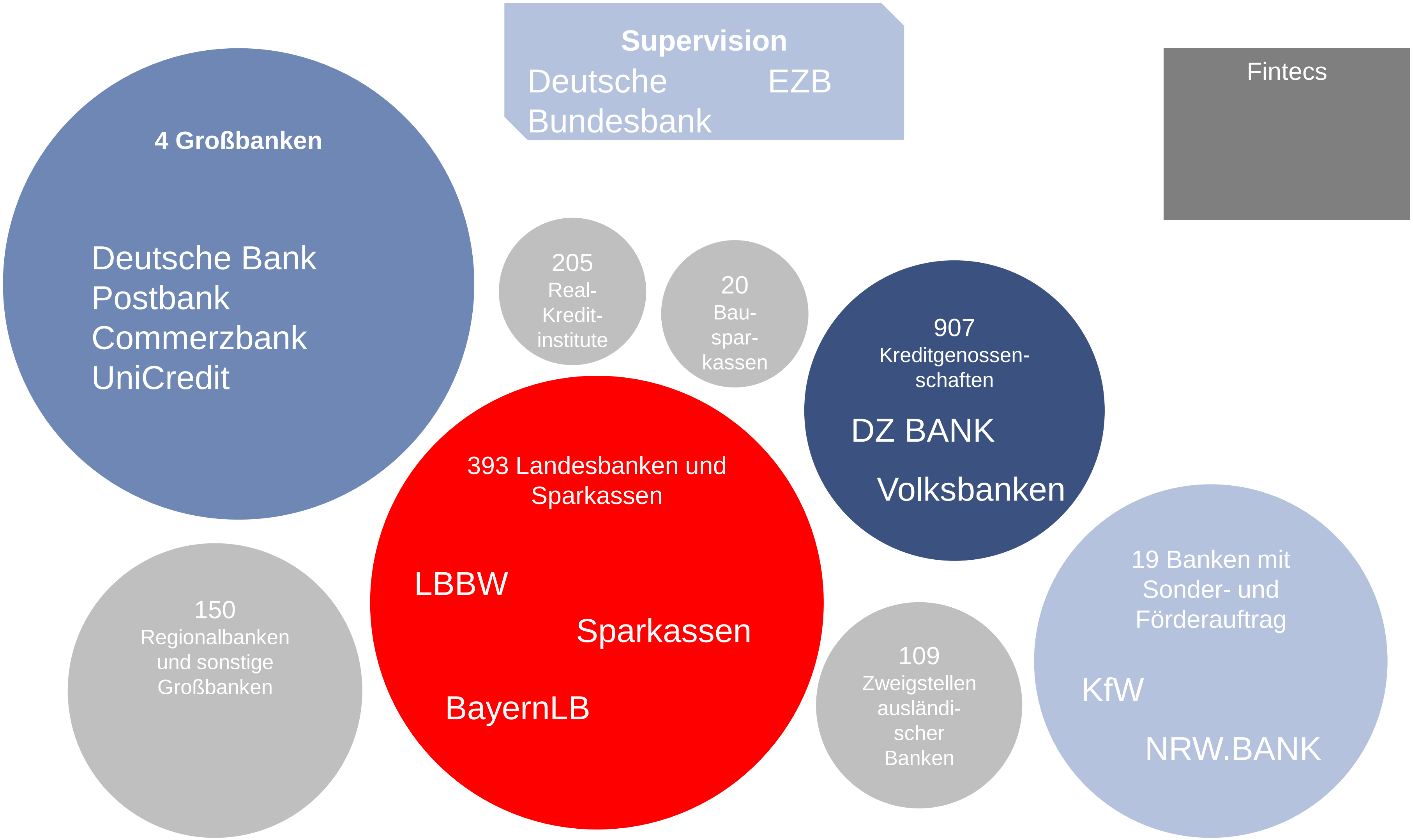
Agenda

The banks’ role in the economy

Banking landscape in Germany



Source: Bankenstatistik, Statistisches Beiheft 1 zum Monatsbericht, Deutsche Bundesbank, September 2018, S. 106, Size of circle proportional to accumulated balance sheet data from July 2018

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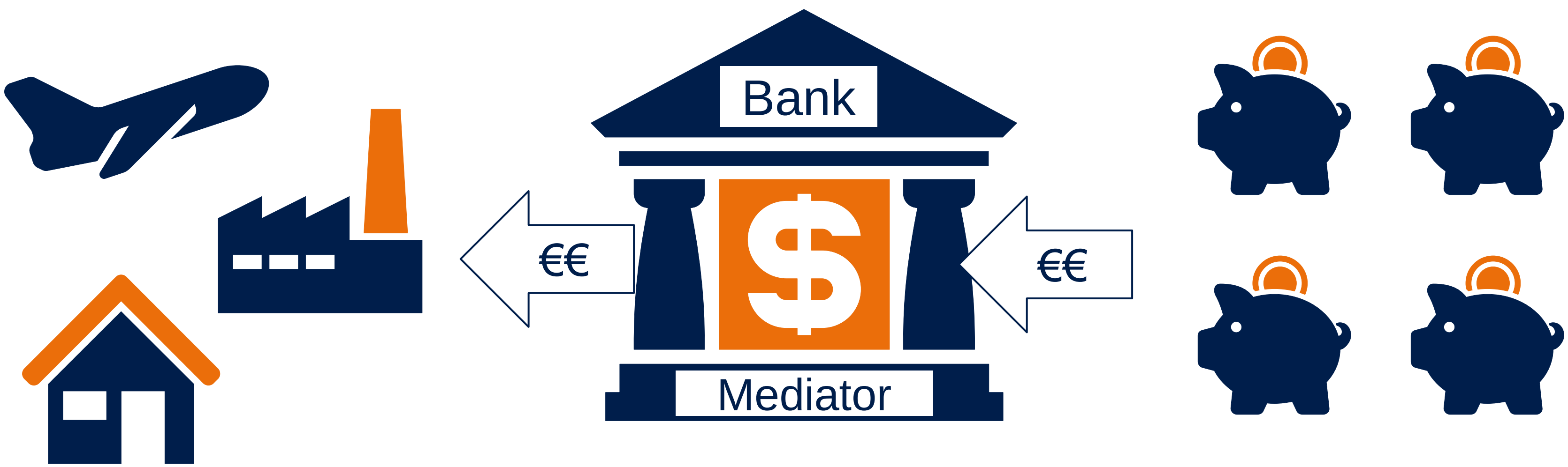
The banks’ role – Transforming money



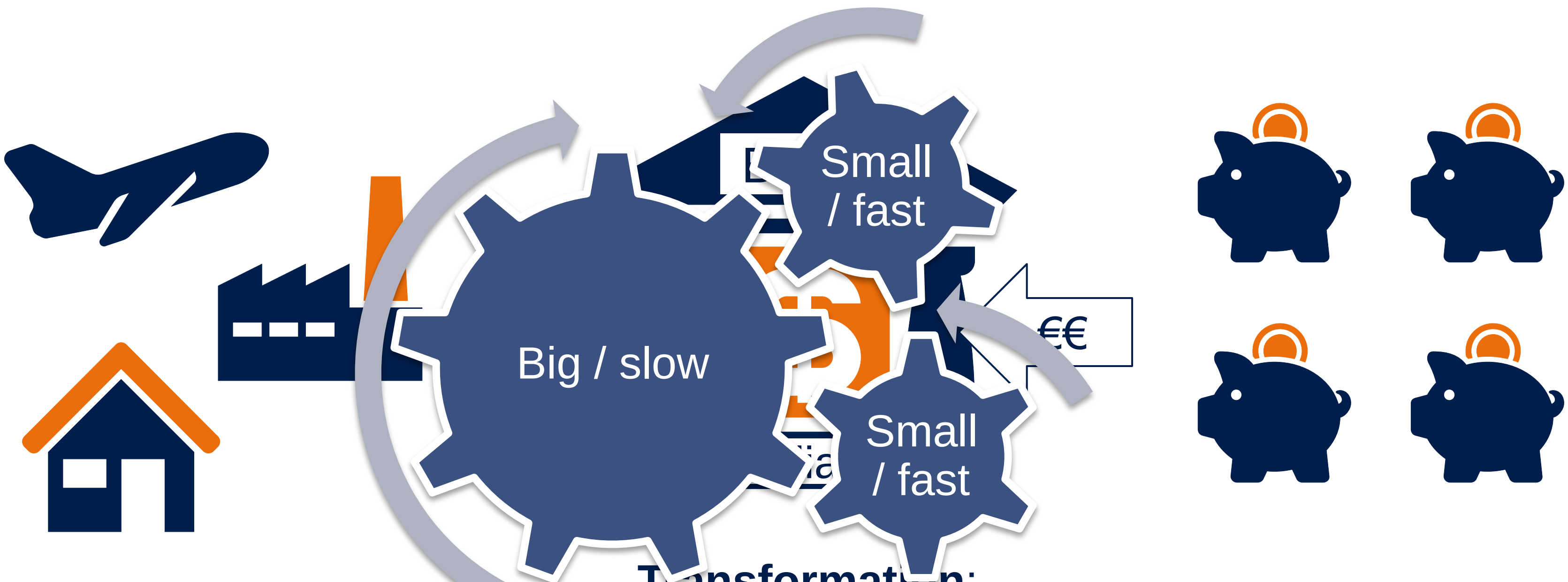
Capital demand:
big, long term demanded capital amounts

Transformation:
- Quantity
- Term
- Risk

Capital supply:
many small, rather short term supplied capital amounts

Transformation is at the heart of banking business

The banks’ role – Transforming money



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Transformation is at the heart of banking business

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Traditional tasks of a bank

Capital / Liquidity transformation

- **Volume transformation**
- **Term transformation**

Risk taking

Information offset

Both forms of transformation hold specific risks for the bank which need to be quantified and controlled:

- » Volume transformation ↔ Credit Risk
- » Term transformation ↔ Liquidity Risk and Interest Rate Risk
- » Currency transformation ↔ FX Rate Risk
- » Equity Prices, Stock Exchange Rates, …

Transformation is at the heart of banking business

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Traditional tasks of a bank

Capital / Liquidity transformation	Risk taking	Information offset

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Both forms of transformation hold specific risks for the bank which need to be quantified and controlled:

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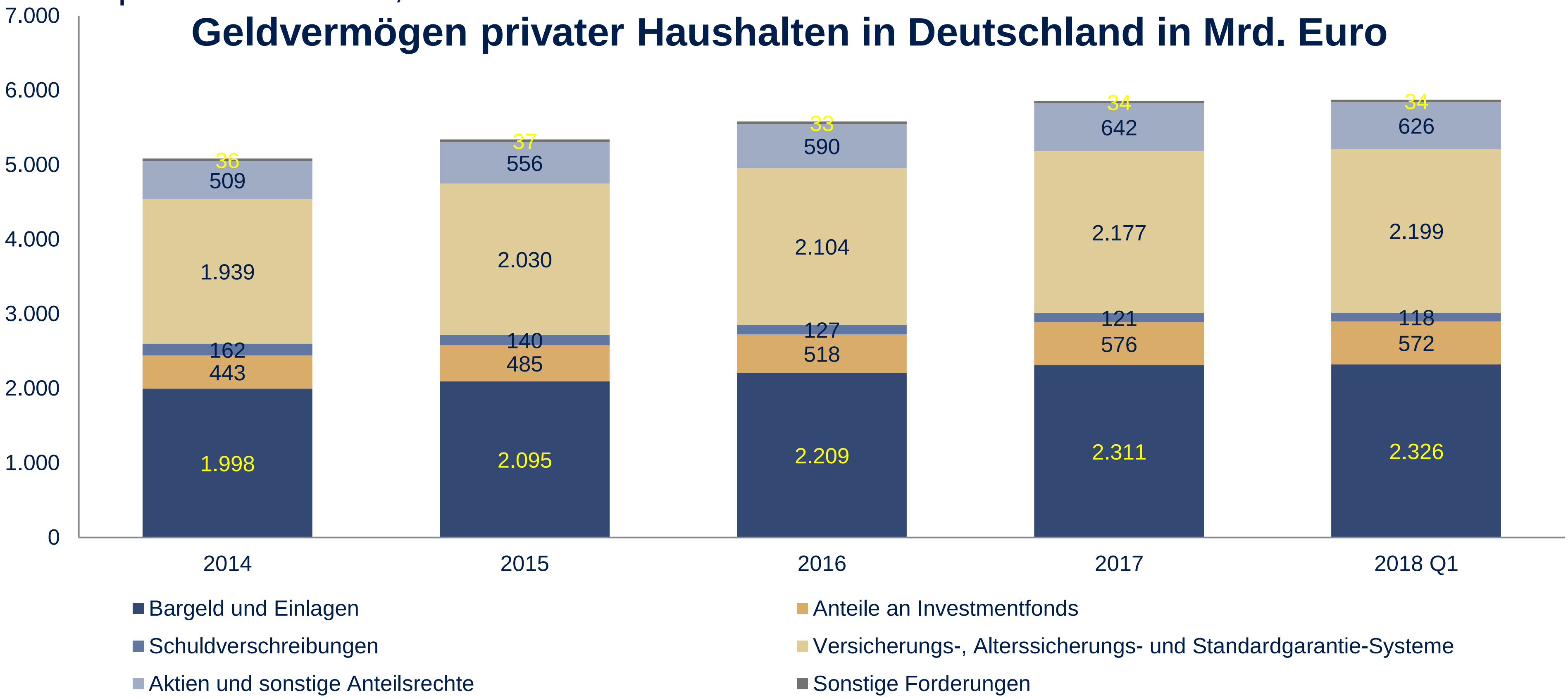
» Equity Prices, Stock Exchange Rates, …

Transformation is at the heart of banking business

German saving behaviour

» Germans still invest the largest part of their capital in savings- / sight- / term-deposits and cash, as well as insurances



We have savings of about 5,5 trillion EUR

Data Source: Deutsche Bundesbank, September 2018

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Time series in finance – non-linearity and prediction of the future

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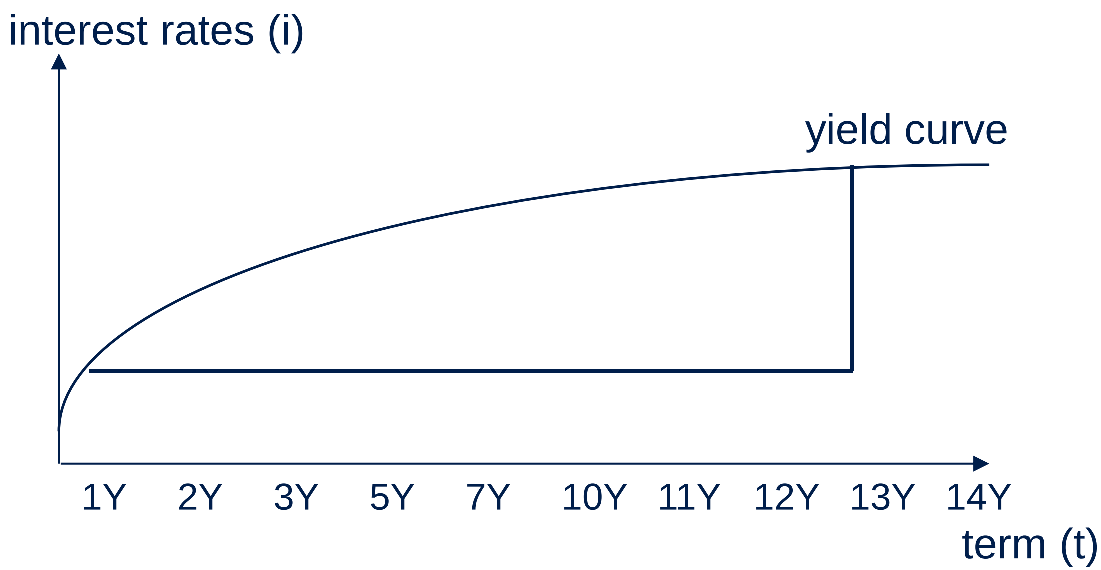
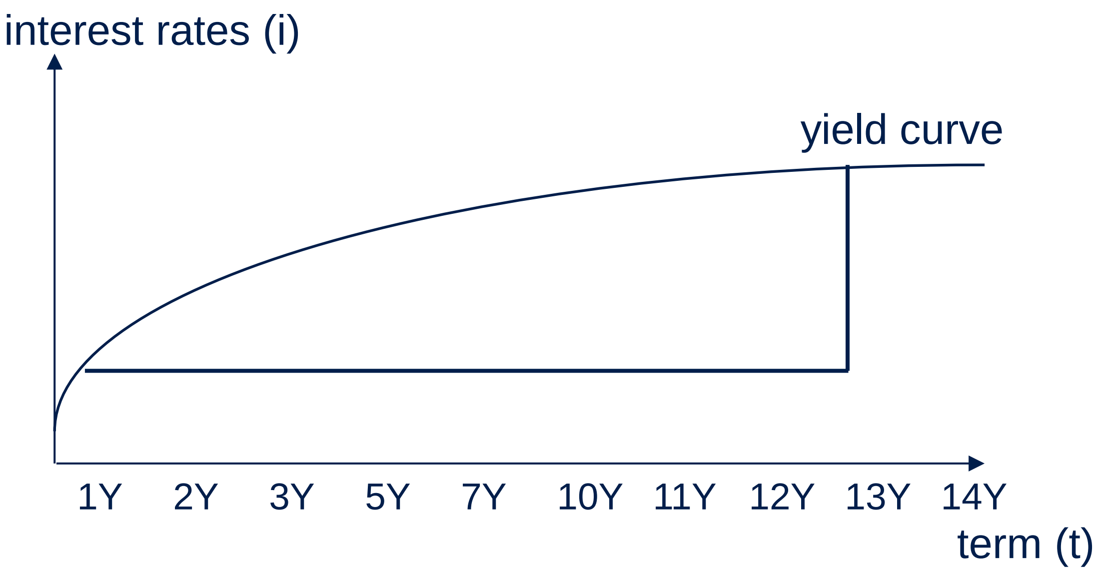
The yield curve



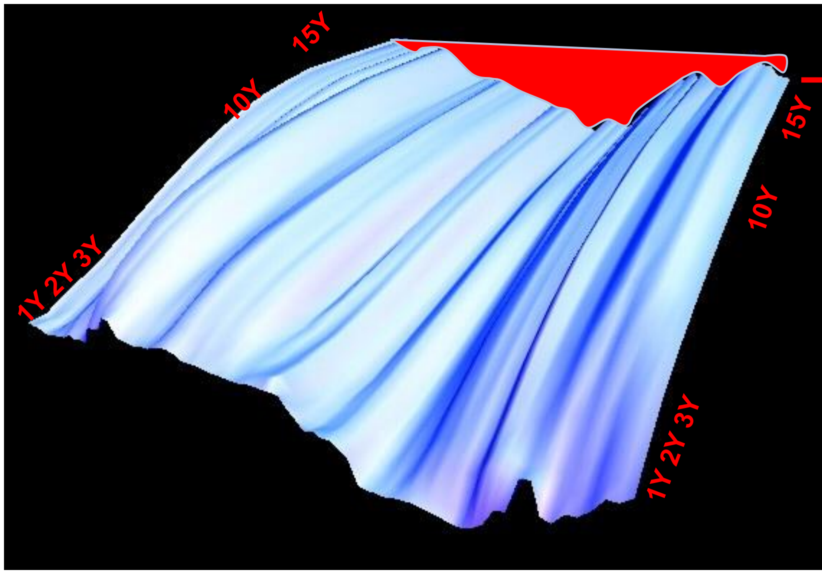
Term transformation, i.e., transformation in time, is a major transformation

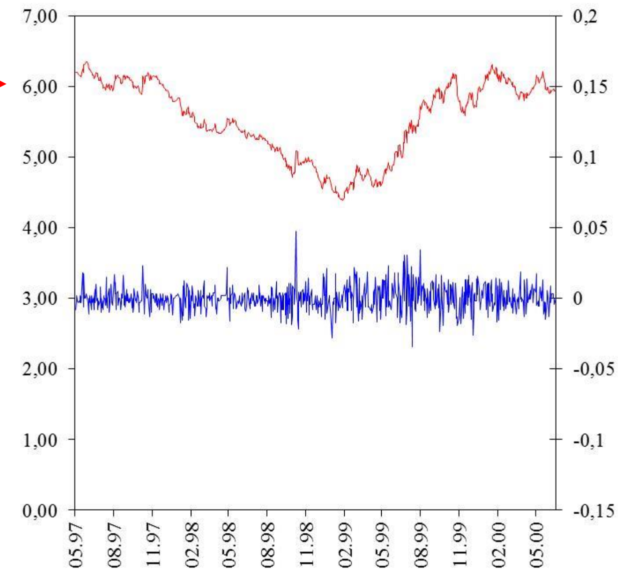
The yield curve



Term transformation, i.e., transformation in time, is a major transformation

Interest rates and their dynamics





The change in interest rates follows no simple statistics

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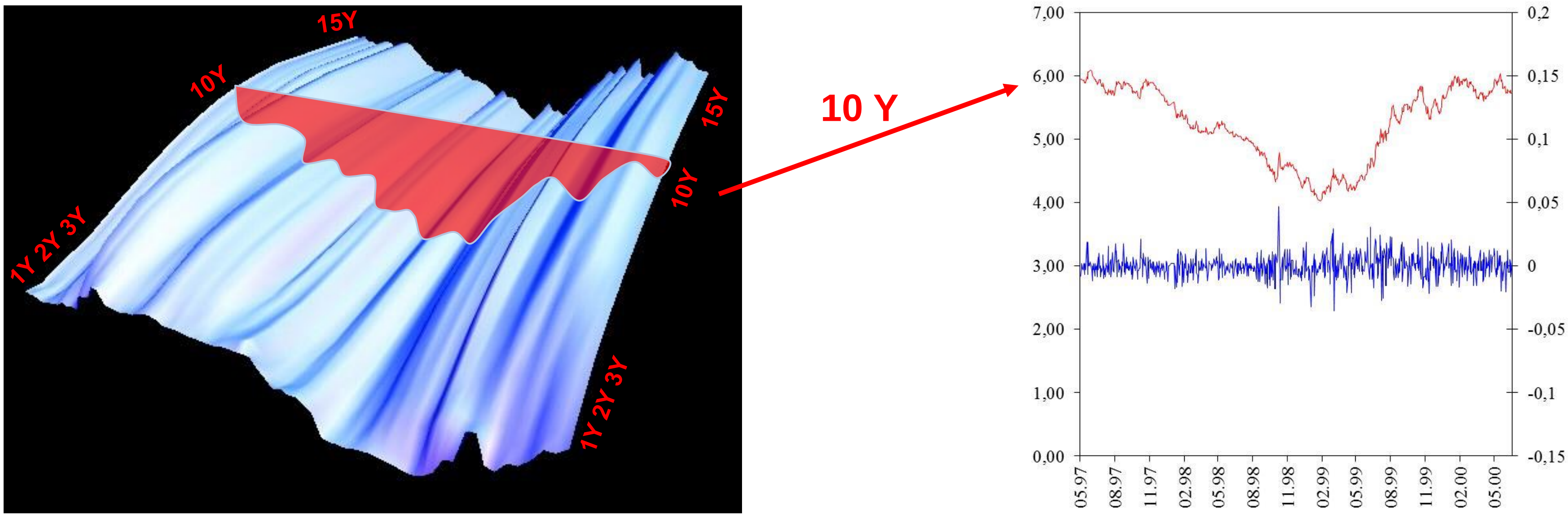
Interest rates and their dynamics



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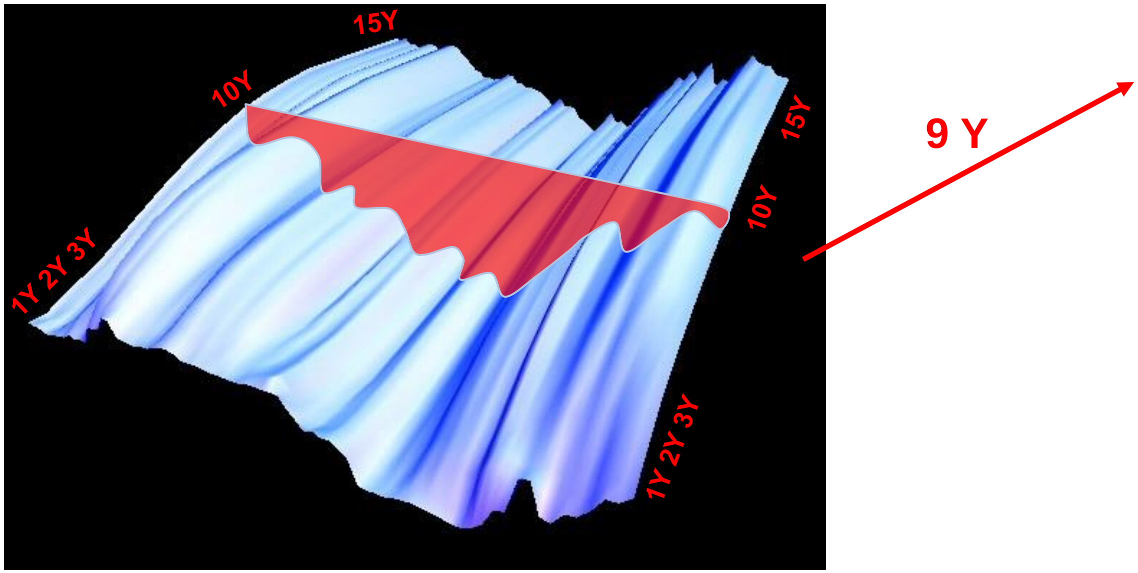

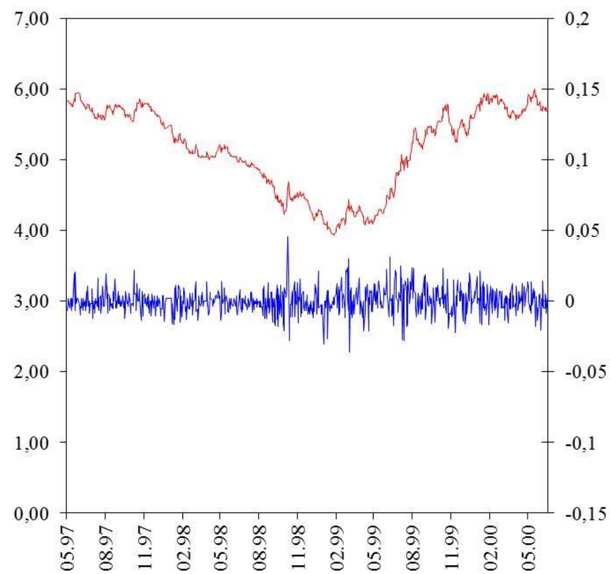

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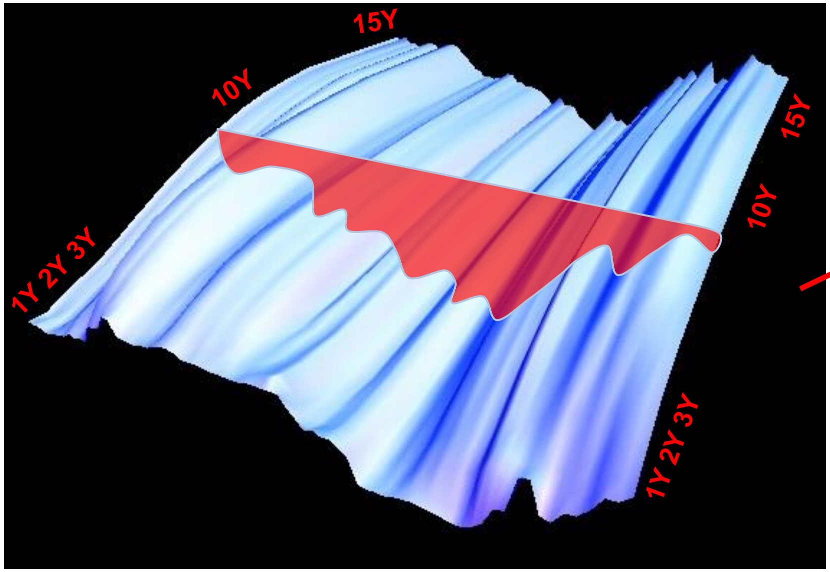

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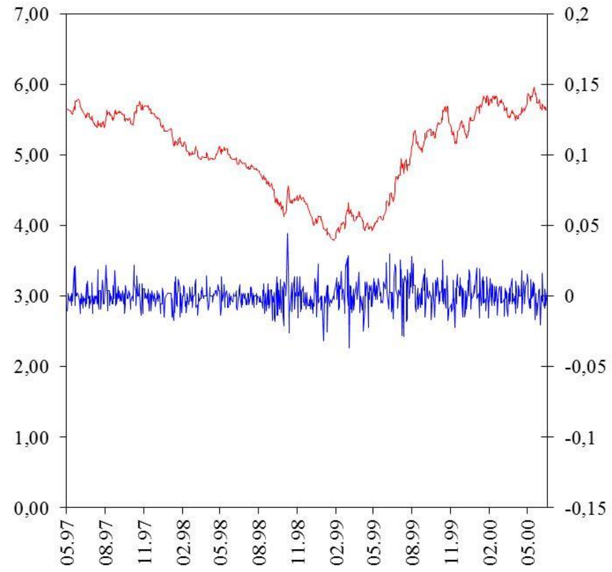

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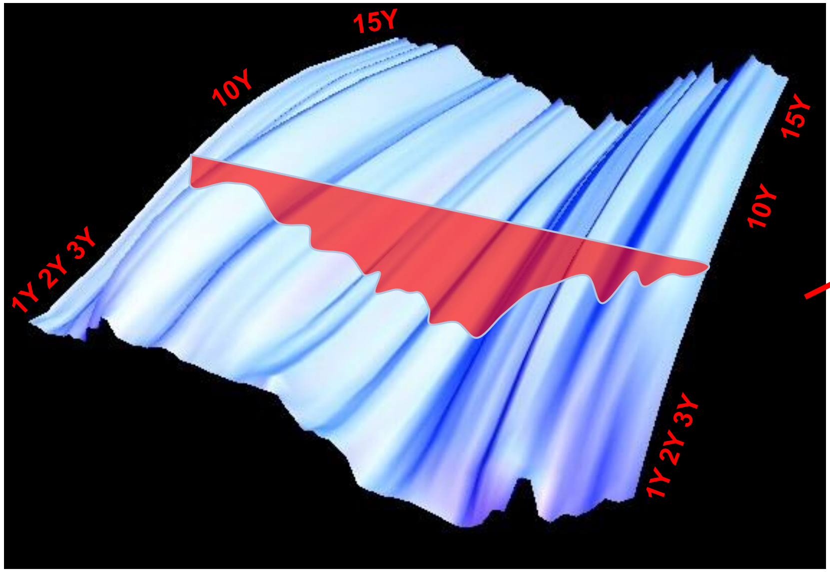

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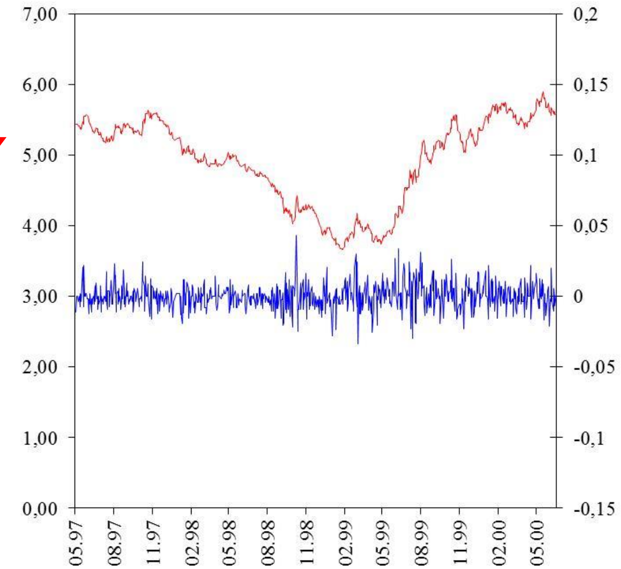

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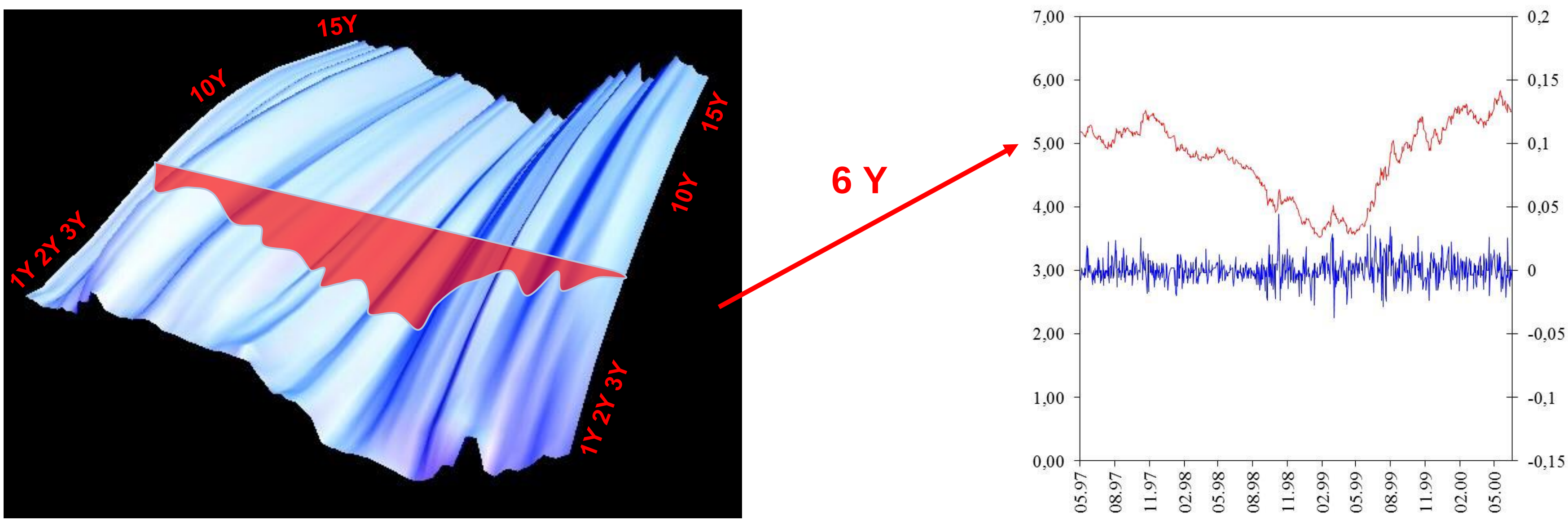

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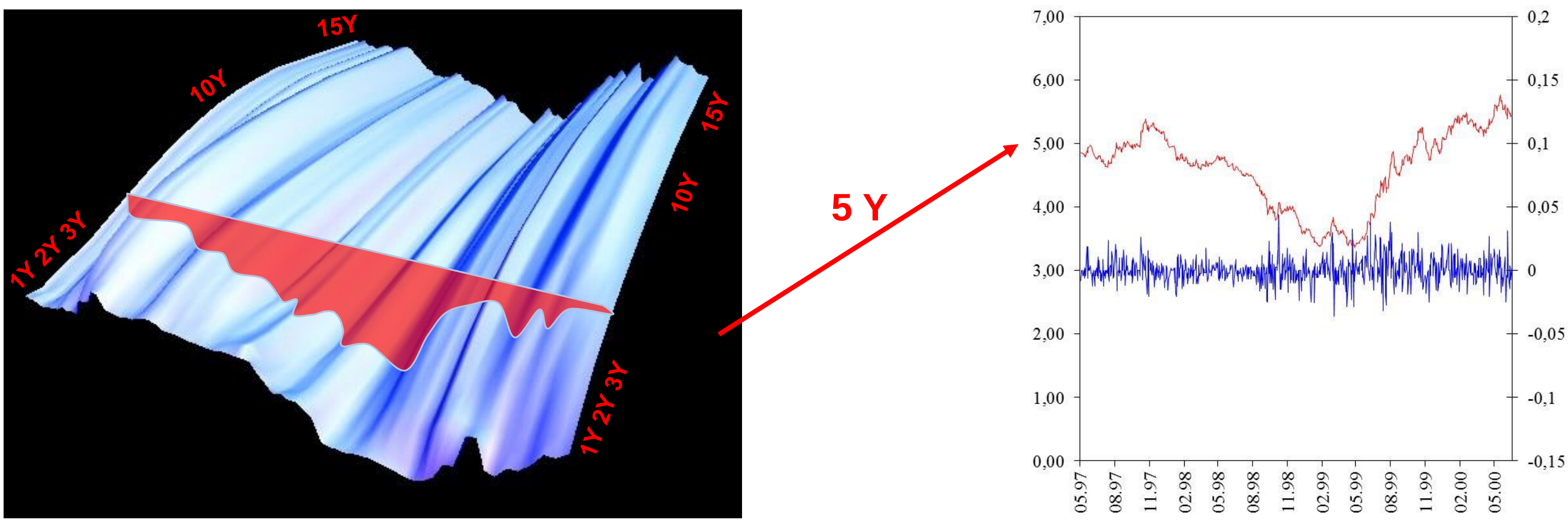

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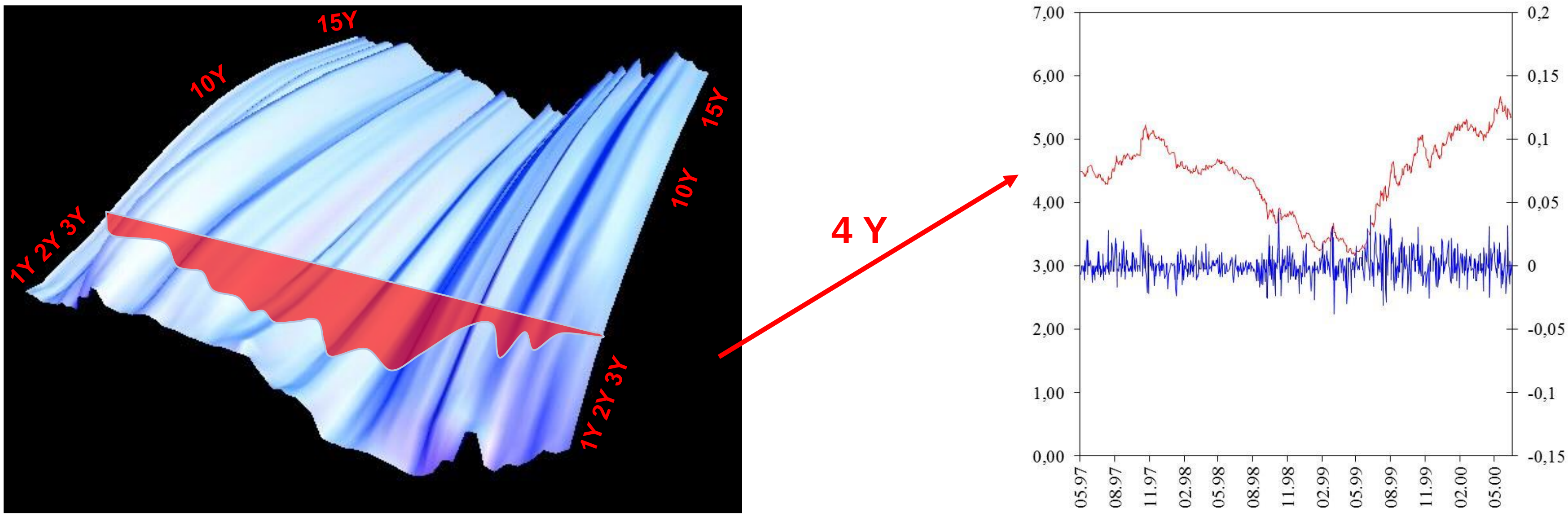

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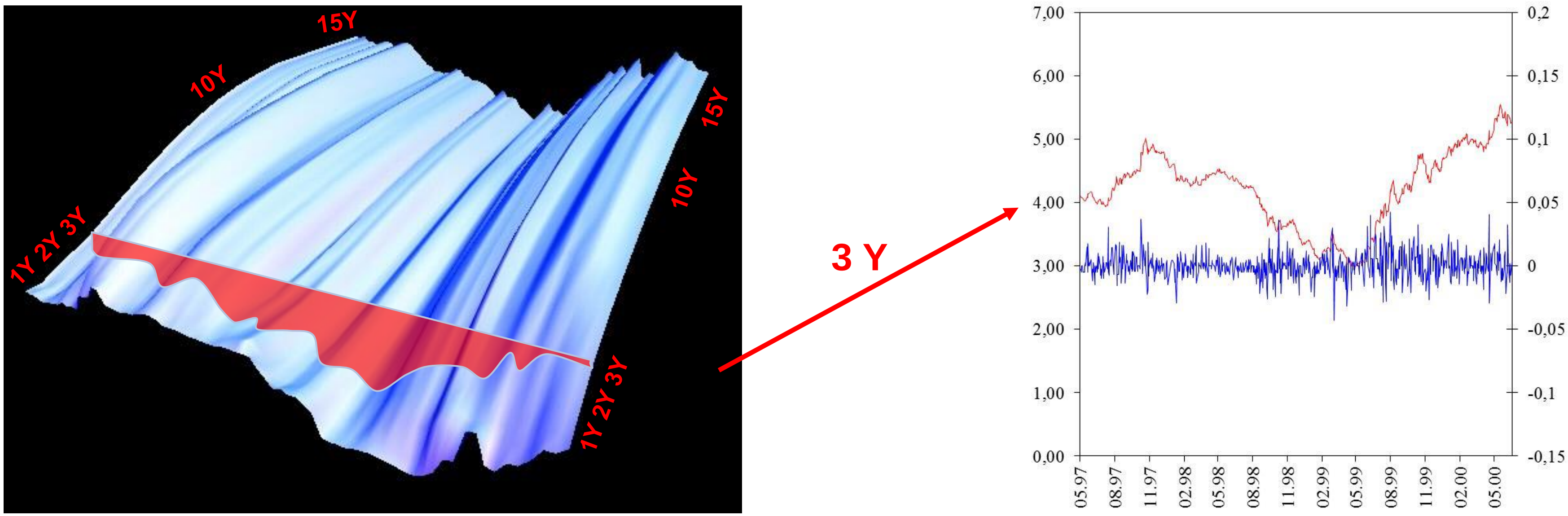

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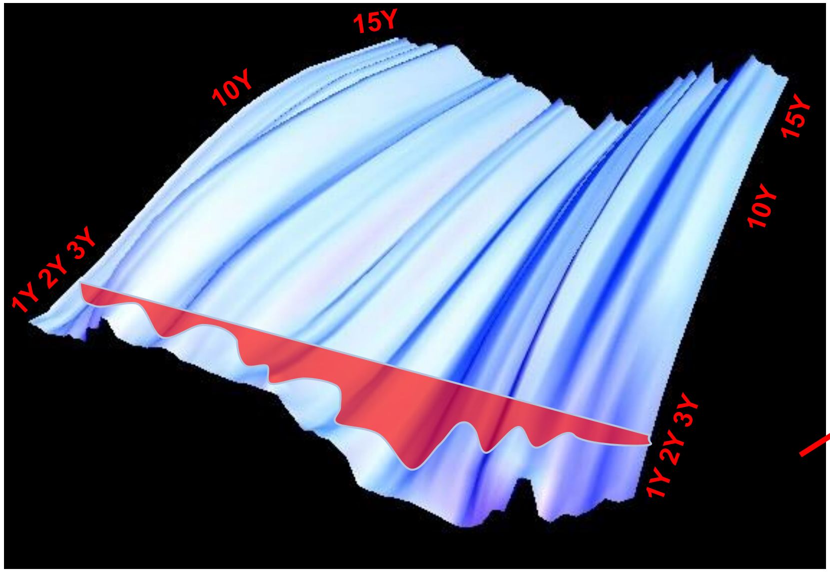

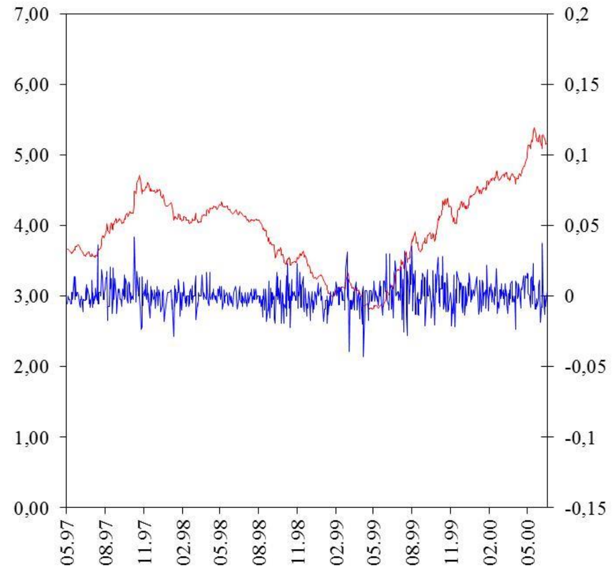

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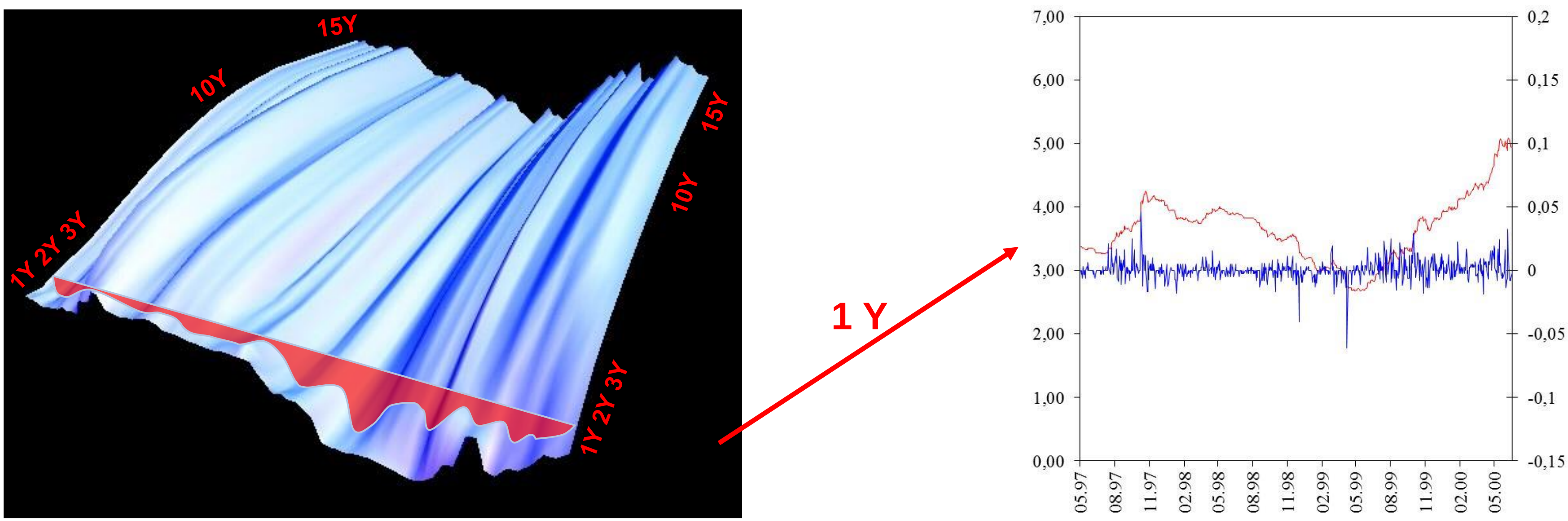

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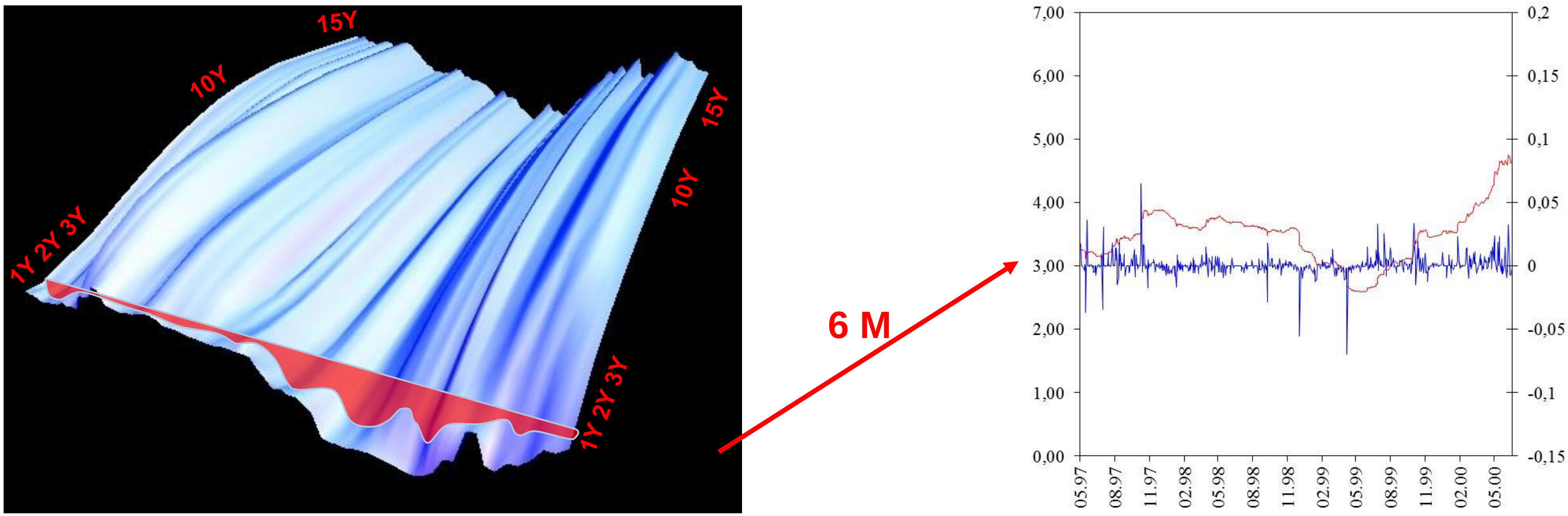

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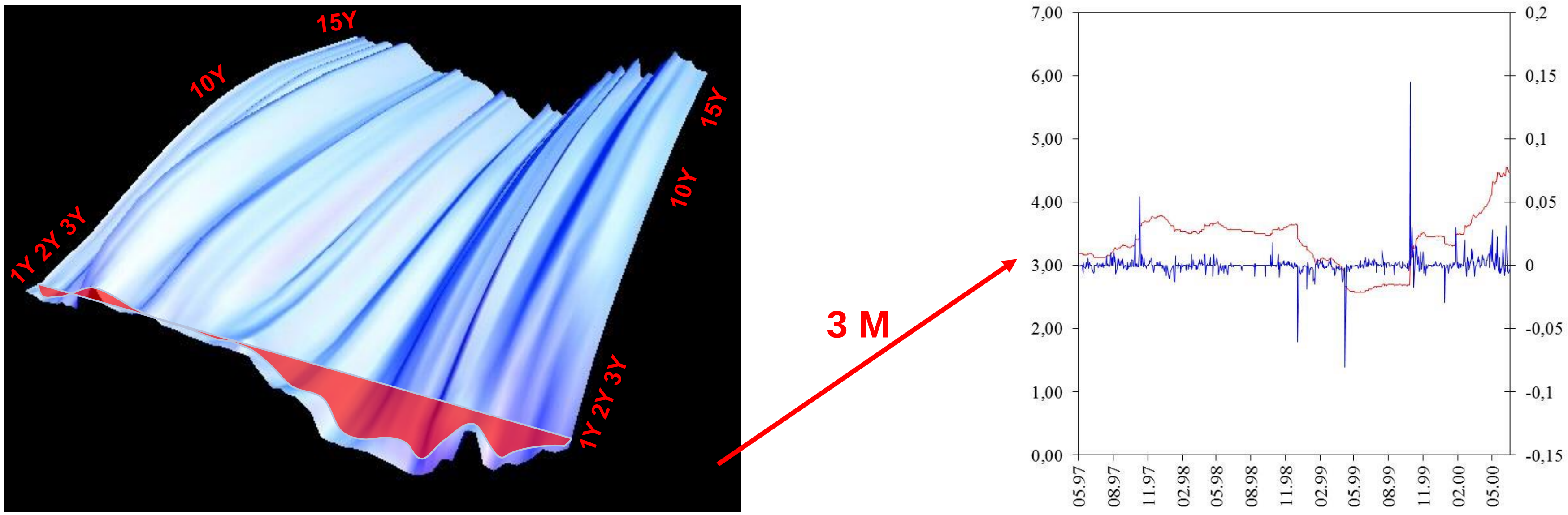

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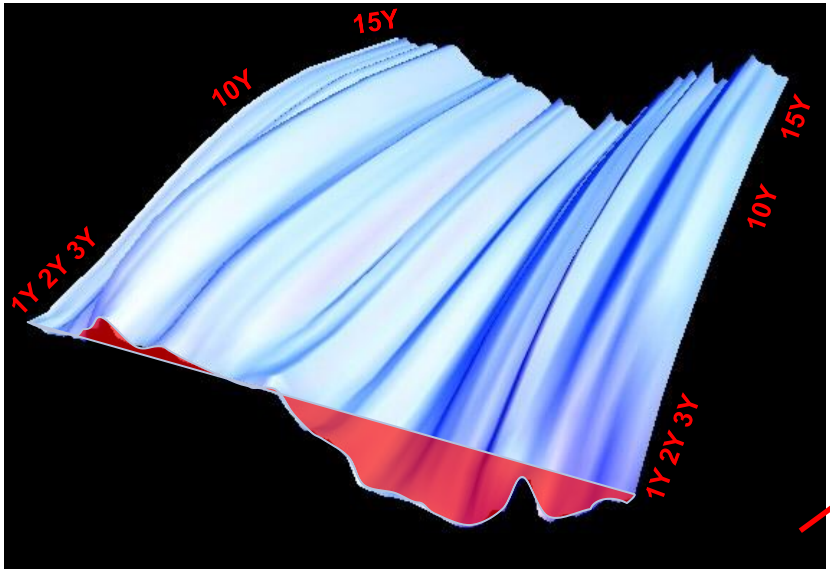

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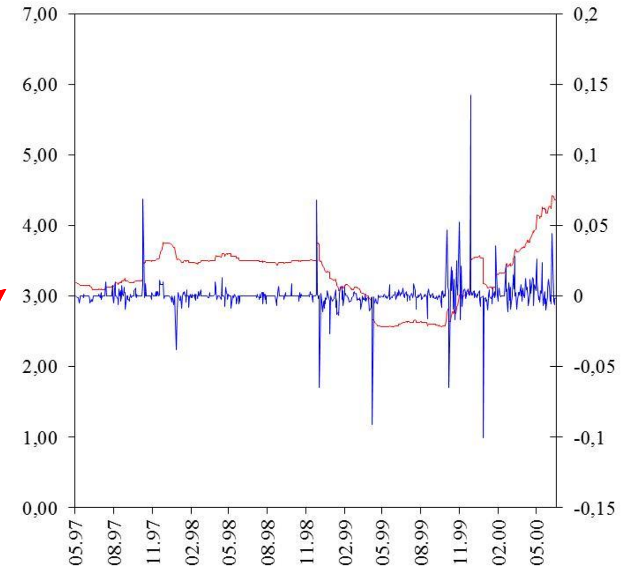

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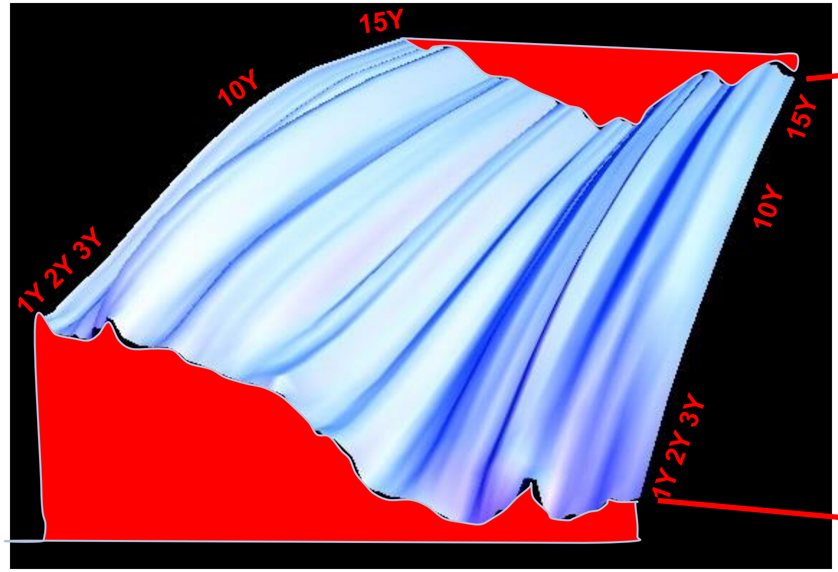
Interest rates and their dynamics



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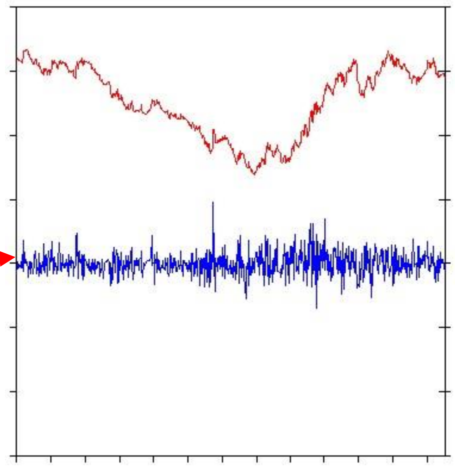

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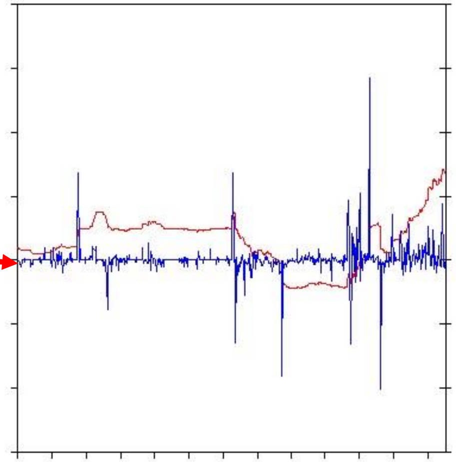

The change in interest rates follows no simple statistics

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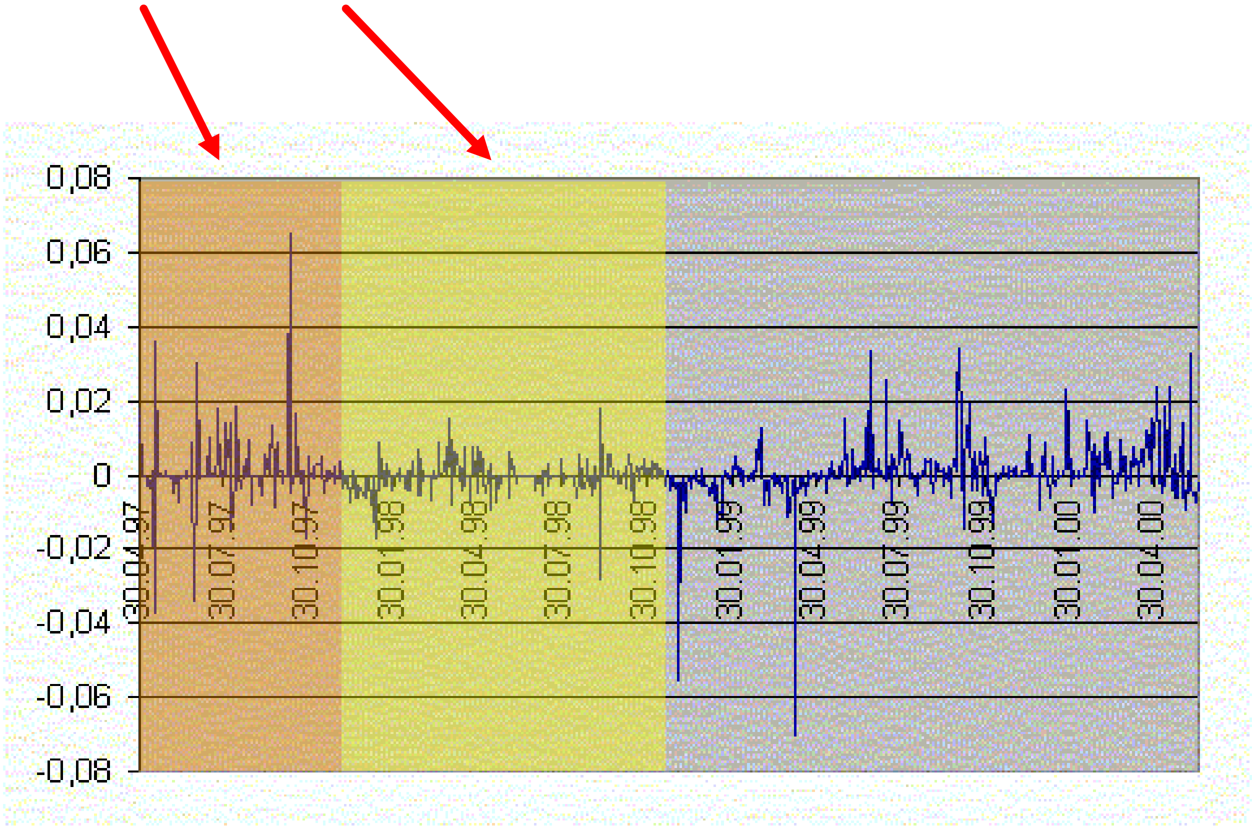
Phenomenology of financial time series

Data are heteroscedastic, i.e., there are alterations of volatile and tranquil periods



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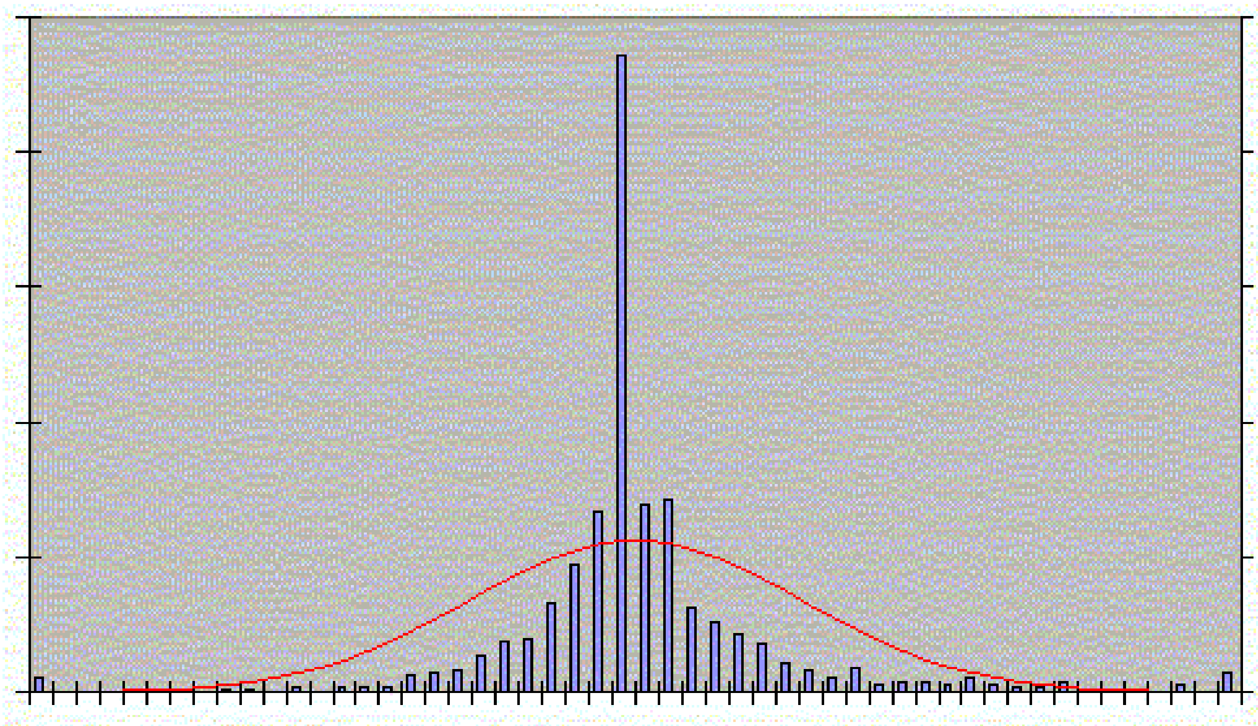
Phenomenology of financial time series

Data are leptocurtic, i.e., the empirical distribution is more pronounced / steeper in the middle of the distribution as the normal distribution and it has more mass in the tails as a normal distribution (fat tails).



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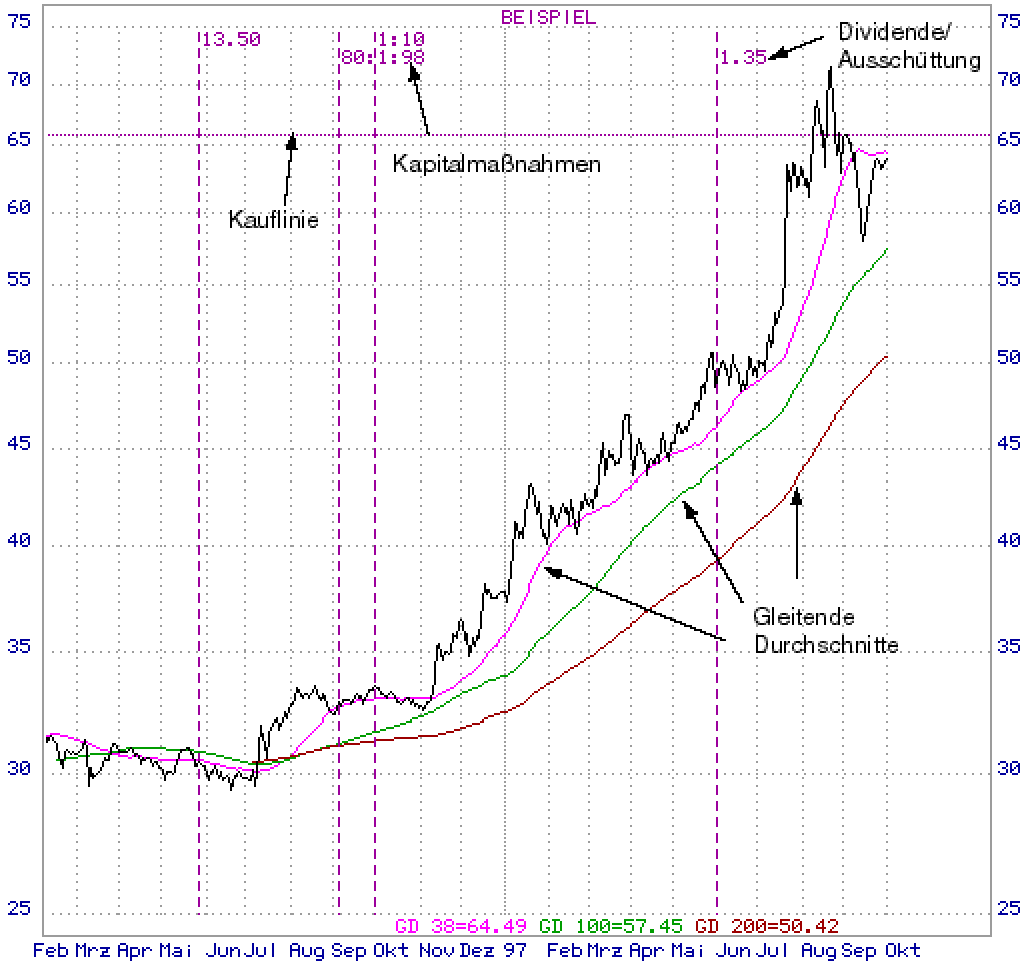
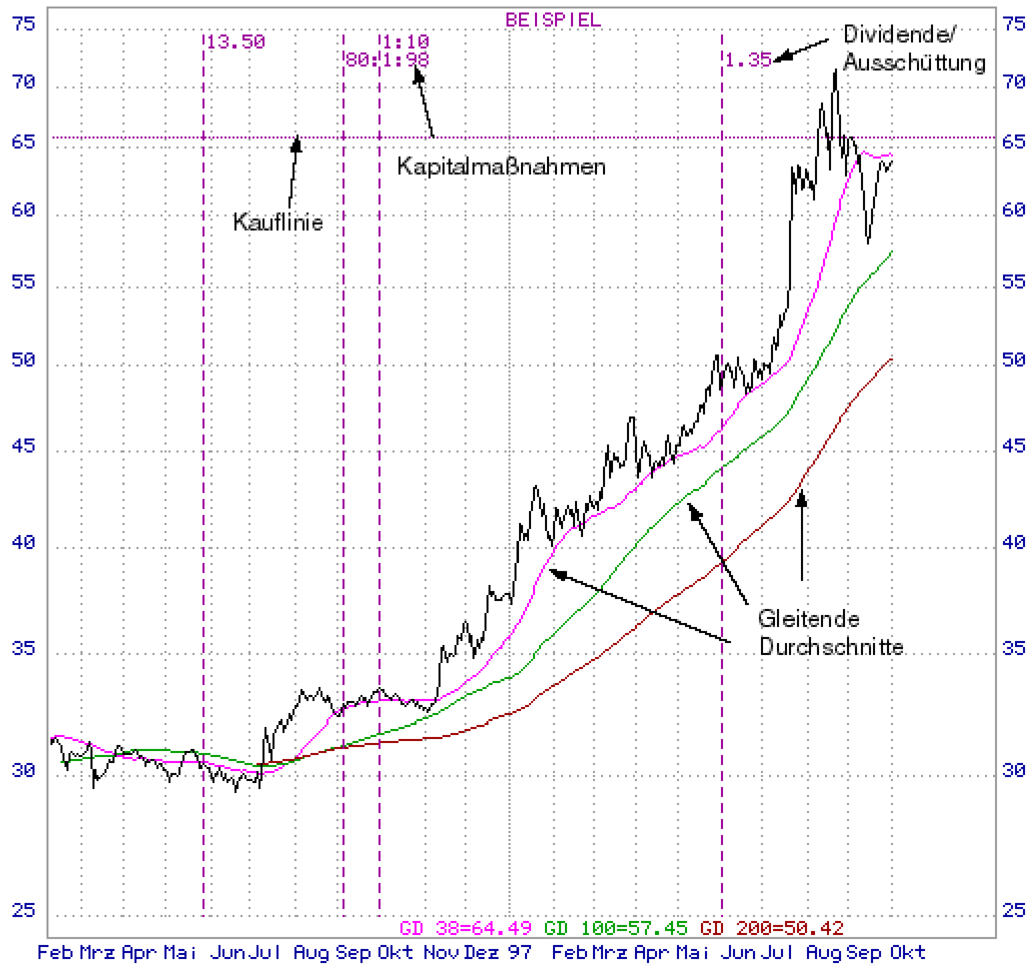
How to “explain” the curves – Different approaches



Can we see patterns?

How to “explain” the curves – Different approaches



Euclidean geometry approach

vs

fractal geometry approach

vs

stochastic approach

See also: Source: B. B. Mandelbrot, Börsenturbulenzen neu erklärt, Spektrum der Wissenschaft, Mai 1999, 74-77

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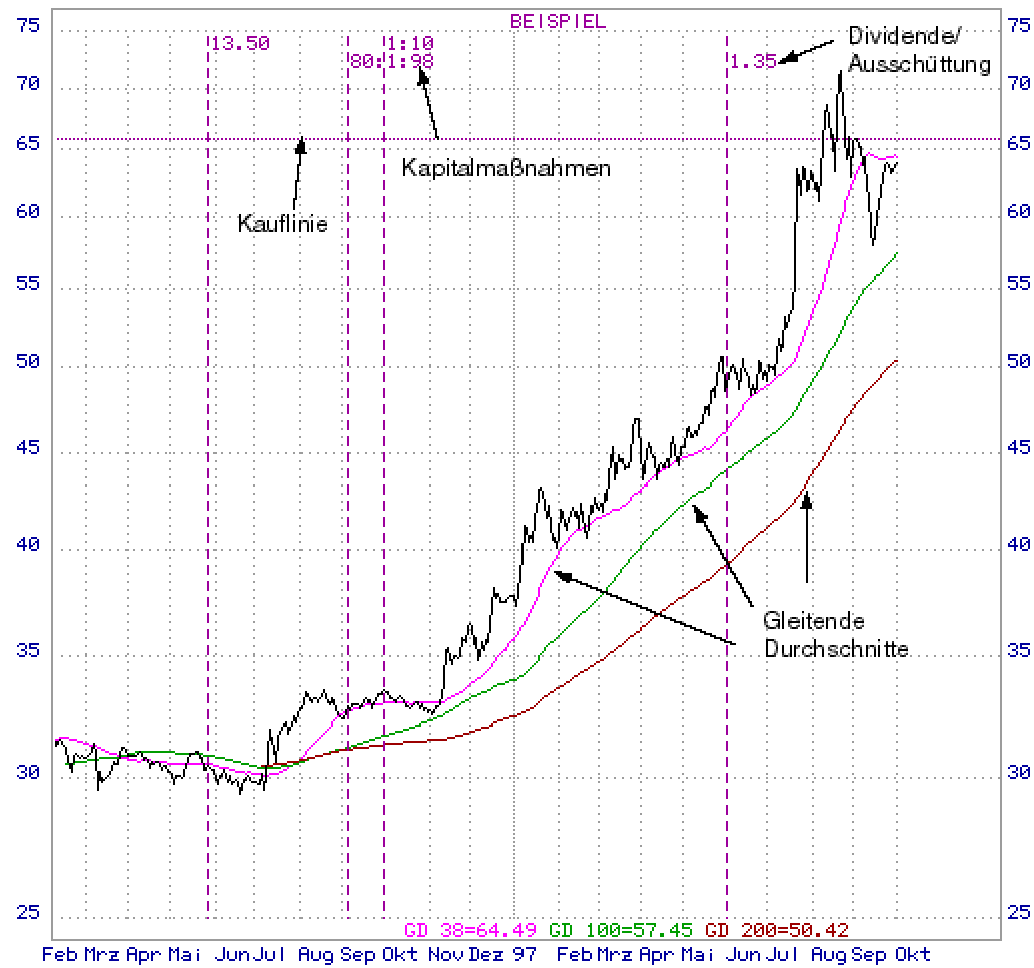
How to “explain” the curves – Different approaches



Beschreibende SDE	Parameterspezifikation	Stationäre Verteilung
Mean-Reverting-Prozeß		
$dX_t = \mu(X_t)dt + \sigma(X_t)dB_t$ für $t \geq 0,\ X_0 = x_0 \in I$ $\mu(x) = \beta + \alpha x \ \forall x \in I$ $\sigma(x) > 0 \ \forall x \in I$	$\alpha \in \mathbb{R}^-,\ \beta \in \mathbb{R}$	
Ornstein-Uhlenbeck-Prozeß		
$dX_t = \mu(X_t)dt + \sigma(X_t)dB_t$ für $t \geq 0,\ X_0 = x_0 \in \mathbb{R}$ $\mu(x) = \alpha x \ \forall x \in I = \mathbb{R}$ $\sigma(x) \equiv \sigma$	$\alpha \in \mathbb{R}^-$ $\sigma \in \mathbb{R}^+$	$N\left(0, -\frac{\sigma^2}{2\alpha}\right)$
Vasicek-Modell		
$dX_t = \mu(X_t)dt + \sigma(X_t)dB_t$ für $t \geq 0,\ X_0 = x_0 \in \mathbb{R}$ $\mu(x) = \beta + \alpha x \ \forall x \in I = \mathbb{R}$ $\sigma(x) \equiv \sigma$	$\alpha \in \mathbb{R}^-,\ \beta \in \mathbb{R}$ $\sigma \in \mathbb{R}^+$	$N\left(-\frac{\beta}{\alpha}, -\frac{\sigma^2}{2\alpha}\right)$
Cox-Ingersoll-Ross-Modell (CIR)		
$dX_t = \mu(X_t)dt + \sigma(X_t)dB_t$ für $t \geq 0,\ X_0 = x_0 \in \mathbb{R}^+$ $\mu(x) = \beta + \alpha x \ \forall x \in I = \mathbb{R}^+$ $\sigma(x) = \sigma \sqrt{x} \ \forall x \in \mathbb{R}^+$	$\alpha \in \mathbb{R}^-,\ \beta \in \mathbb{R}^+$ $\sigma \in \mathbb{R}^+,\ 2\beta \geq \sigma^2$	$\Gamma\left(-\frac{2\alpha}{\sigma^2}, \frac{2\beta}{\sigma^2}\right)$
Verallgemeinertes CIR-Modell		
$dX_t = \mu(X_t)dt + \sigma(X_t)dB_t$ für $t \geq 0,\ X_0 = x_0 \in \mathbb{R}^+$ $\mu(x) = \beta + \alpha x \ \forall x \in I = \mathbb{R}^+$ $\sigma(x) = \sigma x^\gamma \ \forall x \in \mathbb{R}^+$	Stationärer Mean-Reverting Prozeß, falls gelten: $\gamma = \frac{1}{2}:\ 2\beta \geq \sigma^2, \alpha < 0$ $\frac{1}{2} < \gamma < 1:\ \beta > 0, \alpha < 0$ $\gamma \geq 1:\ \beta > 0, \alpha < 0$ Stets: $\sigma \in \mathbb{R}^+$	Im Fall γ=1: Verteilung einer Zufallsvariablen Z, für die gilt: $Z^{-1} \overset{d}{=} \Gamma\left(\frac{2\beta}{\sigma^2}, -\frac{2\alpha}{\sigma^2} + 1\right)$

The stochastic approach

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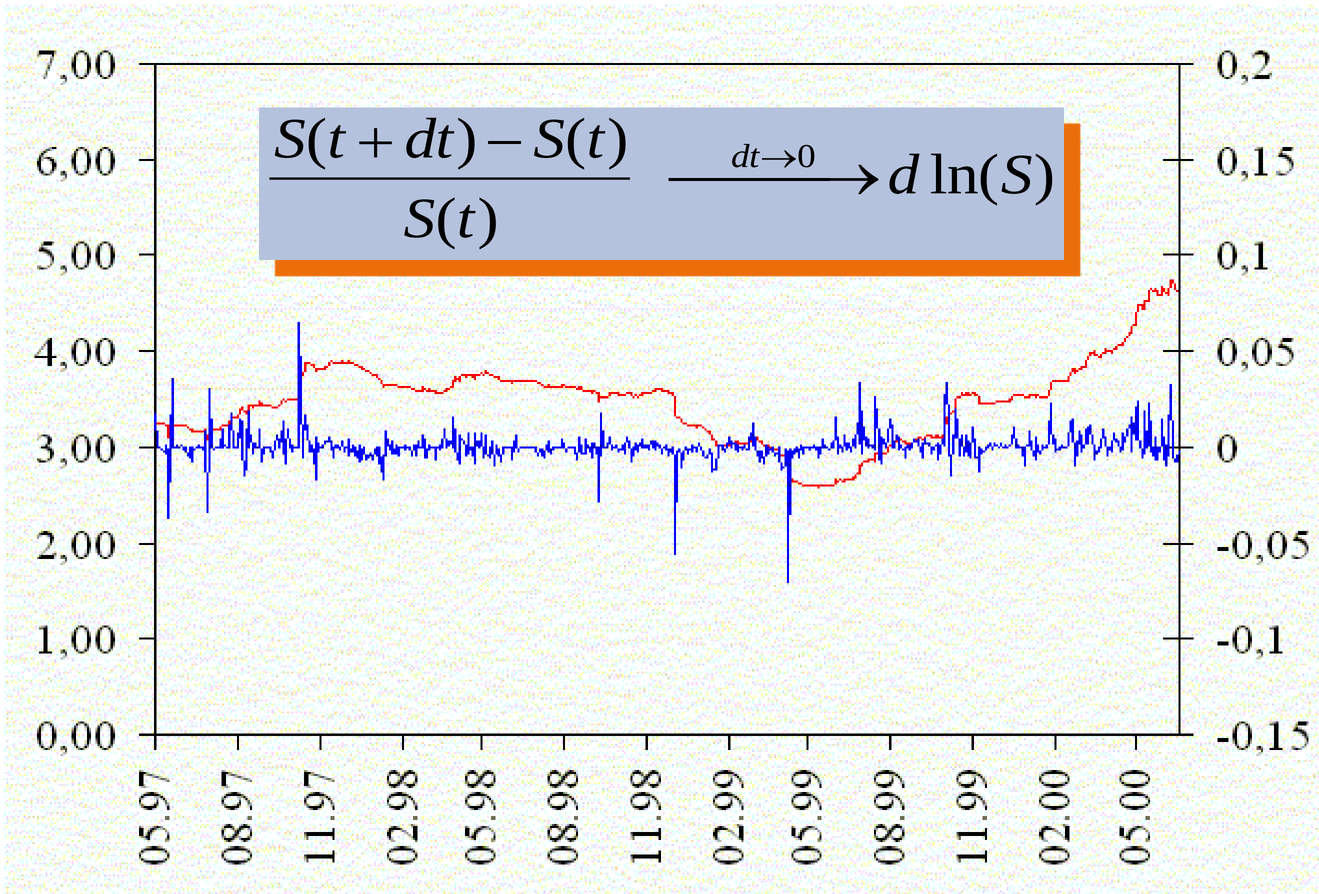
How to “explain” the curves – Different approaches

Modelling the logarithmical price change



$$\frac{S(t+dt)-S(t)}{S(t)} \xrightarrow{dt \to 0} d\ln(S)$$

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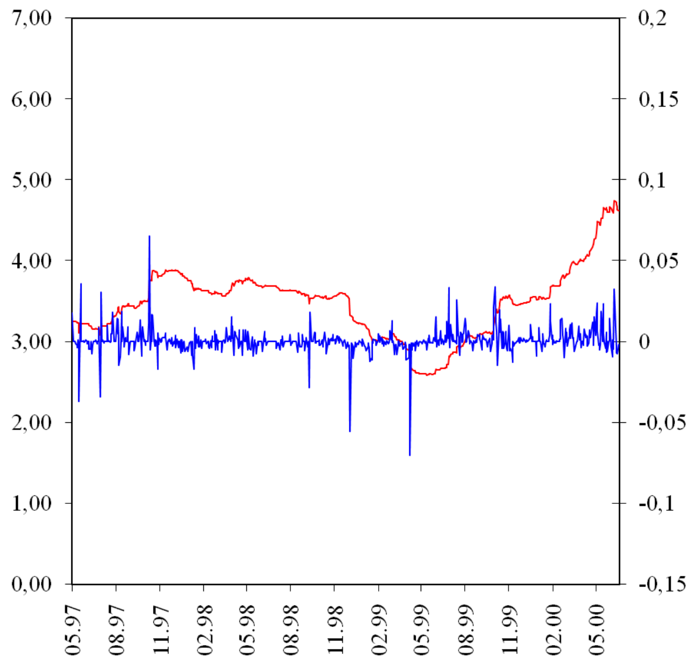
Interest rate models

» **Basic model: $X_t = \sigma_t Z_t$ with**

$\{Z_t\}$ is IID with mean 0, variance 1, e.g. N(0,1)

very simple: fixed σ, more advanced: $\{\sigma_t\}$ is a volatility process



» GARCH model

$X_t = \sigma_t Z_t$

GARCH(p,q) process (General AutoRegressive Conditional Heteroscedastic)

$$\sigma_t^2 = c_0 + c_1 X_{t-1}^2 + \cdots + c_p X_{t-p}^2 + \beta_1 \sigma_{t-1}^2 + \cdots + \beta_q \sigma_{t-q}^2 \quad .$$

Special case ARCH(1)

$$\begin{aligned} X_t^2 &= (c_0 + c_1 X_{t-1}^2) Z_t^2 \\ &= c_1 Z_t^2 X_{t-1}^2 + c_0 Z_t^2 \\ &= A_t X_{t-1}^2 + B_t \end{aligned}$$

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» Stochastic volatility models

$X_t = \sigma_t Z_t$

σ_t is a second process, independent of Z_t

Model for the volatility (Taylor 1986)

$$\log \sigma_t^2 = \alpha_0 + \alpha_1 \log \sigma_{t-1}^2 + \alpha_2 \varepsilon_t, \ \{\varepsilon_t\} \sim \text{IID N}(0,1)$$

Stochastic recurrence model

$$X_t = X_{t-1}\varepsilon_t + \eta_t \text{ mit } \{\varepsilon_t, \eta_t\} \sim \text{IID}$$

» Extensions to the basic GARCH model

General formula: $r_t = \sigma_t \varepsilon_t$

Bilinear (Granger / Andersen 1978): $\sigma_t^{\,2} = r_{t-1}^{\,2}$

ARCH(1, 1) (Engle 1982): $\sigma_t^{\,2} = c_0 + c_1 r_{t-1}^{\,2}$

GARCH(1, 1) (Bollerslev 1986): $\sigma_t^{\,2} = c_0 + c_1 r_{t-1}^{\,2} + c_2 \sigma_{t-1}^{\,2}$

EGARCH (Nelson 1990):

$$\log(\sigma_t) = c_0 + c_1 \log(\sigma_{t-1}) + \frac{c_2 \varepsilon_{t-1}}{\sqrt{\sigma_{t-1}}} + c_3 \left(\frac{|\varepsilon_{t-1}|}{\sqrt{\sigma_{t-1}}} - \sqrt{\frac{2}{\pi}} \right)$$

Further: ARCH-M, AARCH, NARCH, PARCH, PNP_ARCH, STARCH, SWARCH, Component-ARCH, IARCH, multiplicative ARCH

For weather derivatives e.g. the ARFIMA-FIGARCH approach is used

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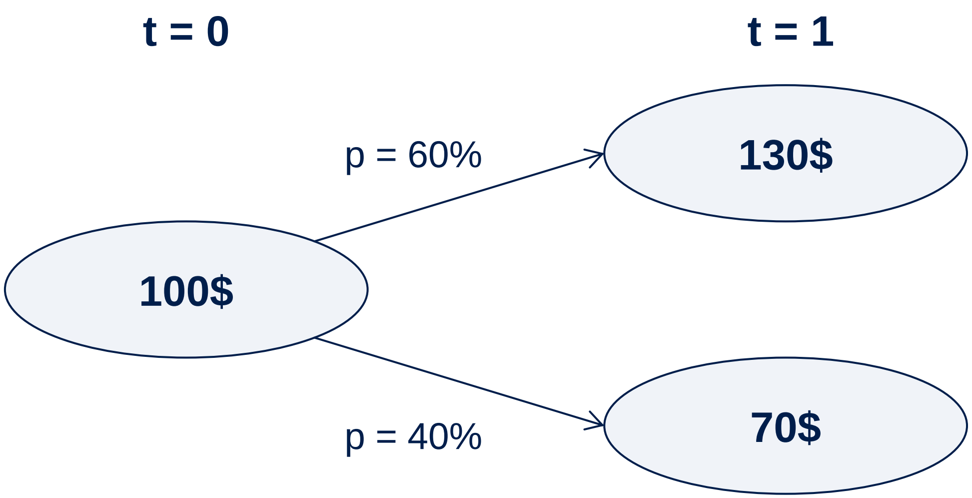
Options in finance

Suppose we have a stock that is worth 100$ today. Tomorrow we have two scenarios: the stock can go up to 130$ with empirical probability of 60% or it can go down to 70$ with empirical probability of 40% .

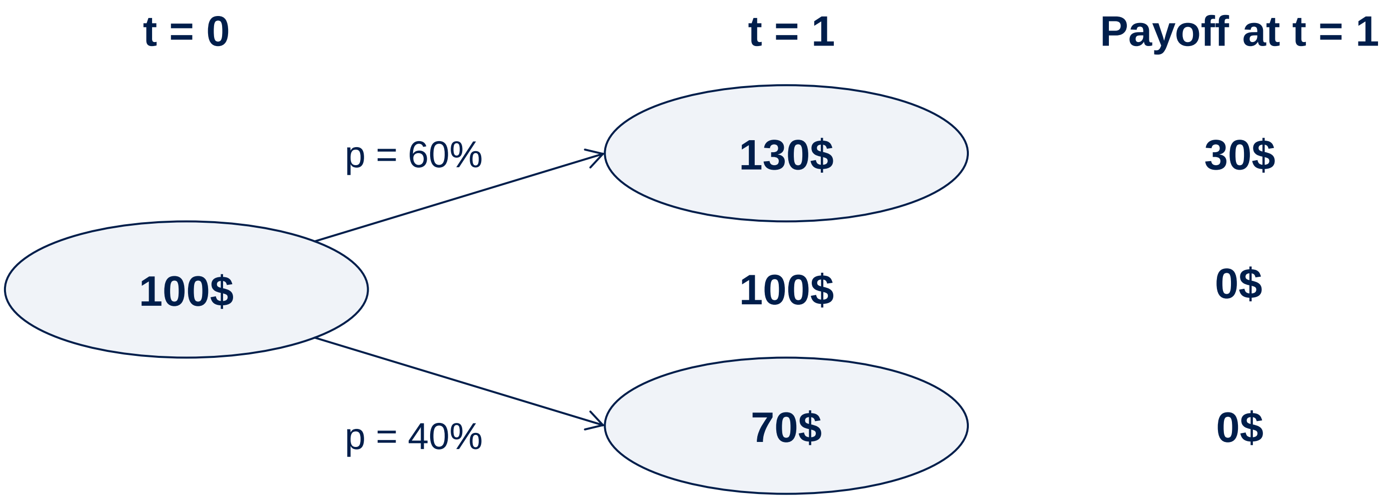


What is the fair price of such a contract today?

Options in finance

Suppose we have a stock that is worth 100$ today. Tomorrow we have two scenarios: the stock can go up to 130$ with empirical probability of 60% or it can go down to 70$ with empirical probability of 40% .

Now define the following contract: The holder of the contract has the right to buy the stock tomorrow for 100$. If the price tomorrow is 130$, the holder can buy the stock for 100$ and immediately sell it for 130$, thus making a profit of 30$. If the price tomorrow is 70$ the holder will not use his right to buy the stock for 100$ since he can buy it in the market for 70$.



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Now define the following contract: The holder of the contract has the right to buy the stock to ... d
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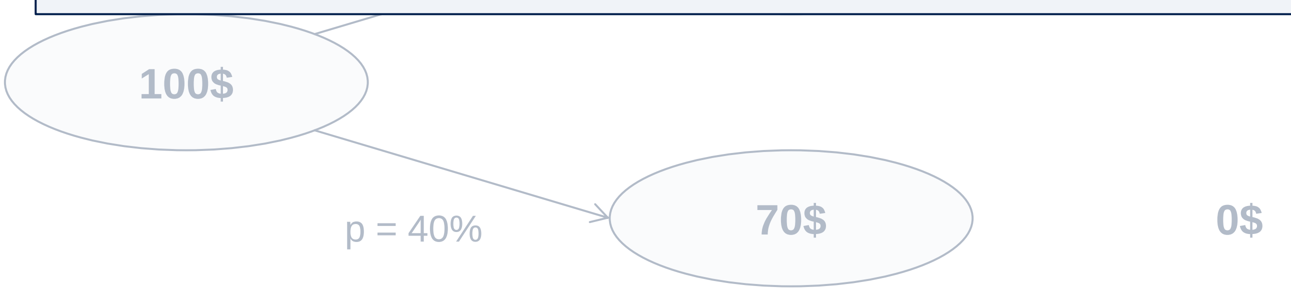
Suppose we find somebody who pays us the expected profit of (60%*30$) 18$ for such a contract.



What is the fair price of such a contract today?

Options in finance

We could then accept the 18$ and do the following: we buy ½ of the stock today for 50$ and wait until tomorrow. If the stock goes up we have to deliver one stock for the price of 100$, so we have to buy another ½ for 65$. Having spent a total of 115$ and received a total of 118$ we make a profit of 3$. If the stock goes down we don't have to deliver the stock and can sell our ½ stock for 35$, adding the 18$ we got for the contract and subtracting the 50$ we paid for the ½ stock at t = 0 again gives us a profit of 3$.

	Money spent		**Money received**		**Profit**
130$	» Buy ½ stock at t = 0:	**-50$**	» Initial contract:	**18$**	
	» Buy ½ stock at t = 1:	**-65$**	» Delivery of 1 stock:	**100$**	
	» **Total -115$**		» **Total**	**118$**	**3$**
100$					
	» Buy ½ stock at t = 0:	**-50$**	» Initial contract:	**18$**	
			» Sell ½ stock at t = 1:	**35$**	
70$	» **Total**	**-50$**	» **Total**	**53$**	**3$**

We make a profit of 3$, no matter what happens tomorrow!

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Options in finance

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	Money spent		Money received		Profit
130$	Buy ½ stock at t = 0:	**-50$**	Initial contract:	**18$**	
↑	Buy ½ stock at t = 1:	**-65$**	Delivery of 1 stock:	**100$**	
	Total -115$		**Total**	**118$**	3$
100$					
↓	Buy ½ stock at t = 0:	**-50$**	Initial contract:	**18$**	
			Sell ½ stock at t = 1:	**35$**	
70$	**Total**	**-50$**	**Total**	**53$**	**3$**

We make a profit of 3$, no matter what happens tomorrow!

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Options in finance

We could then accept the 18$ and do the following: we buy ½ of the stock today for 50$ and wait until tomorrow. If the stock goes up we have to deliver one stock for the price of 100$, so we have to buy another ½ for 65$. Having spent a total of 115$ and received a total of 118$ we make a profit of 3$. If the stock goes down we don't have to deliver the stock and can sell our ½ stock for 35$, adding the 18$ we got for the contract and subtracting the 50$ we paid for the ½ stock at t = 0 again gives us a profit of 3$.

	Money spent		**Money received**		**Profit**
130$	» Buy ½ stock at t = 0:	**-50$**	» Initial contract:	**18$**	
	» Buy ½ stock at t = 1:	**-65$**	» Delivery of 1 stock:	**100$**	
	» **Total -115$**		» **Total**	**118$**	**3$**
100$					
	» Buy ½ stock at t = 0:	**-50$**	» Initial contract:	**18$**	
			» Sell ½ stock at t = 1:	**35$**	
70$	» **Total**	**-50$**	» **Total**	**53$**	**3$**

We make a profit of 3$, no matter what happens tomorrow!

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Options in finance

We could then accept the 18$ and do the following: we buy ½ of the stock today for 50$ and wait until tomorrow. If the stock goes up we have to deliver one stock for the price of 100$, so we have to buy another ½ for 65$. Having spent a total of 115$ and received a total of 118$ we make a profit of 3$. If the stock goes down we don't have to deliver the stock and can sell our ½ stock for 35$, adding the 18$ we got for the contract and subtracting the 50$ we paid for the ½ stock at t = 0 again gives us a profit of 3$.

Expected values based on empirical probabilities do not give the fair price!

Profit

3$

100$

» Buy ½ stock at t = 0:	**-50$**	» Initial contract:	**18$**	
		» Sell ½ stock at t = 1:	**35$**	
» **Total**	**-50$**	» **Total**	**53$**	**3$**

70$

We make a profit of 3$, no matter what happens tomorrow!

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Physical models applied to financial markets

- » The application of stochastic methods to questions from the world of finance is nowadays an established standard.
- » Many well understood paradigms from physics can be applied to problems arising in a financial context. Time will tell which of them will also have practical relevance.
- › Ising models, chaos theory, fractals, etc.

The statistical physics approach

Physical models applied to financial markets - Hamiltonians

Stock markets and quantum dynamics: a second quantized description

F. Bagarello

https://www.flickr.com/photos/bankenverband/9930916773, Jochen Zick, public domain

Physical models applied to financial markets - Hamiltonians

Stock markets and quantum dynamics: a second quantized description

F. Bagarello

» Toy model of a stock market based on the following assumptions:
   - Our market consists of L traders exchanging a single kind of share;
   - The total number of shares, N, is fixed in time;
   - A trader can only interact with a single other trader: i.e. the traders feel only a *two-body interaction*;
   - The traders can only buy or sell one share in any single transaction;
   - The price of the share changes with discrete steps, multiples of a given monetary unit;
   - When the tendency of the market to sell a share, i.e. the *market supply*, increases then the price of the share decreases;
   - For our convenience the supply is expressed in term of natural numbers;
   - To simplify the notation, we take the monetary unit equal to 1.

Article: F. Bagarello, J. Phys. A, 6823-6840 (2006)

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Physical models applied to financial markets - Hamiltonians

- The *formal H*amiltonian of the model is the following operator:
  $\widetilde{H} = H_0 + \widetilde{H}_I, where$
  $$H_0 = \sum_{l=1}^{L} \alpha_l\, a_l^{\dagger} a_l + \sum_{l=1}^{L} \beta_l\, c_l^{\dagger} c_l + o^{\dagger} o + p^{\dagger} p$$
  $$\widetilde{H}_I = \sum_{i,j=1}^{L} p_{ij} \left(a_i^{\dagger} a_j \left(c_i c_j^{\dagger}\right)^{\hat{P}} + a_i a_j^{\dagger} \left(c_j c_i^{\dagger}\right)^{\hat{P}} \right) + o^{\dagger} p + p^{\dagger} o$$
- where $\hat{P} = p^{\dagger} p$ and the following commutation rules are used:
- $[a_l, a_n^{\dagger}] = [c_l, c_n^{\dagger}] = \delta_{ln} I \qquad [p, p^{\dagger}] = [o, o^{\dagger}] = I$
- All other commutators are zero.
- We further assume that $p_{ii} = 0$
- *Number*, *price*, *cash* and *supply* operators: $a_l^{\sharp}, p^{\sharp}, c_l^{\sharp}, o^{\sharp}$
- The states of the market are: $\omega_{\{n\};\{k\};O;M}(.) = \langle \varphi_{\{n\};\{k\};O;M}, \varphi_{\{n\};\{k\};O;M} \rangle$
- where $\{n\} = n_1, n_2, \ldots, n_L, \{k\} = k_1, k_2, \ldots, k_L$ and
  $$\varphi_{\{n\};\{k\};O;M} = \frac{\left(a_1^{\dagger}\right)^{n_1} \ldots \left(a_L^{\dagger}\right)^{n_L} \left(c_1^{\dagger}\right)^{k_1} \ldots \left(c_L^{\dagger}\right)^{k_L} \left(o^{\dagger}\right)^{O} \ldots \left(p^{\dagger}\right)^{M}}{\sqrt{n_1! \ldots n_L!\, k_1! \ldots k_L!\, O!\, M!}} \varphi_0$$
- φ_0 is the vacuum of the model: $a_j \varphi_0 = c_j \varphi_0 = p \varphi_0 = o \varphi_0 = 0, for\ j = 1, 2, \ldots, L$

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Physical models applied to financial markets - Hamiltonians

» The time evolution for the observables, e.g., the price

$$\frac{dX(t)}{dt} = ie^{iHt}[H,X]e^{-iHt} = i[H,X(t)]$$

Article: F. Bagarello, J. Phys. A, 6823-6840 (2006), Foto: https://www.flickr.com/photos/bankenverband/9930916773, Jochen Zick

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How to “explain” the curves – different approaches

Crossing Stocks and the Positive Grassmannian I: The Geometry behind Stock Market

Ovidiu Racorean

Removals of crossings in the permutation associated to stock market reside in the decomposition of the positive Grassmannian $G^{+}(2,4)$ labeled by the stock market polytope in positroid cells as is depicted in the figure 11.

Image, see

O. Racorean, Geometry and Topology of the Stock Market, 2013

The combinatorial approach

Pictures from O. Racorean, Geometry and Topology of the Stock Market, 2013

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Physical models applied to financial markets - A string model in phynance

From the currency rate quotations onto strings and brane world scenarios

D. Horváth R. Pincak

We are currently in the process of transfer of modern physical ideas into the neighboring field called econophysics. The physical statistical view point has proved fruitful, namely, in the description of systems where many-body effects dominate. However, standard, accepted by physicists, bottom-up approaches are cumbersome or outright impossible to follow the behavior of the complex economic systems, where autonomous models encounter the intrinsic variability.

The "cosmological" approach

Article Physica A 391 (2012) 5172-5188

Physical models applied to financial markets – Selected books

R. Mantegna, H. Stanley **Correlations and Complexity in Finance** **Cambridge University Press**	**L. Wille** **New Directions in Statistical Physics** **Econophysics, Bioinformatics, and Pattern Recognition** **Springer**	**M. Small** **Applied Nonlinear Time Series** **Applications in Physics, Physiology and Finance** **World Scientific Series on Nonlinear Science, Series A Vol. 52**	**F. Abergel, B. Chakrabarti, A. Chakraborti, A.Ghosh (Ed)** **Econophysics of Systemic Risk and Network Dynamice** **Systemic Risk and Network Dynamics** **Springer**
B. Mandelbrot **Fractals and Scaling in Finance** **Discontinuity, Concentration, Risk** **Springer**	**O. Racorean** **Geometry and Topology of the Stock Market** **Quantum Computer generation of quants** **CreateSpace**	**H. Kleinert** **Path Integrals in Quantum Mechanics, Statistics, Polymer Physics, and Financial Markets** **World Scientific**	**B. Baaquie** **Quantum Finance** **Path Integrals and Hamiltonians for Options and Interest rates** **Cambridge**

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Known models in different domains of science

Chapman, Hall

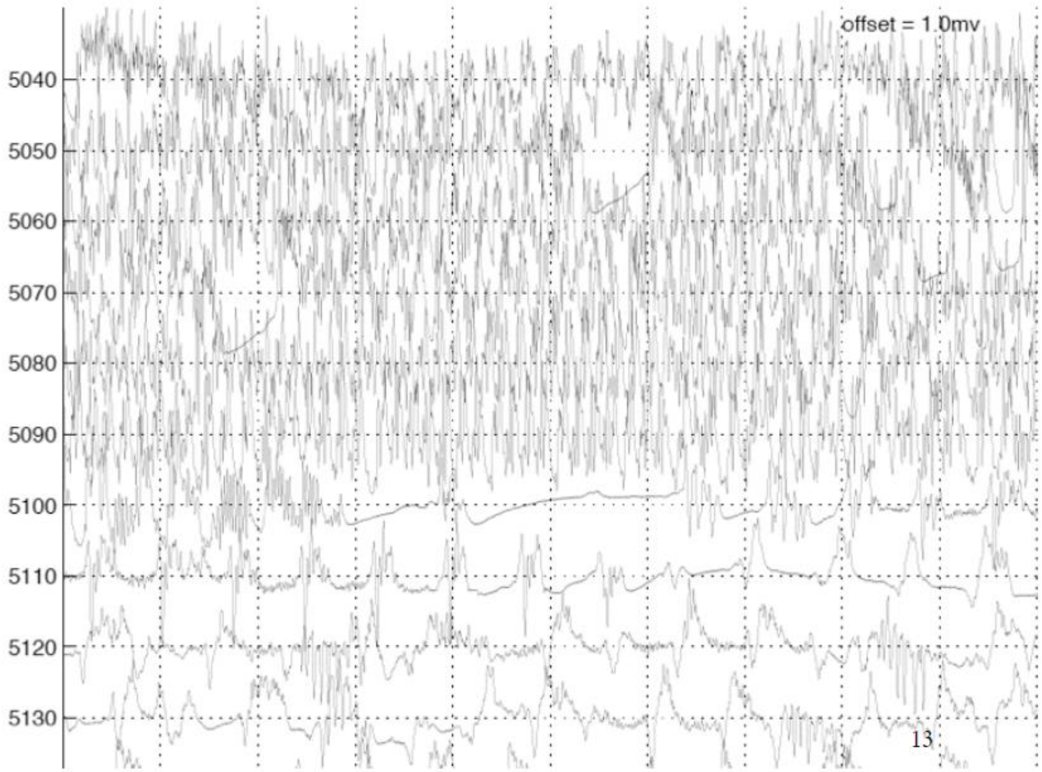
Computational Neuroscience

A Comprehensive Approach

CRC Mathematical Biology and Mediscience Series

Mathematical/physical models in finance – The “patient” financial markets

Parallels between Earthquakes, Financial crashes and epileptic seizures
Didier Sornette



Didier Sornette

Neuron

Reviews on Cognitive Architectures, Vol. 86, Number 1, Oct. 2015

Chapman, Hall

Computational Neuroscience

A Comprehensive Approach

CRC Mathematical Biology and Mediscience Series

See also:

I. Osorio, H. Zaveri, M. Frei, S.Arthurs (Ed.)

Epilepsy

The Intersection of Neurosciences, Biology, Mathematics, Enginieering, and Physics

CRC Press

Our models “fit” in different areas of research – mathematical structures can by analysed by analogies

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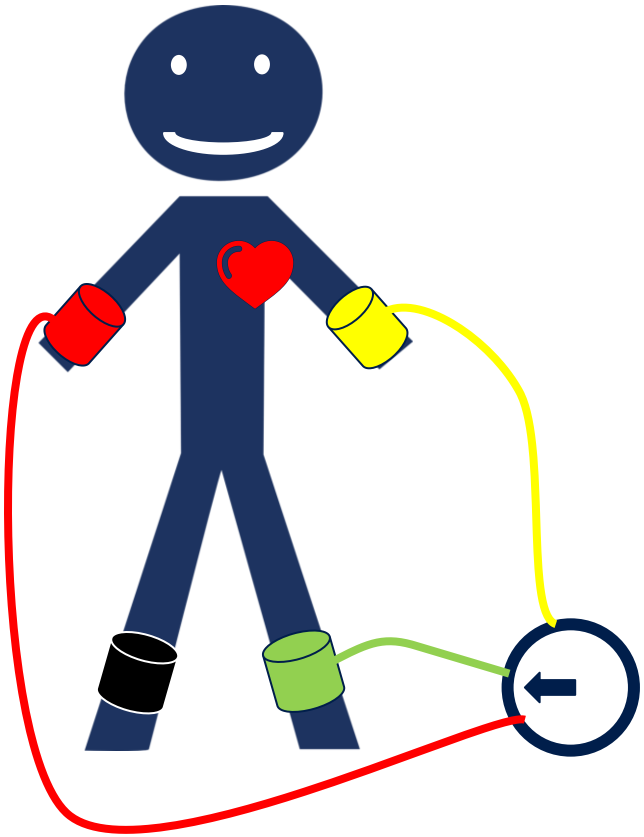
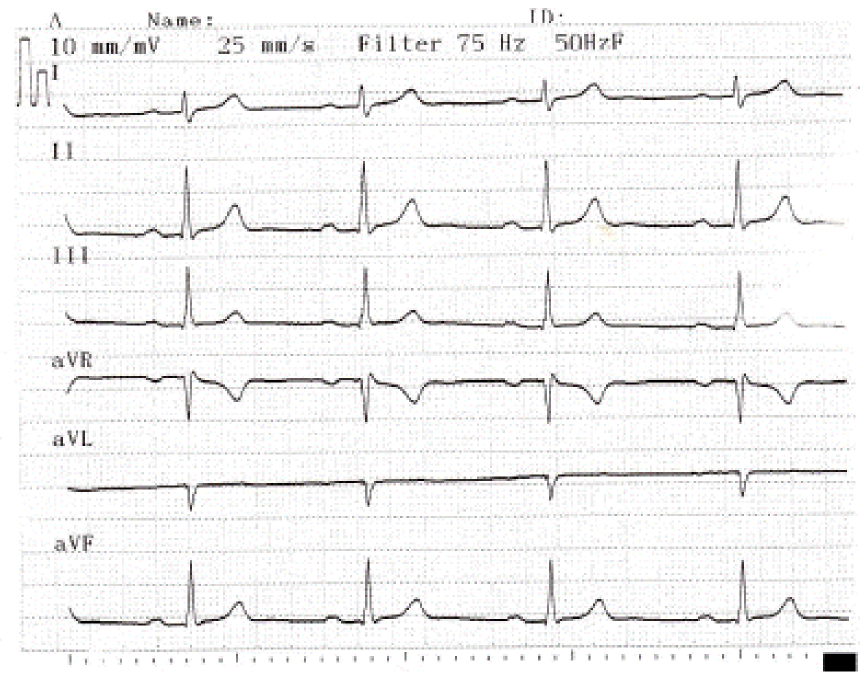
The “patient” financial markets





Our models “fit” in various fields of science

https://pixabay.com/de/mann-junge-m%C3%A4nnlich-schwarz-296526/

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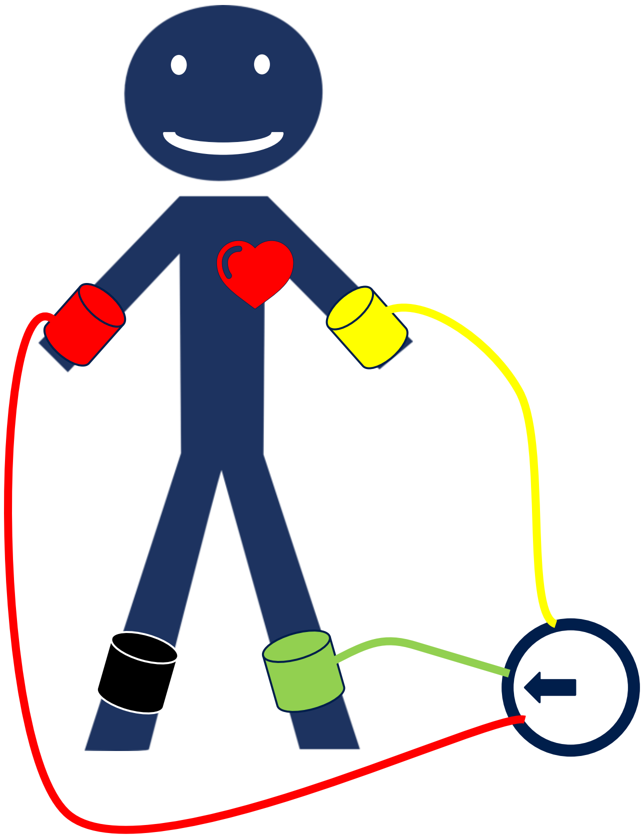
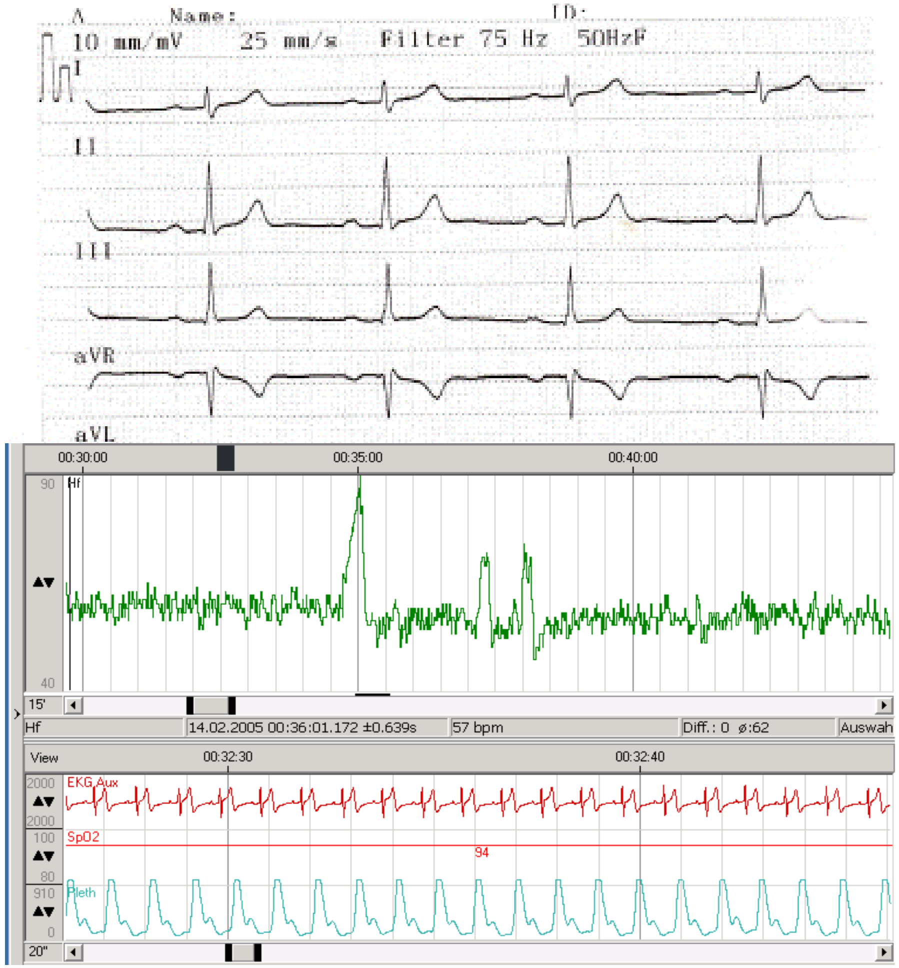
The “patient” financial markets





Our models “fit” in various fields of science

https://pixabay.com/de/mann-junge-m%C3%A4nnlich-schwarz-296526/

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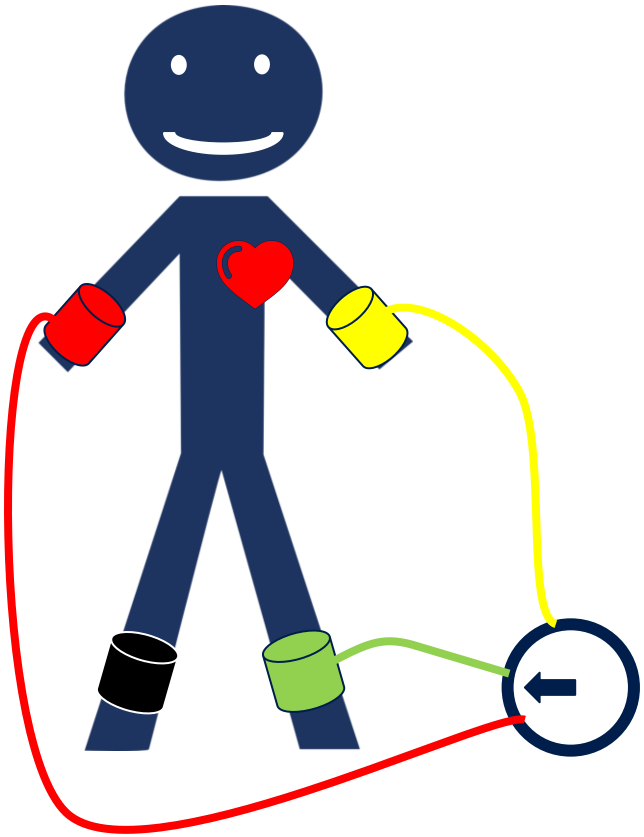
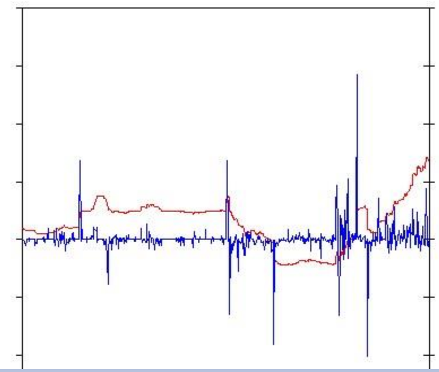
The “patient” financial markets





Our models “fit” in various fields of science – exploring mathematical structures via analogy

https://pixabay.com/de/mann-junge-m%C3%A4nnlich-schwarz-296526/

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Physical models applied to financial markets – Implementation

http://www.er.ethz.ch/financial-crisis-observatory.html

ETH zürich

Student portal | Login | Contact | en

Alumni association

Keyword or person

Departments

Department of Management, Technology and Economics

Chair of Entrepreneurial Risks

News | About us | Research | Education | Media | Real Estate Observatory | Financial Crisis Observatory

ETH Zurich > D-MTEC > Chair of Entrepreneurial Risks

- Description
- Highlights
- Bubble Risk Maps
- Is there an oil bubble?
- Pertinent articles
- Websites and Blogs
- Market Anxiety Measure
- The Financial Crisis: How Much Longer and Deeper?

Financial Crisis Observatory

Entrepreneurial Risks

The Financial Crisis Observatory (FCO) is a scientific platform aimed at testing and quantifying rigorously, in a systematic way and on a large scale the hypothesis that financial markets exhibit a degree of inefficiency and a potential for predictability, especially during regimes when bubbles develop.

2018

- **1st November 2018:** Synthesis report (PDF, 2.8 MB)
- **1st October 2018:** Synthesis report (PDF, 3.9 MB)
- **1st September 2018:** Synthesis report (PDF, 3.4 MB)
- **1st August 2018:** Synthesis report (PDF, 5.4 MB)

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The mechanics of the balance sheet – an engineers approach

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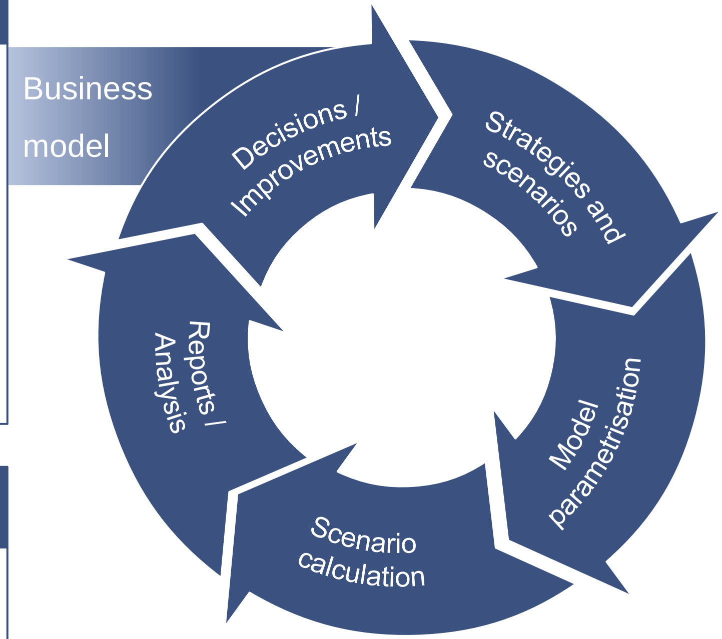
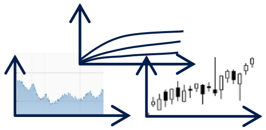
Continuous improvements to the business model require flexible analyses based on economic scenarios

1 Business model

- » Starting point is the business model of the bank
- » The scenario modelling is done working closely to the annual report



2 Strategies and scenarios



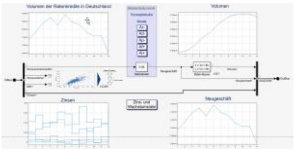
- » Consolidated scheme to organize all macro economical influences
- » Intuitive scenario definition by the combined signal

5 Reports / Analysis to support decision making

	Plan 2018 (Mio. EUR)
Bilanzsumme	25.000
Zinsüberschuss	350
Provisionsüberschuss	100
Gesamtertrag	500
Gesamtaufwand	300

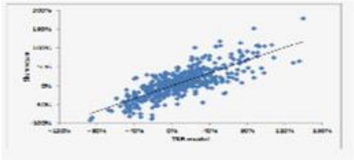
- » Flexible evaluation and analysis
- » What-If balance sheet and P&L impact analysis

4 Scenario calculation



- » Balance sheet and P&L: Derivation by following the economical relevant planning inputs

3 Model parametrisation



- » Parametrisation is done on basis of economical relevant planning inputs
- » Diverse set of integrated tools for time series and regression analysis to determine the parameters

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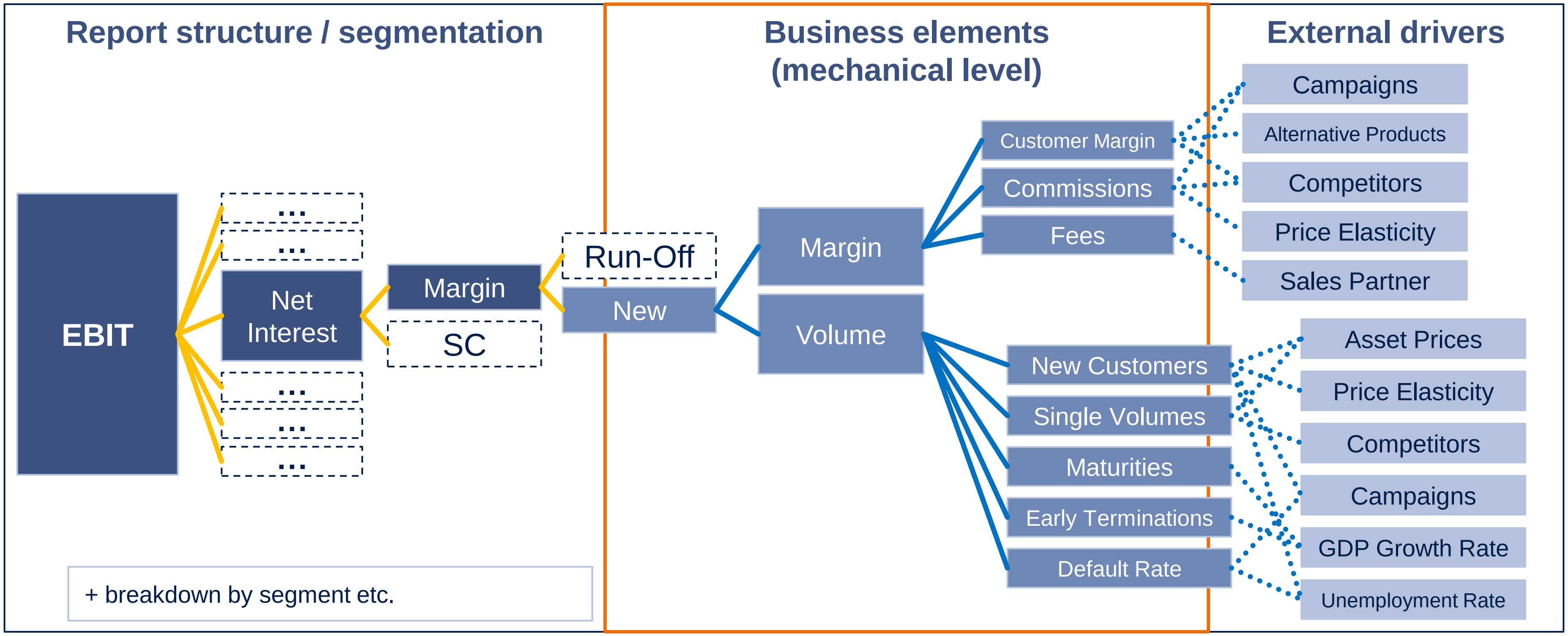
Modelling as a challenge: Mechanically modelling the product as „hinge“



Mechanical level

» Breaking down internal mechanisms into determining factors that can be connected to the external world

» Constructing the model on this level is a key element for BI skills – explanation (storyline) and scenario simulation

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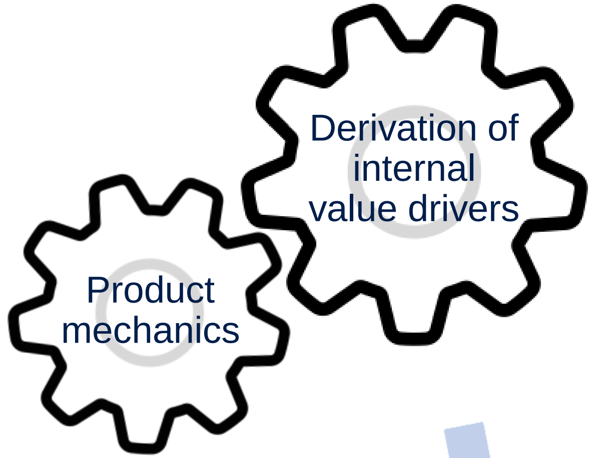
Integrated modelling:
From a macro-economic scenario to the dynamics of the balance sheet

Consolidated P&L
Net interest income
Commissions and fees
OPEX
…



Macro-economic scenario

- GDP development of different regions (US, Europe, …)
- Stock indices (Dow Jones, …)
- Government bond yields
- Interest reference rates
- Rate of unemployment
- …

$$\Delta KPI(t,\Delta t) \approx \sum_{EF} \sum_{P} \sum_{IT^P} \frac{\partial KPI^P}{\partial IT^P} \cdot \frac{\partial IT^P}{\partial EF} \cdot \Delta EF(t,\Delta t)$$

Modelling result KPI: The modelling is based on the definition of the macro-economic scenario.

Product mechanics: Resulting quantities are derived by means of internal value drivers.

Derivation of internal drivers: The model for coupling the internal value drivers IT^P of a product P to the scenario is defined via the external factors EF.

External factors EF: The external factors are extracted from the macro-economic scenario.

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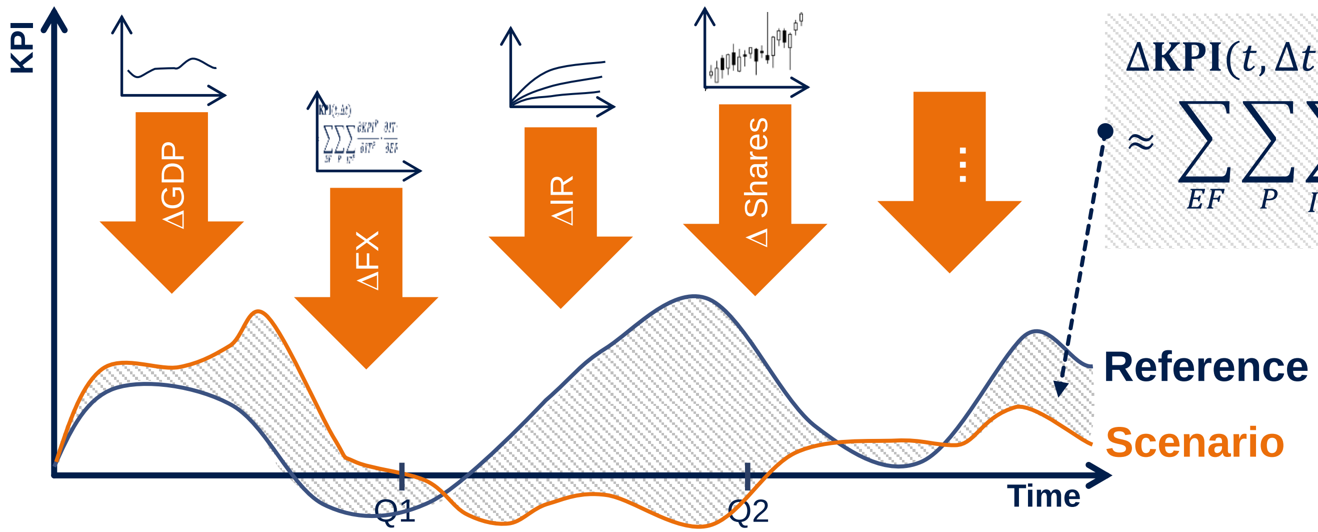
Delta analysis: How to identify crucial parameters

Exemplary delta analysis:



$$\Delta \mathbf{KPI}(t,\Delta t) \approx \sum_{EF}\sum_{P}\sum_{IT^P} \frac{\partial KPI^P}{\partial IT^P} \cdot \frac{\partial IT^P}{\partial EF} \cdot \Delta EF(t,\Delta t)$$

Product mechanics | **Internal value drivers** | **External factors**

- » The model provides the sensitivity of the results w.r.t. modifications of the different external factors; nonlinear effects, cut-offs etc. may be taken into account
- » On this basis, the delta analysis allows for a corresponding decomposition of results into different contributing factors:
  - › The influence of different external factors may be analysed separately
  - › Specific effects (e.g. separate sales activities) have to be considered in addition
- » The modelling framework may be enhanced step by step by considering further external factors or improved by taking additional value drivers into account

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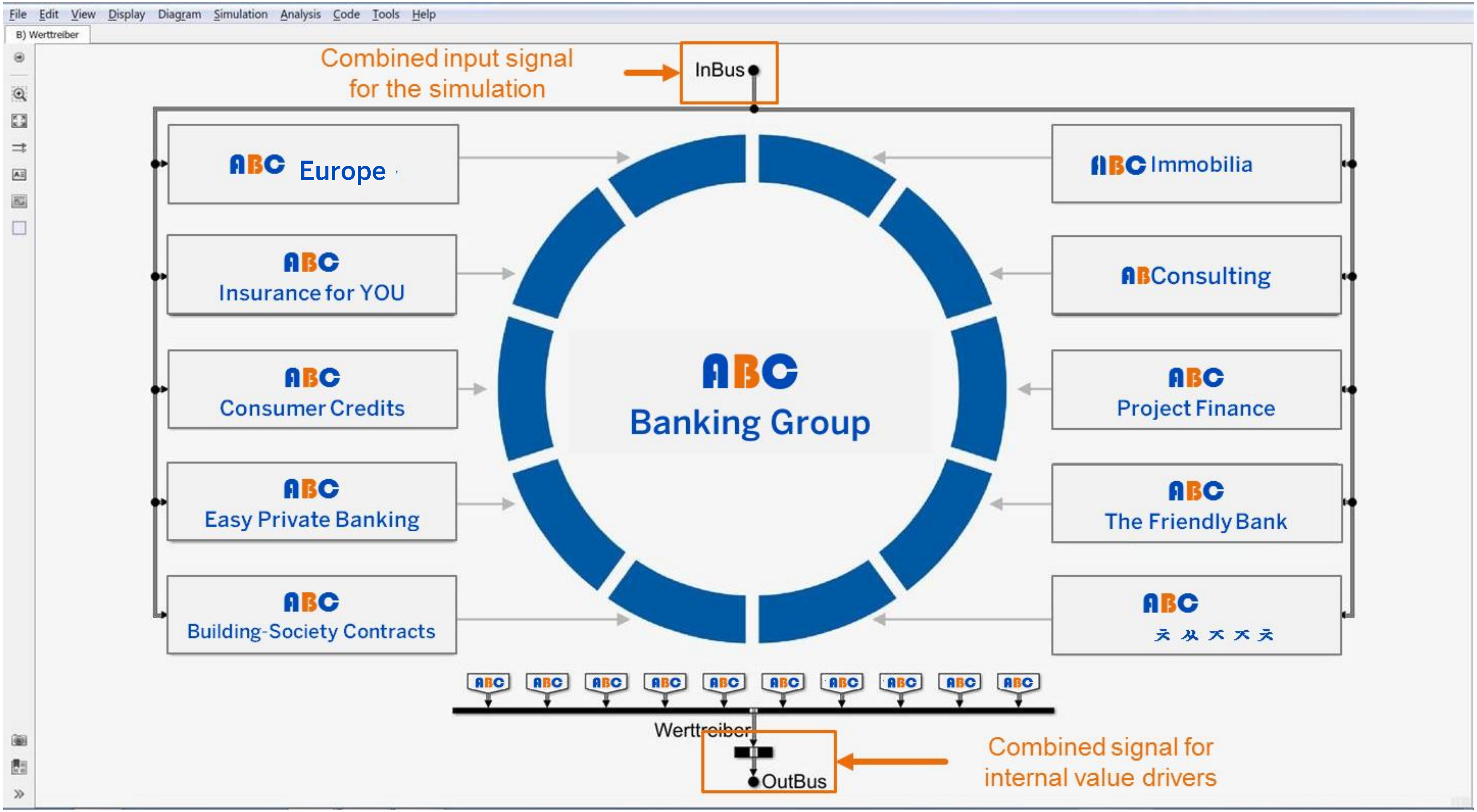
A simple dynamical analogue to model consumer credits in a bank

see: Bestandsdynamik im Konsumentenkreditgeschäft, Hagen Linderstädt, Die Bank 6/97, 350 - 352

Translation of external value drivers to internal value drivers



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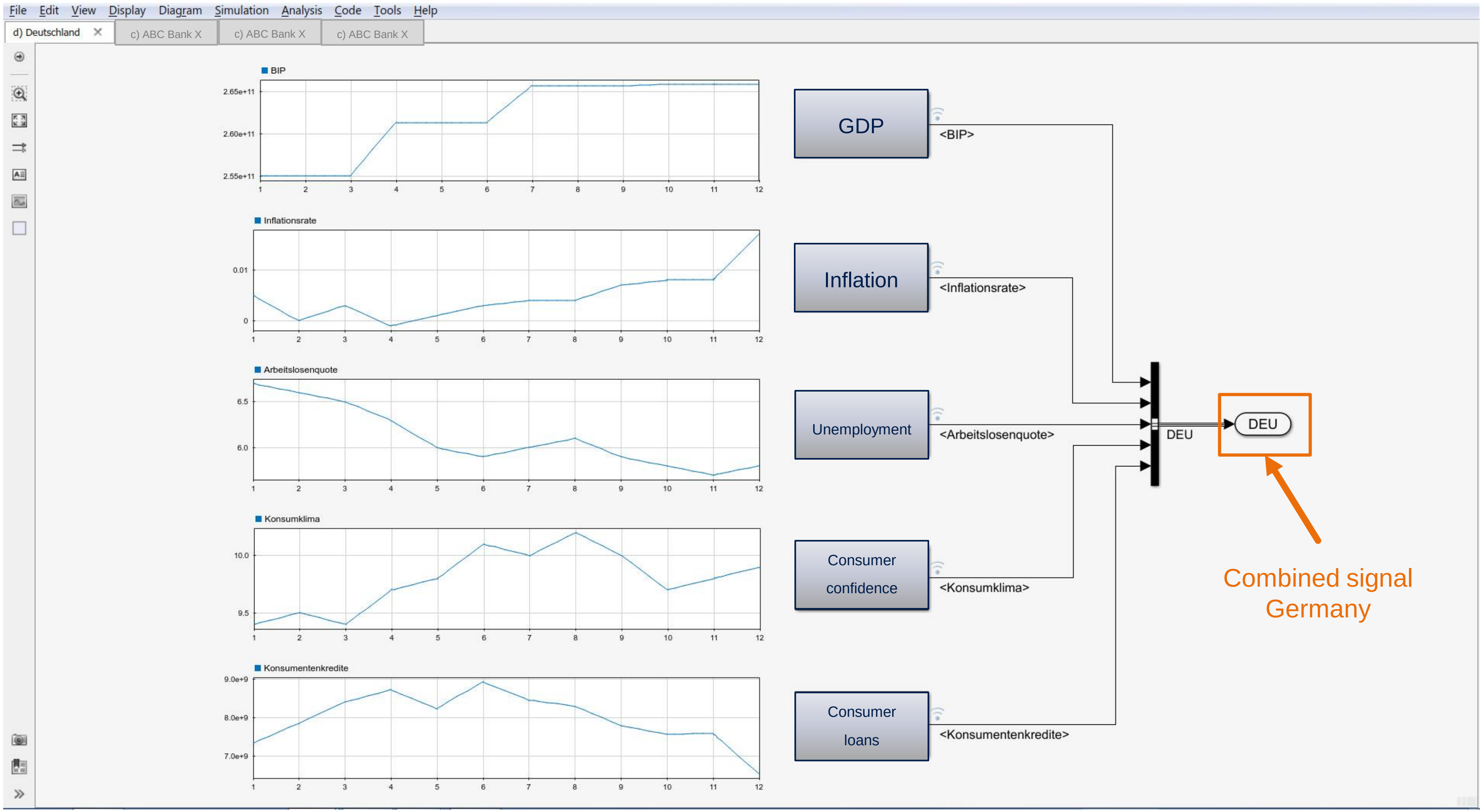
Scenario definition Germany



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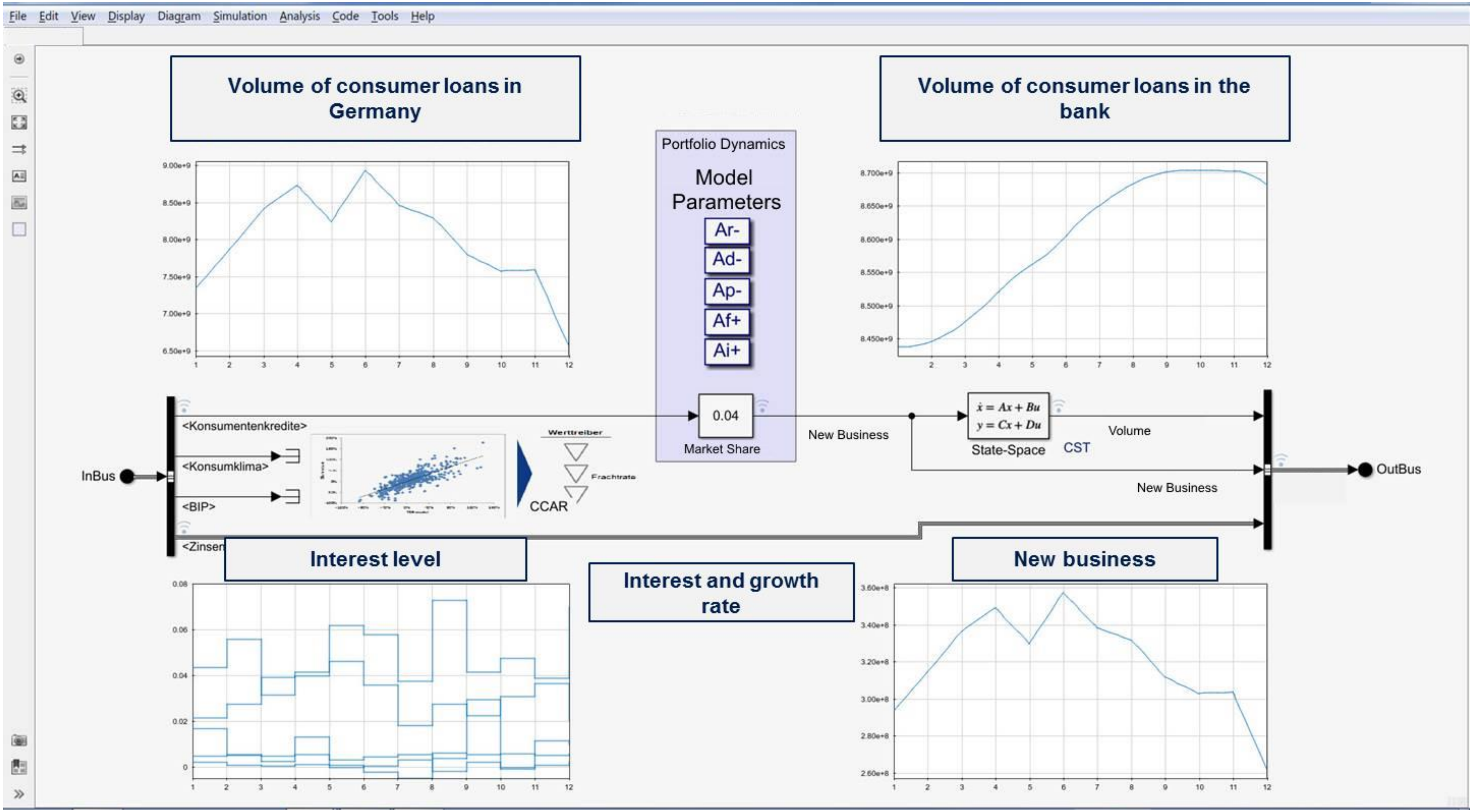
Determination of internal value drivers for a mortgage bank



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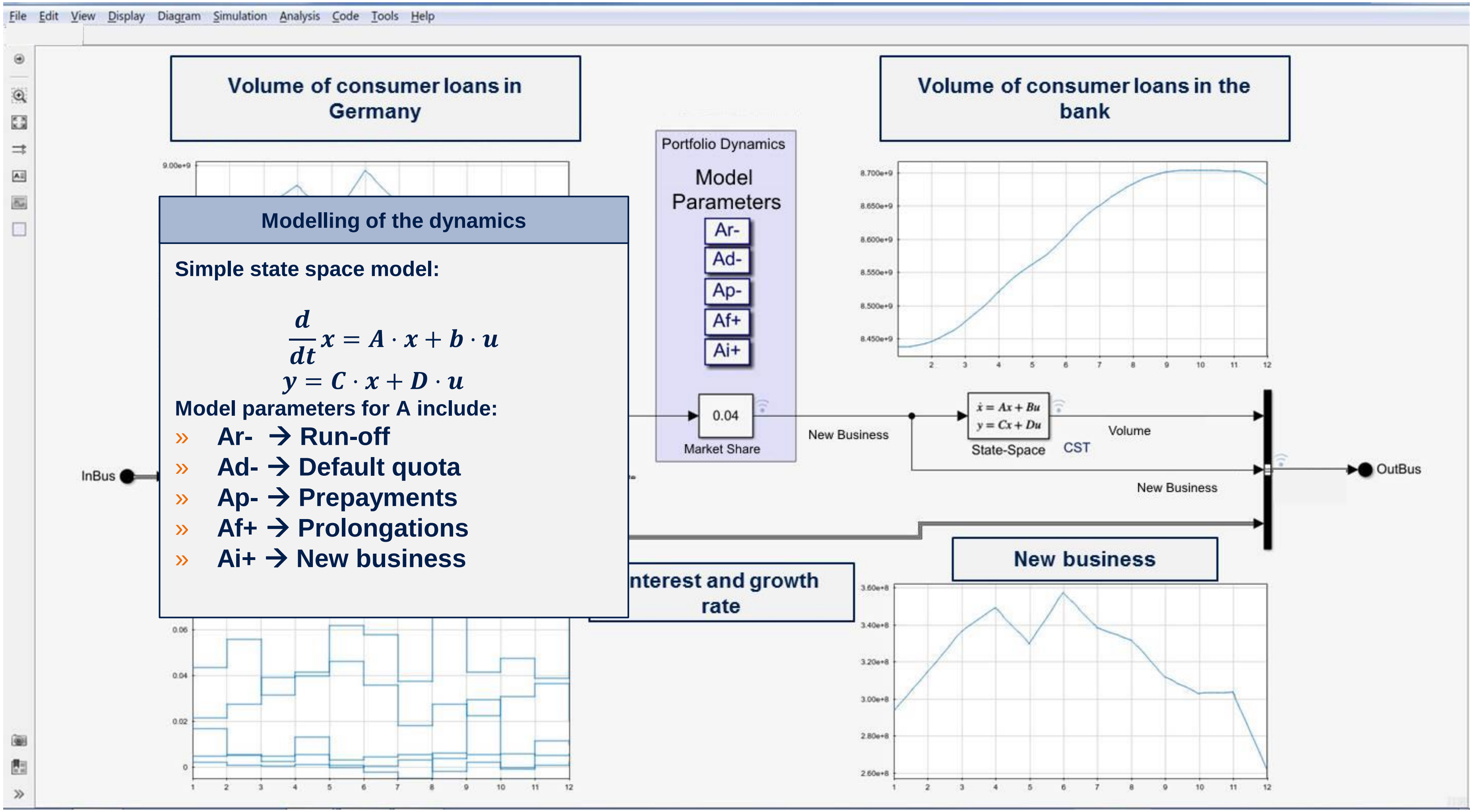
Calculation based on simple dynamics



Modelling of the dynamics

Simple state space model:

$$\frac{d}{dt}x = A \cdot x + b \cdot u$$
$$y = C \cdot x + D \cdot u$$

Model parameters for A include:

- **Ar- → Run-off**
- **Ad- → Default quota**
- **Ap- → Prepayments**
- **Af+ → Prolongations**
- **Ai+ → New business**

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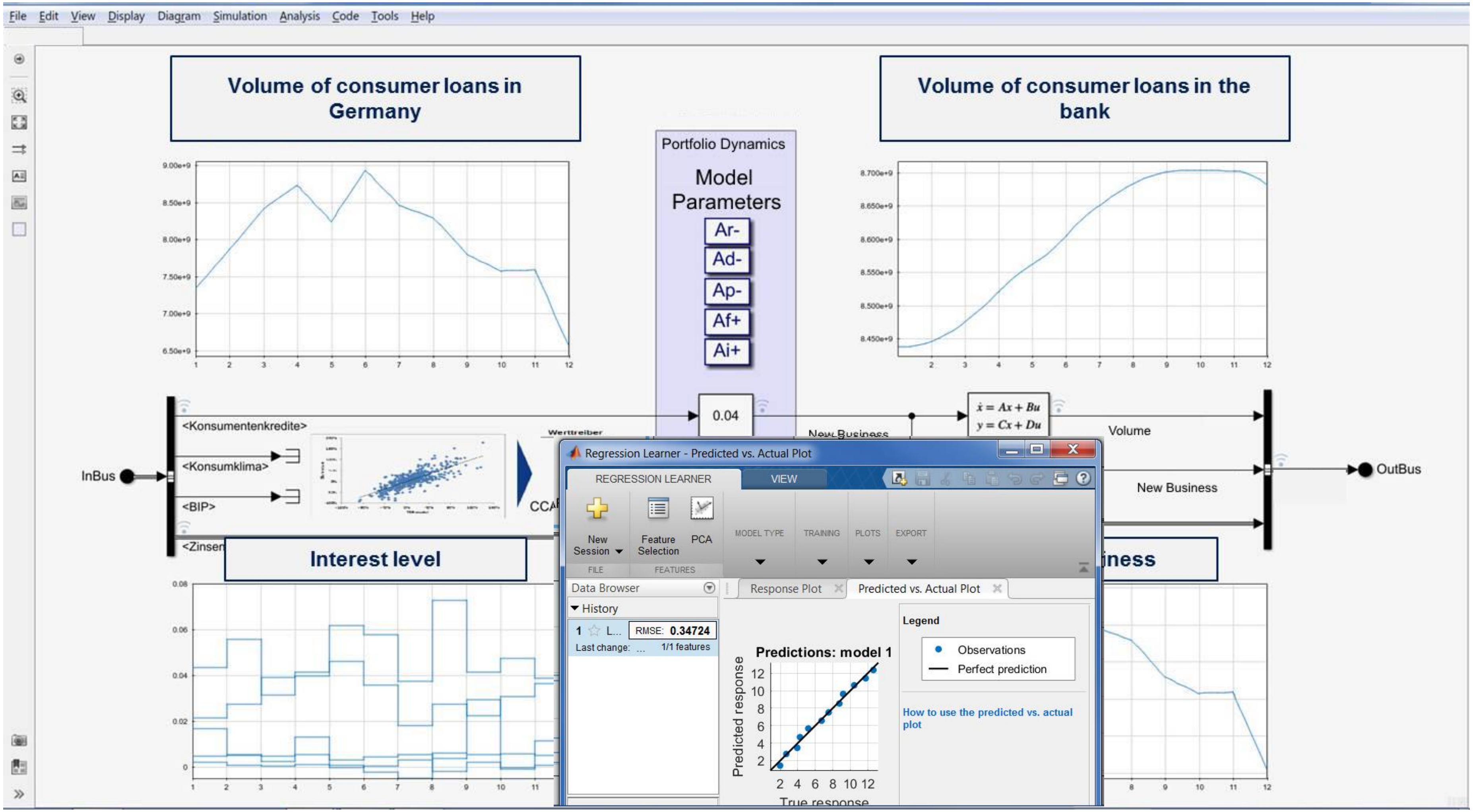
Determination of parameters based on build in regression methods



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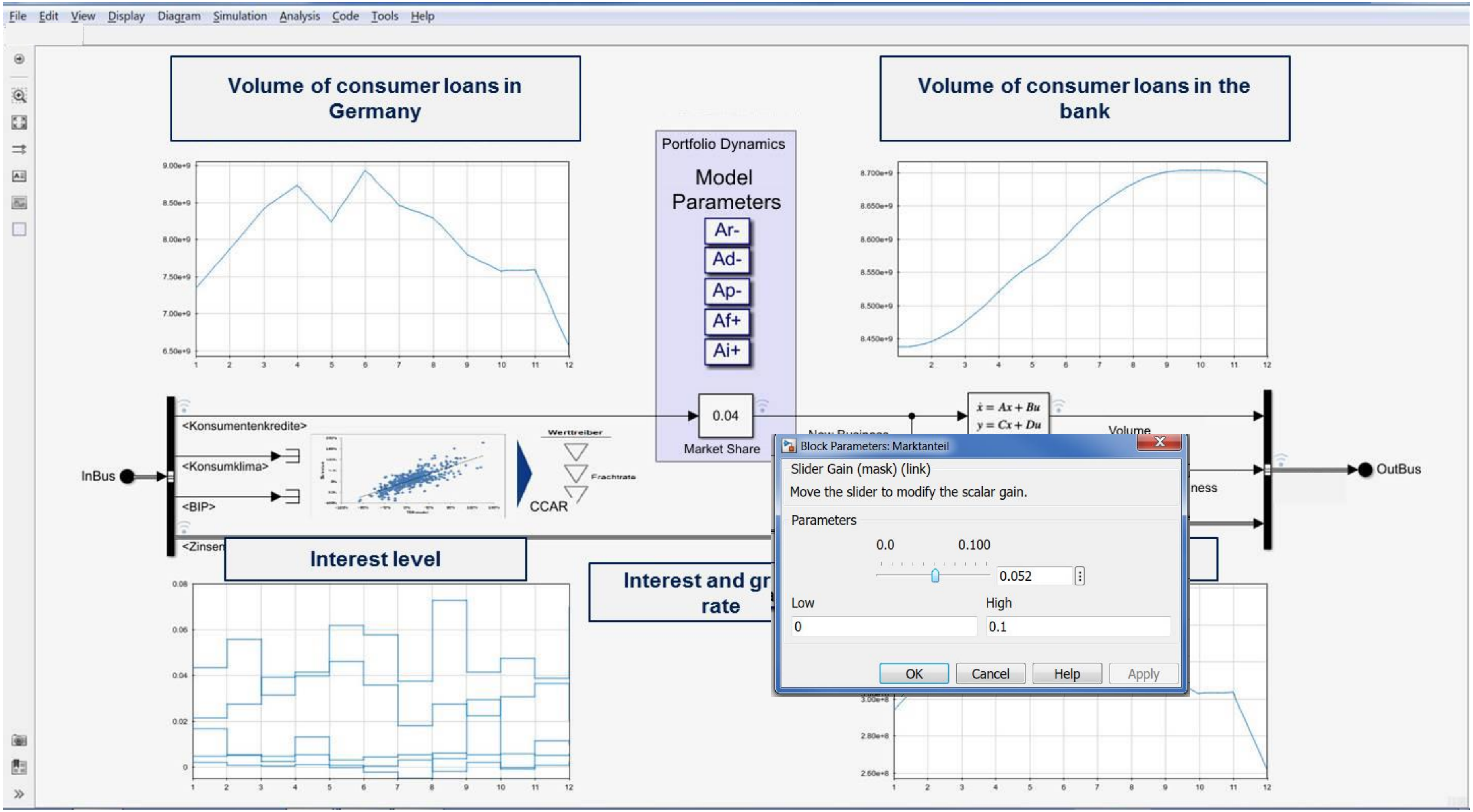
Every model parameter can be easily adjusted



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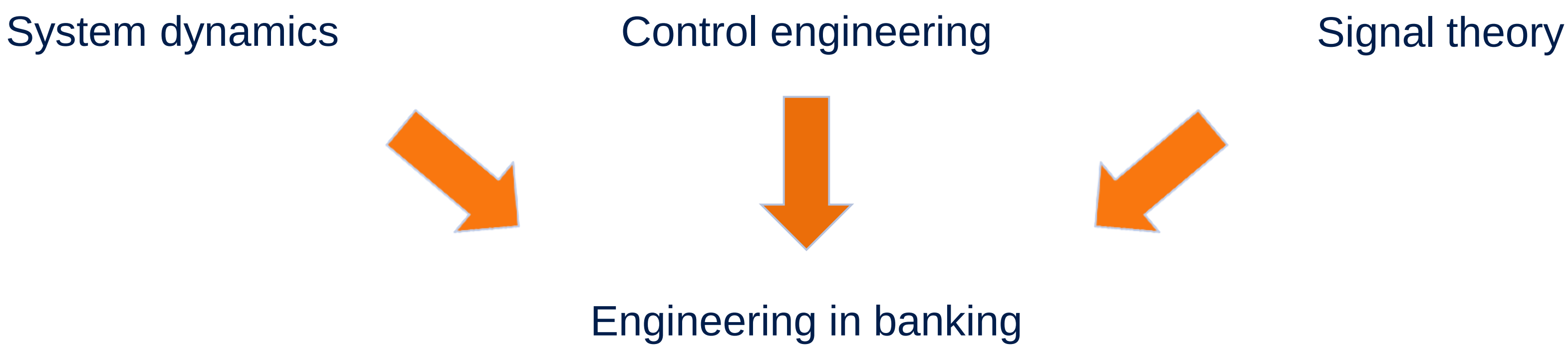
Simulink / MATLAB in a banking context



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Simulink / MATLAB in a banking context

J.W. Forrester

World Dynamics

Wright Allen Press 1971

D.H Meadows, D.L. Meadows, J. Randers, W. Behrens III

The limits of growth

Potomac Asscosiates – University Books

1972

D.H Meadows, D.L. Meadows, E. Zahn, P. Milling

Die Grenzen des Wachstums

Bericht des Club of Rome zur Lage der Menschheit

dva informativ

1972

D.H Meadows, D.L. Meadows, J. Randers

The limits of growth

- The 30 year update

Chealsea Green Publishing

2013

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Is the financial complexity manageable?

High frequency trading

- HFT incorporates proprietary trading strategies carried out by computers
- Electronic exchanges were first authorized by the U.S. Securities and Exchange Commission in 1998
- Execution times have fallen from several seconds in the year 2000 to milliseconds on modern systems

Image from Handelsblatt 2012

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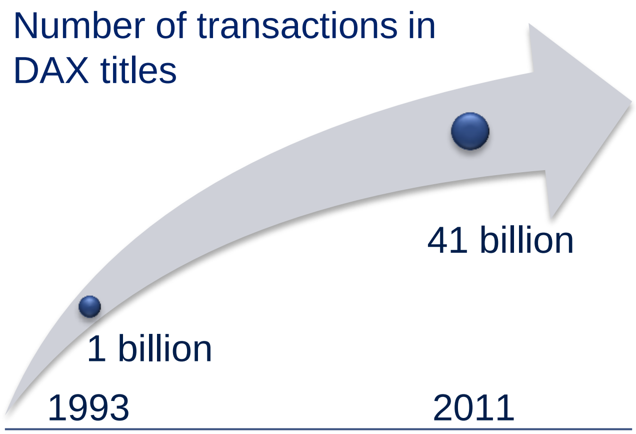
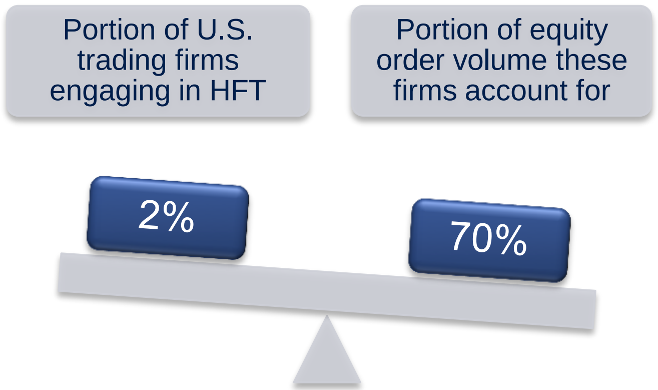
Volume of high frequency trading

- Portion of HFT in U.S. equity trades has increased from less than 10 % in 2000 to over 70% in 2010
- About 40% of Xetra transactions are carried out by HFT systems





Data Source: Handelsblatt 2012

Role of high frequency trading in the crisis

- In 2010 the Dow Jones Index experienced its largest one-day point decline in history
  ⇨ “Flash Crash”
- The U.S. Securities and Exchange Commission and the Commodity Futures Trading Commission concluded in a joint investigation that the actions of HFT firms largely contributed to volatility during the crash.

Image from Handelsblatt 2012

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Role of high frequency trading in the crisis

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» The U.S. Securities and Exchange Commission and the Commodity Futures Trading Commission concluded in a joint investigation that the actions of HFT firms largely contributed to volatility during the crash.

S. Patterson

Dark Pools

Crown Business

M. Lewis

Flash Boys

Norton & Company

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Network topologies of interbank payments

CHAPS: Clearing House Automated Payment System

CHAPS offers same-day sterling fund transfers

Many flows are routed through settlement banks

See: Becher, Millard, and Soramäki, The network topology of CHAPS Sterling, Bank of England, Working Paper 355

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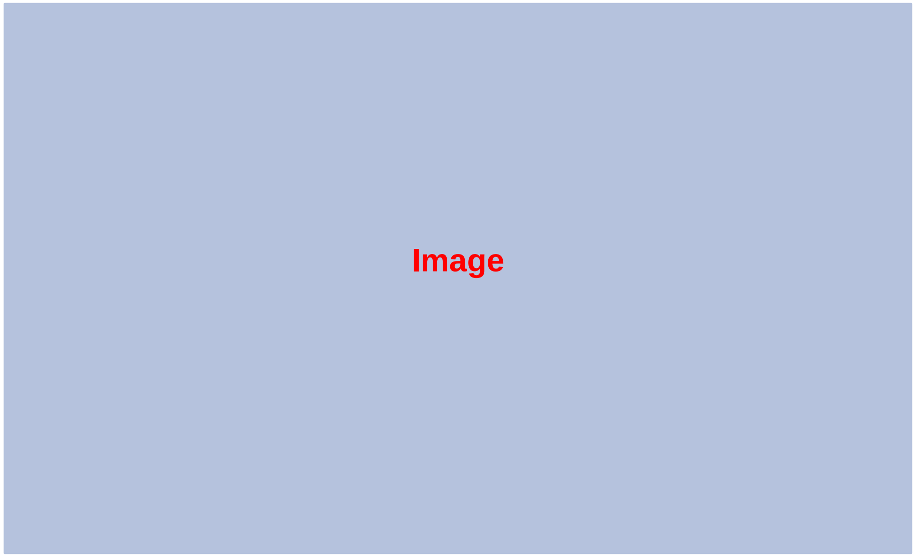
Network topologies of interbank payments

CHAPS: Clearing House Automated Payment System

CHAPS offers same-day sterling fund transfers

Many flows are routed through settlement banks



- The settlement banks form a complete network
- 4 settlement banks account for almost 80% of the payments, measured by value or volume!

Source: Becher, Millard, and Soramäki, The network topology of CHAPS Sterling, Bank of England, Working Paper 355

Network topologies of interbank payments

CHAPS: Clearing House Automated Payment System

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Becher, Millard, and Soramäki,

The network topology of CHAPS Sterling,

Bank of England, Working Paper 355

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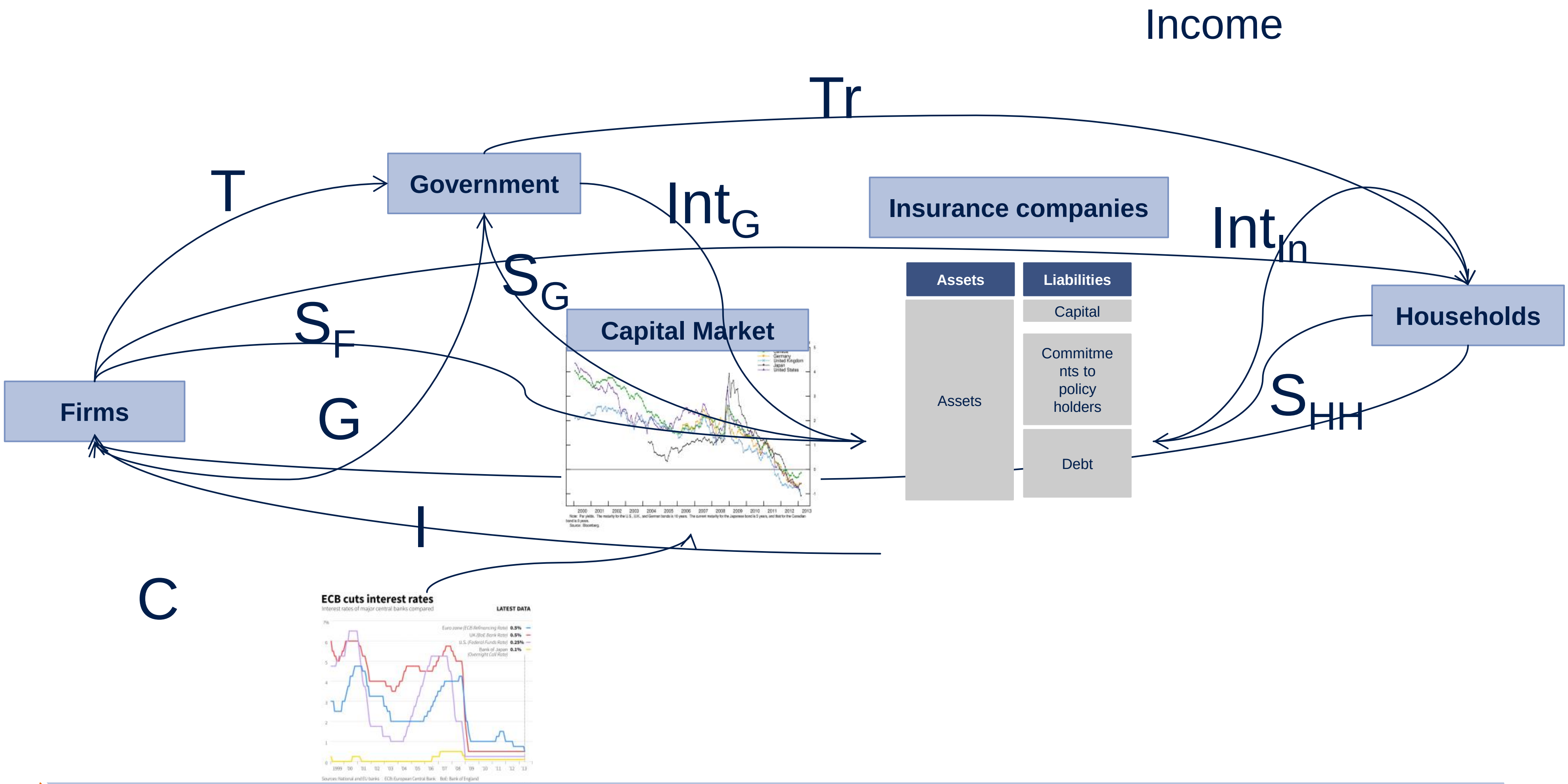
Economics and banking – a complex network of dependencies



Insurance companies form a vital part of the macroeconomic flow chart

Collecting and processing information

Digital economy is founded on data

Photo source: en.wikipedia.org / de.wikipedia.org, free to use

Combating the crisis: When does financial instability become so widespread that it impairs the functioning of a financial system?

- Need a robust measure for systemic financial stress, here: *CISS = Composite Indicator of Systemic Stress*
- CISS includes 15 individual stress indicators in five segments:

Money market	Bond market	Equity market	Financial intermediaries	FX market
3M Euribor realised vola.	German 10Y Bond realised vola.	NFS stock market index realised vola.	Realised vola. equity return of bank sector index	FX rate EUR - USD realised vola.
Interest rate Spread: 3M Euribor - 3M Frech T-Bills	Yield-Spread: A-rated NFC vs. gov. Bonds (7Y)	NFS maximum cumulated index losses over 2Y window	Yield-Spread: A-rated NFC vs. A-rated FC (7Y)	FX rate EUR - GBP realised vola.
MFI emergency lending	10Y interest rate spread	Stock-bond correlation	FS equity market maximum cumulated book-price ratio (2Y-wind.)	FX rate EUR - JPY reailsed vola.

- On basis of the raw stress indicators x_i, transformed stress indicators z_i are calculated with the following empirical CDF:
  - $(x_{[1]}, x_{[2]}, \dots, x_{[n]})$ denotes the ordered sample with $x_{[1]} \leq x_{[2]} \leq \dots \leq x_{[n]}$
  - $z_t := \begin{cases} \frac{r}{n} \text{ for } x_{[r]} \leq x_t < x_{[r+1]}, & r \in \{1,2,\dots,n-1\} \\ 1 \text{ for } x_t > x_{[n]} \end{cases}$ for values running from Jan. 1999 – Jan. 2002
  - $z_{n+T} := \begin{cases} \frac{r}{n+T} \text{ for } x_{[r]} \leq x_{n+T} < x_{[r+1]}, & r \in \{1,2,\dots,n-1,\dots,n+T-1\} \\ 1 \text{ for } x_{n+T} > x_{[n+T]} \end{cases}$ to update CISS with near real time data
- In every segment, the stress factors are aggregated by the arithmetic average, denoted $s_{i,t}, i \in \{1,\dots,5\}$.
- The CISS for time t $(\mathrm{CISS_t})$ is computed with methods from portfolio theory:
  - $\mathrm{CISS}_t = \sum_{i,j} (w \cdot s_t)_i \, C_{t,i,j} \, (w \cdot s_t)_j$, with weights $w = (0.15, 0.15, 0.25, 0.3, 0.15)$, and $(w \cdot s)_i$ the component wise multiplication
  - And the cor.-matrix $C_{t,i,j} = \begin{cases} 1 \text{ for } i = j \\ \rho_{ij,t} \text{ else} \end{cases}$ with $\rho_{ij,t} = \frac{\sigma_{ij,t}}{\sigma_{i,t}\ \sigma_{j,t}}, \sigma_{ij,t} = \lambda\, \sigma_{ij,t-1} + (1-\lambda)\, \widetilde{s_{i,t}}\, \widetilde{s_{j,t}},\ \sigma_{i,t}^2 = \lambda\, \sigma_{i,t-1}^2 + (1-\lambda)\, \widetilde{s_{i,t}}^2, \widetilde{s_{i,t}} = s_{i,t} - 0.5, \lambda \approx 0.93$
- CISS puts relatively more weight on situations where stress prevails in several market segments.

Source: European Systemic Risk Board (ESRB) Risk Dashboard, Hollo, D., Kremer, M. and Lo Duca, M., "CISS - A composite indicator of systemic stress in the financial system", Working Paper Series, No 1426, ECB, March 2012, MFI: Monetary Financial Institution, NFS: Non-Financial sector, (N)FC: (Non-)Financial corporation

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Combating the crisis: Is the financial and European debt crisis over?

» CISS = Composite Indicator of Systemic Stress

Image, see:

https://www.hvst.com/posts/ecb-ciss-index-there-is-no-trend-in-stress-be-happy-oqMTgn4x

Source: European Systemic Risk Board (ESRB) Risk Dashboard, Hollo, D., Kremer, M. and Lo Duca, M., "CISS - A composite indicator of systemic stress in the financial system", Working Paper Series, No 1426, ECB, March 2012

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Has physics caused the crisis?

- Risk management depends heavily on sophisticated models
- Developed models were too complex to be understood intuitively
- Computer experts construct “financial hydrogen bombs” as already suspected by Felix Rohatyn in 1998

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Physical models applied to financial markets

The main problem is: Our models have in fact become extremely complex but are still too simple to be able to incorporate the whole spectrum of variables that drive the global economy. A model is necessarily an abstraction without all details of the real world.

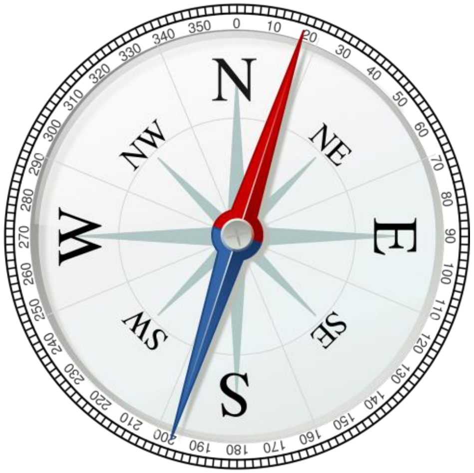
The four "business dimensions"

Business Acumen

Global bank management

Liquidity risk

Greed



Fear

Modelling

Interest rate risk

Risk
duty of due care

Image source> https://pixabay.com/de/kompass-richtung-navigation-reisen-1299559/

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Has physics caused the crisis?

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Physics has not caused the crisis

Ignoramus et ignorabimus

versus

We have to know. We will know.

D. Hilbert

Everything which is not forbidden is compulsory.

M. Gell-Mann

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