From Physics to Finance

XXXIX Heidelberg Physics Graduate Days

Heidelberg, October 09th, 2017

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Agenda

The banks’ role in the economy

The “Banks”

Deutsche Bank

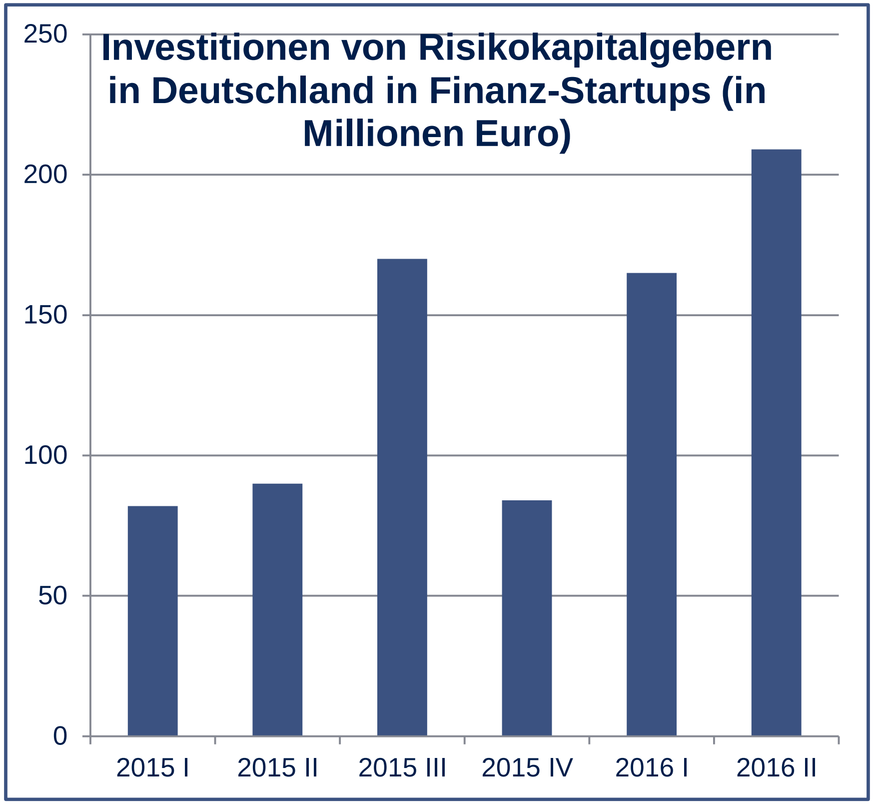
COMMERZBANK

Photo source: © NH1977 / PIXELIO

New players – Fintecs try to disrupt the banking industry

New opportunities arise from disrupting old and inefficient processes in the banking business:

- » Use of Blockchain technologies contemplated in:
  - › Money (Bitcoin etc.)
  - › Stock exchange
  - › Account management
  - › Interbanking transactions
  - › Title register…
- » Brokerage of fix rate invest in foreign countries
- » Assistance in changing the bank-account
- » Support of collection services
- » Credit rating with the help of user profiles/social network data (currently not legal in Germany)



- » First Fintechs in Germany are in possession of a bank licence
- » Established banks take notice → Cooperation with or acquisition of Fintechs

Digitalization of the banking business is a trend for years to come

Quelle: Barkow-Consulting

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Banking landscape in Germany

Universalbanken (1.635)			
266	Kreditbanken	4	Großbanken
		155	Regionalbanken und sonstige Kreditbanken
		107	Zweigstellen ausländischer Banken
963	Genossenschaftliche Kreditinstitute	963	Kreditgenossenschaften
406	Öffentlich-rechtliche Kreditinstitute	397	Sparkassen
		9	Landesbanken

three pillars

Spezialbanken (54)	
20	Bausparkassen
14	Realkreditinstitute
20	Banken mit Sonderaufgaben

Stand: Juli 2017

Source: Bankenstatistik, Statistisches Beiheft 1 zum Monatsbericht, Deutsche Bundesbank, September 2017, S. 106

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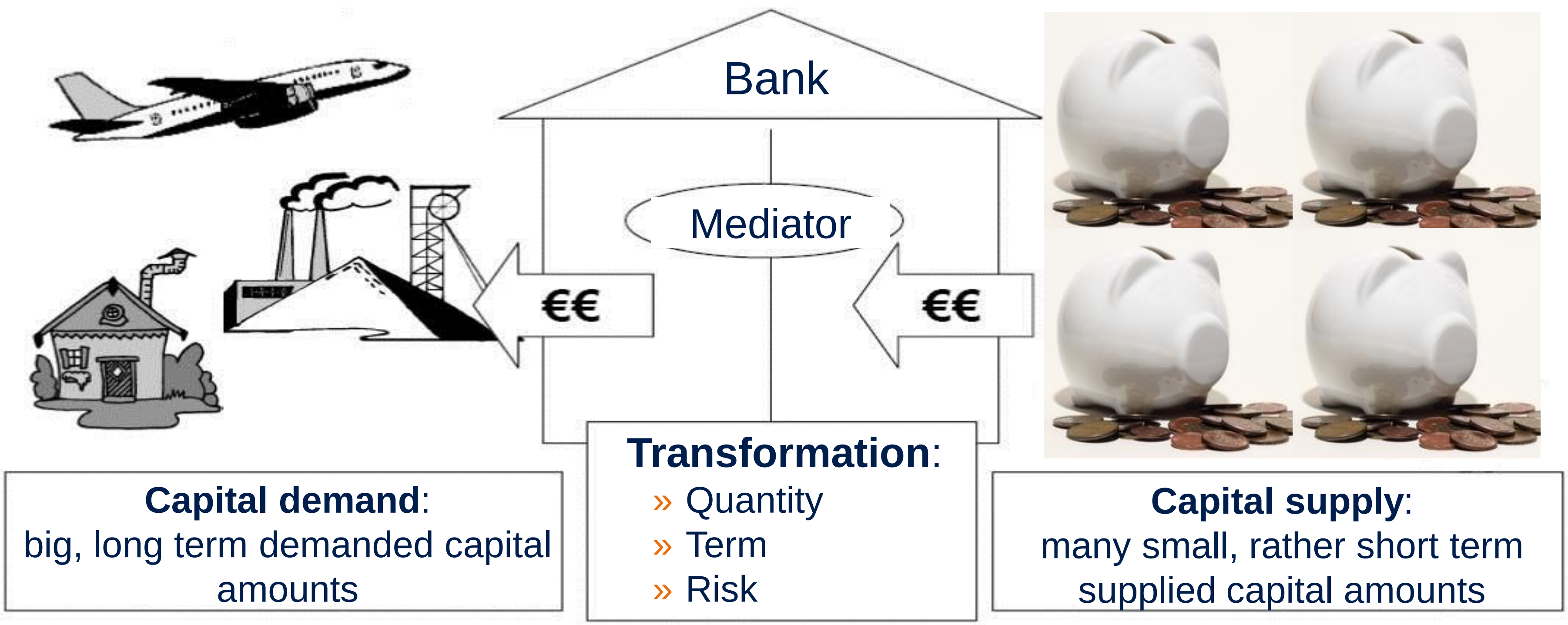
The banks’ role – Transforming money



Transformation is at the heart of banking business

Photo source: © segavax, Andreas Hermsdorf / PIXELIO

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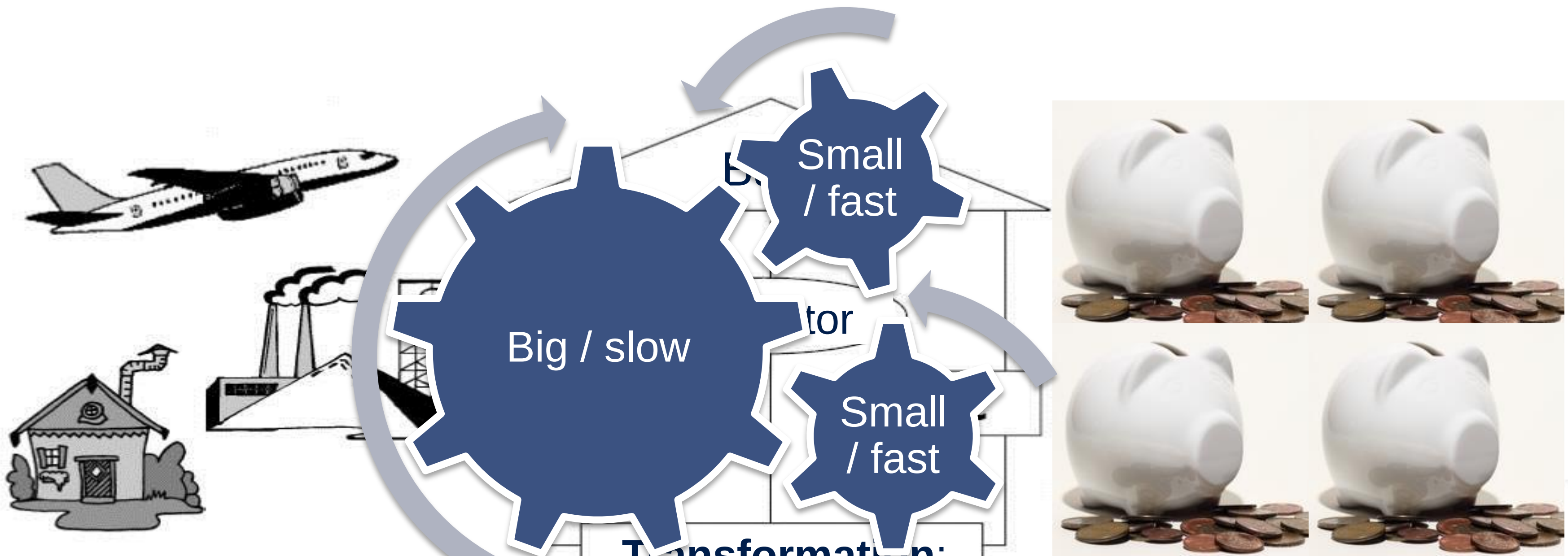
The banks' role – Transforming money



Transformation:
- » Quantity
- » Term
- » Risk

Capital demand:
big, long term demanded capital amounts

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

Transformation is at the heart of banking business

Photo source: © segavax, Andreas Hermsdorf / PIXELIO

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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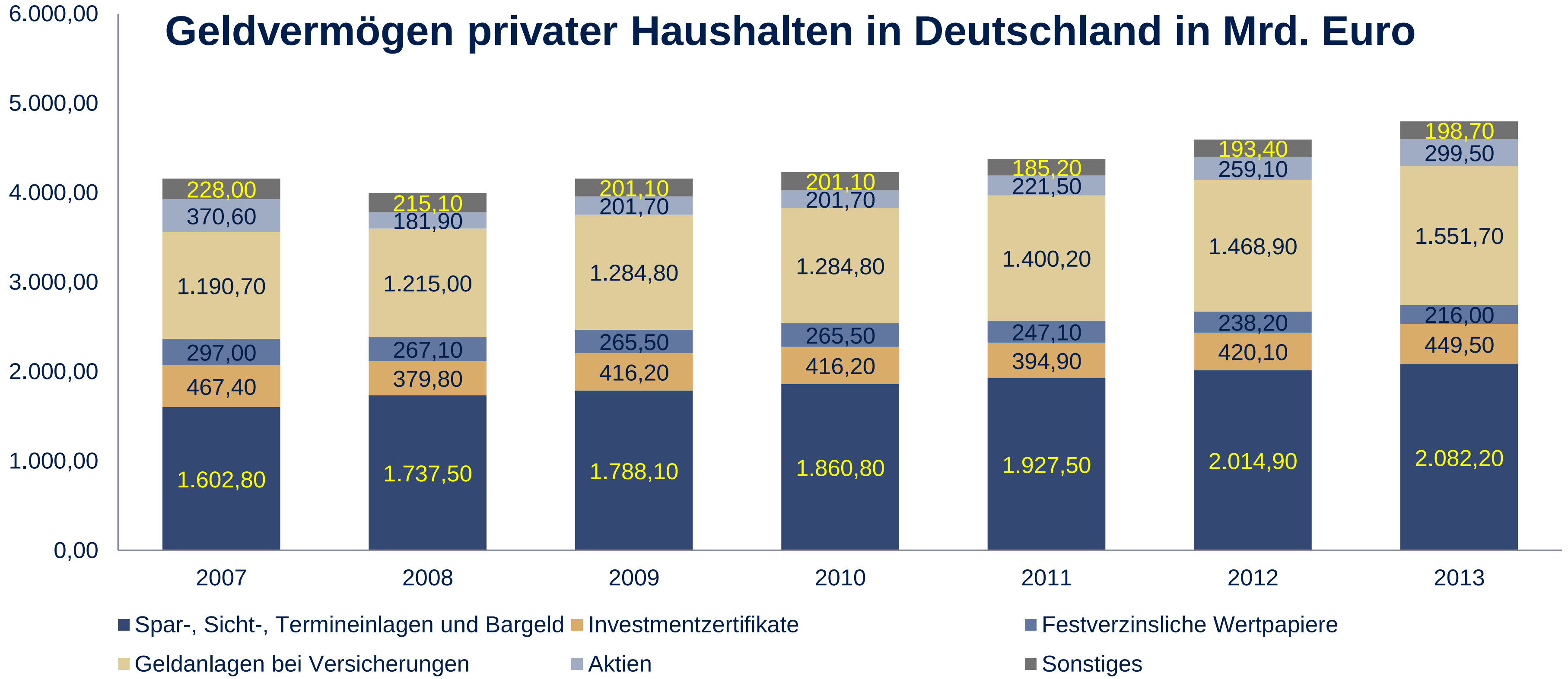
German saving behaviour

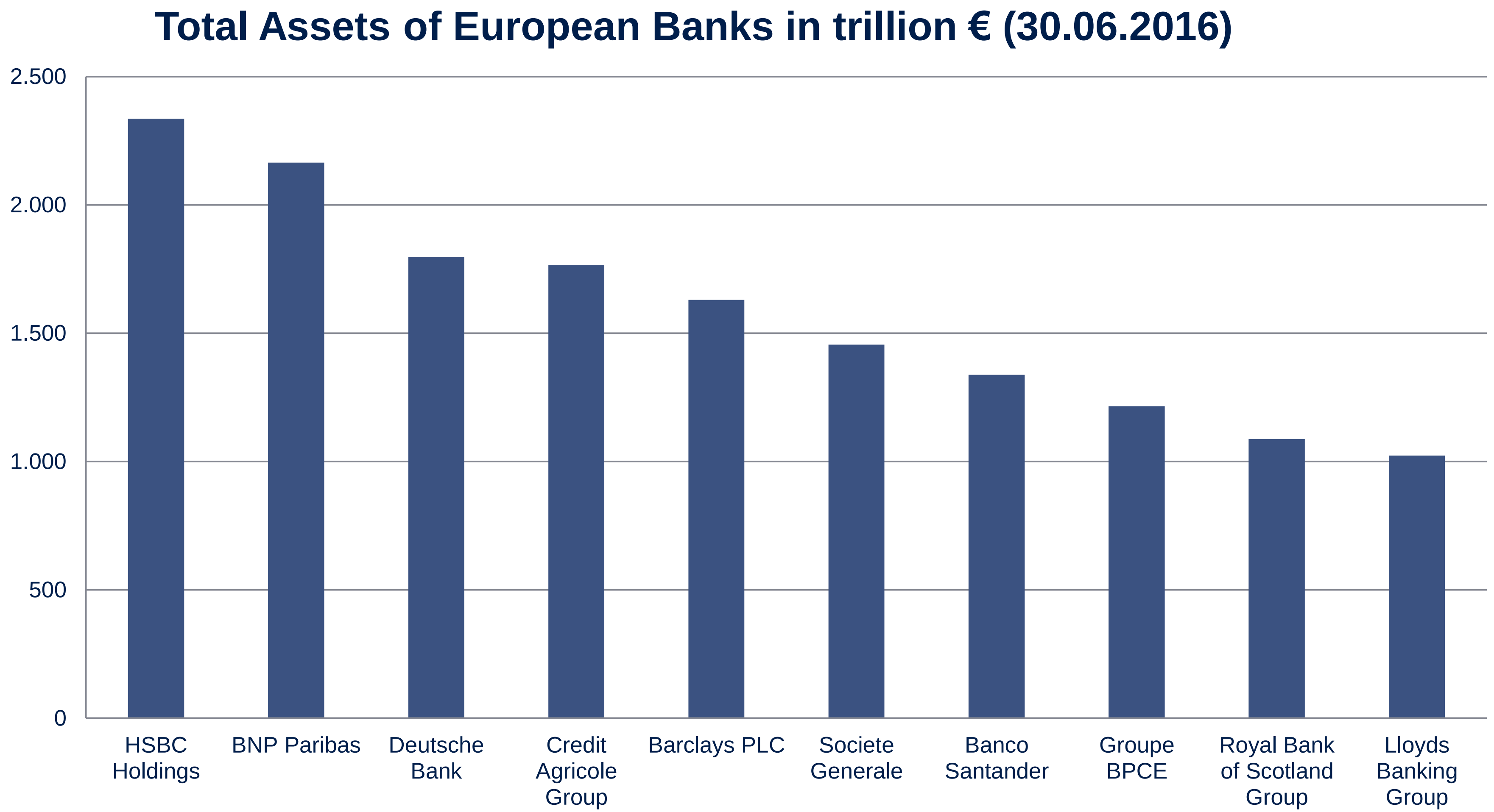
» Germans still invest the largest part of their capital in savings- / sight- / term-deposits and cash, as well as insurances



We have savings of about 5 trillion EUR

Source: Deutsche Bundesbank, September 2014

The ten biggest banks in Europe



Source: http://www.relbanks.com/, http://www.xe.com

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

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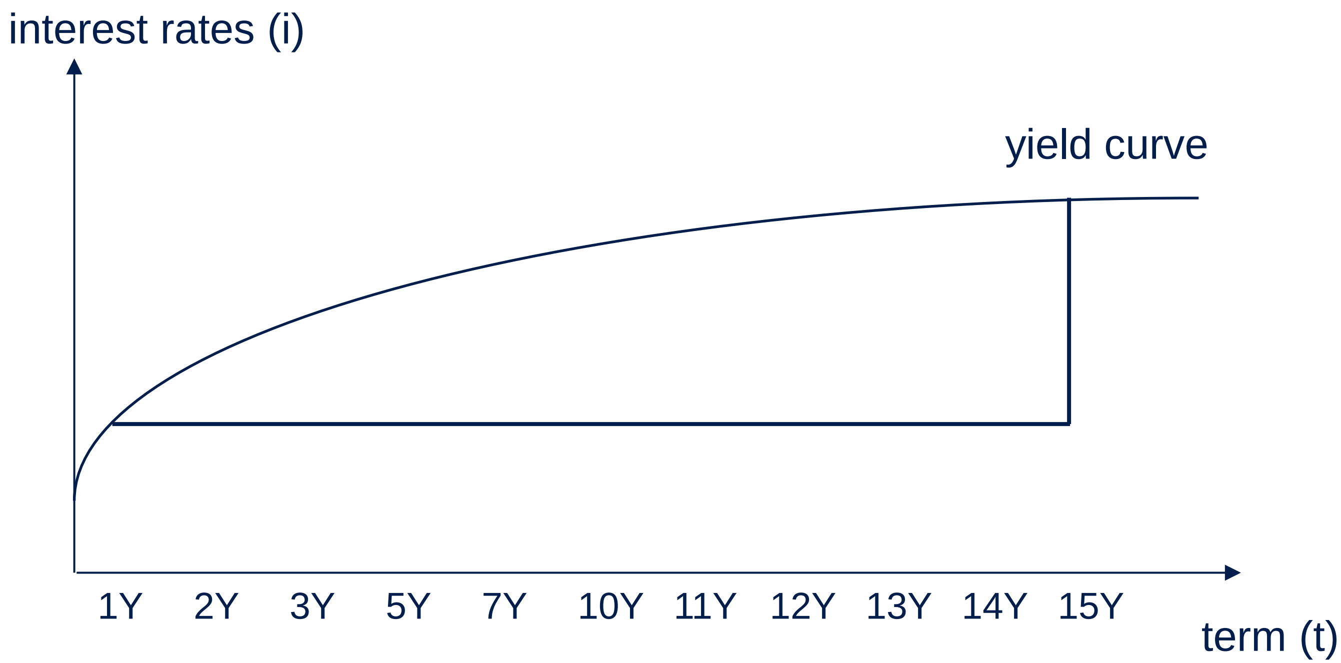
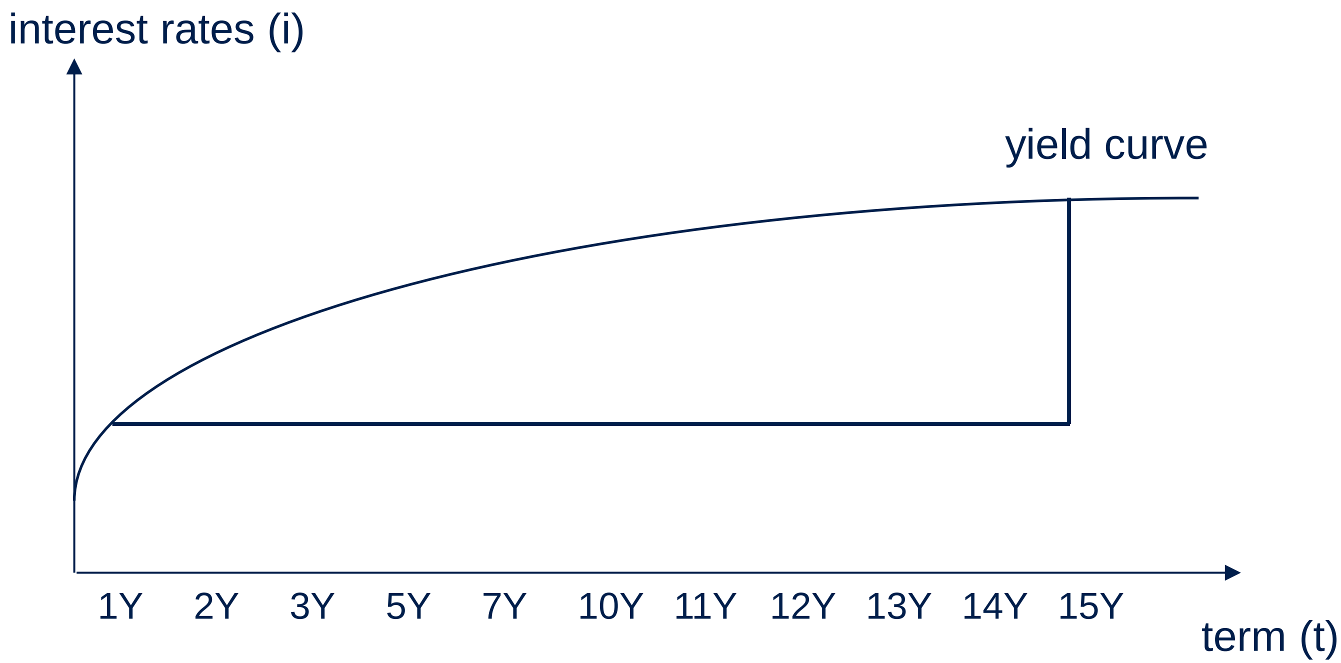
The yield curve



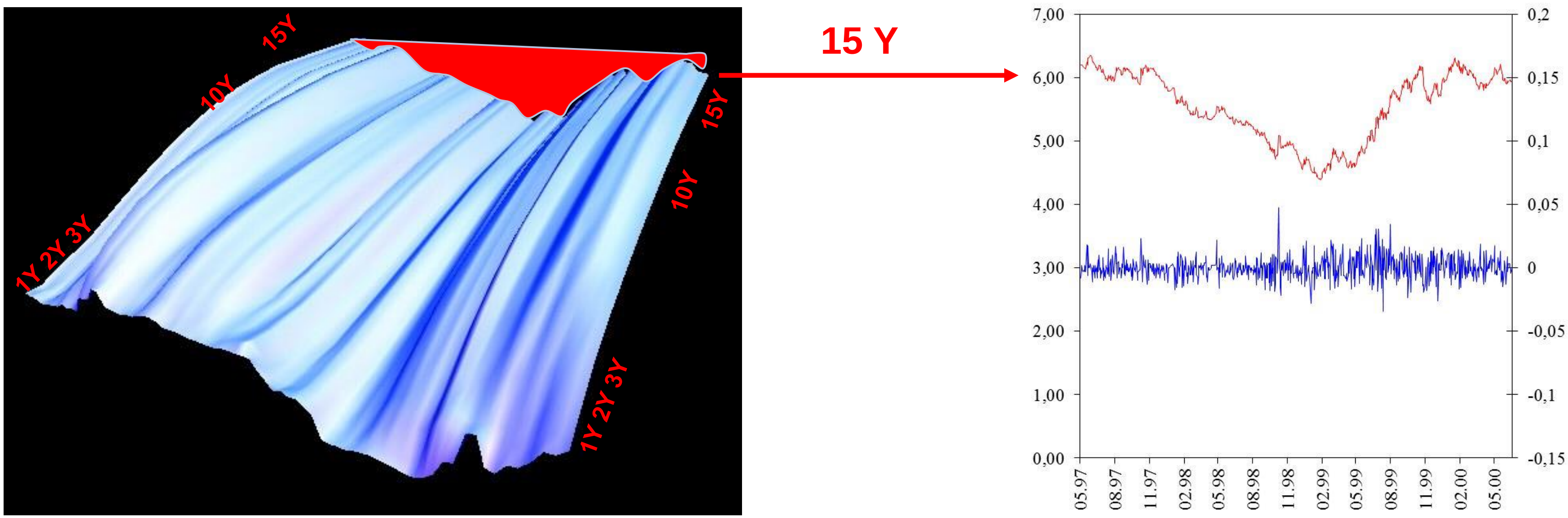
Term transformation, i.e., transformation in time, is a major transformation

The yield curve



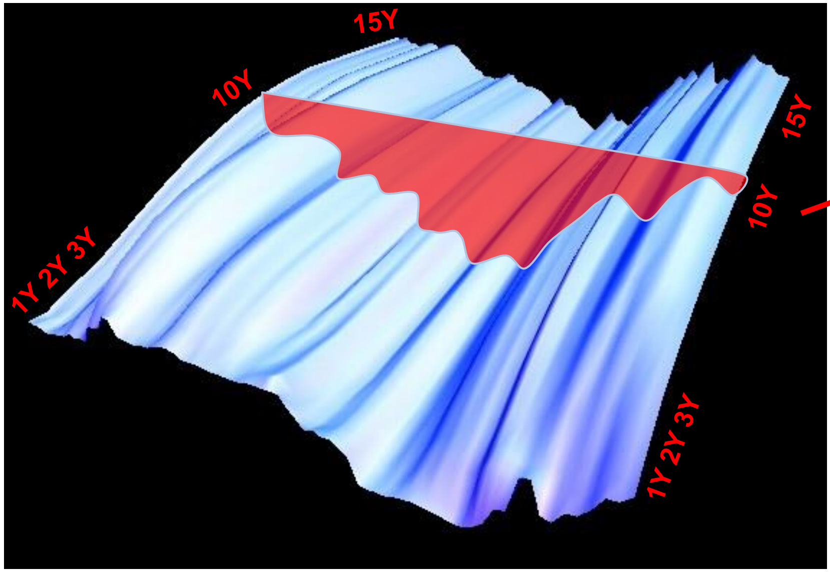
Term transformation, i.e., transformation in time, is a major transformation

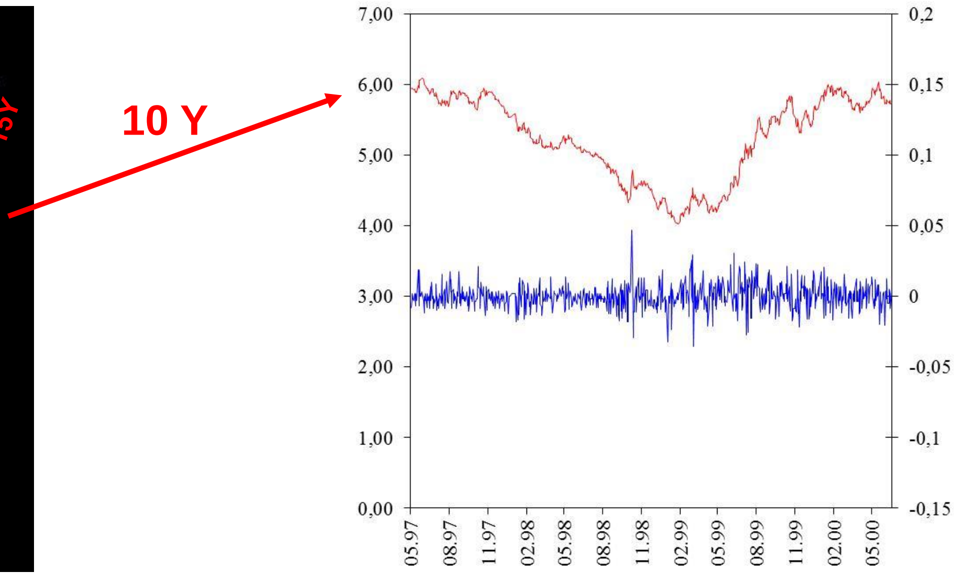
Interest rates and their dynamics



The change in interest rates follows no simple statistics

Interest rates and their dynamics





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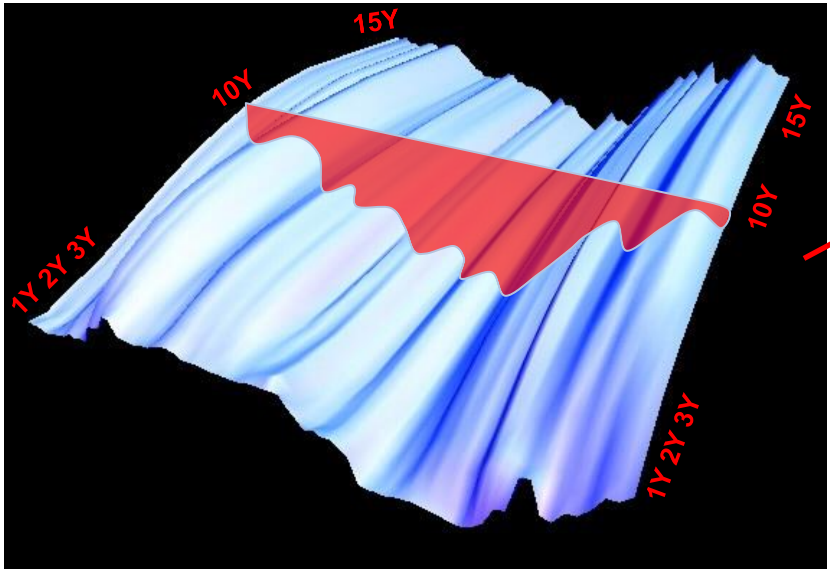

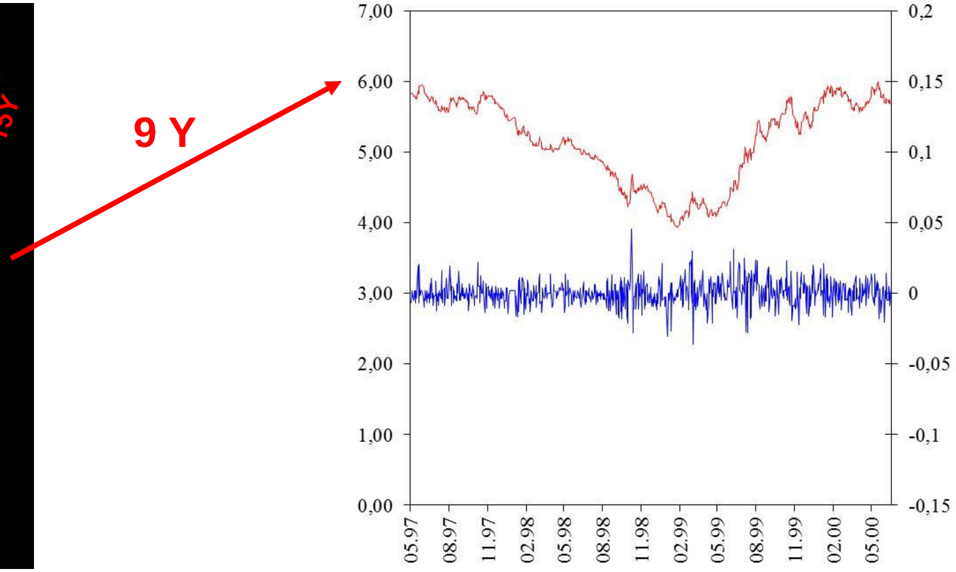

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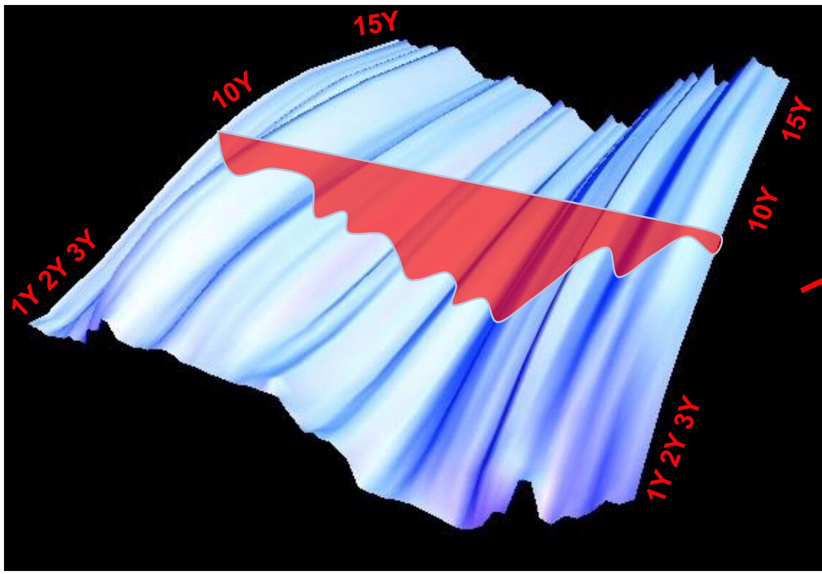

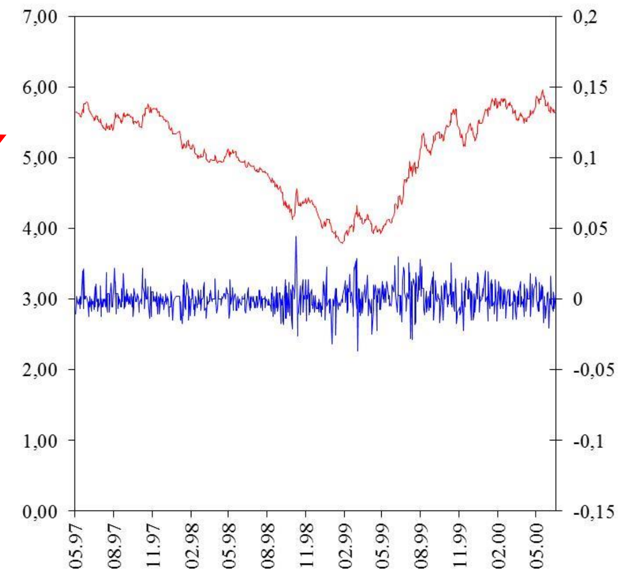

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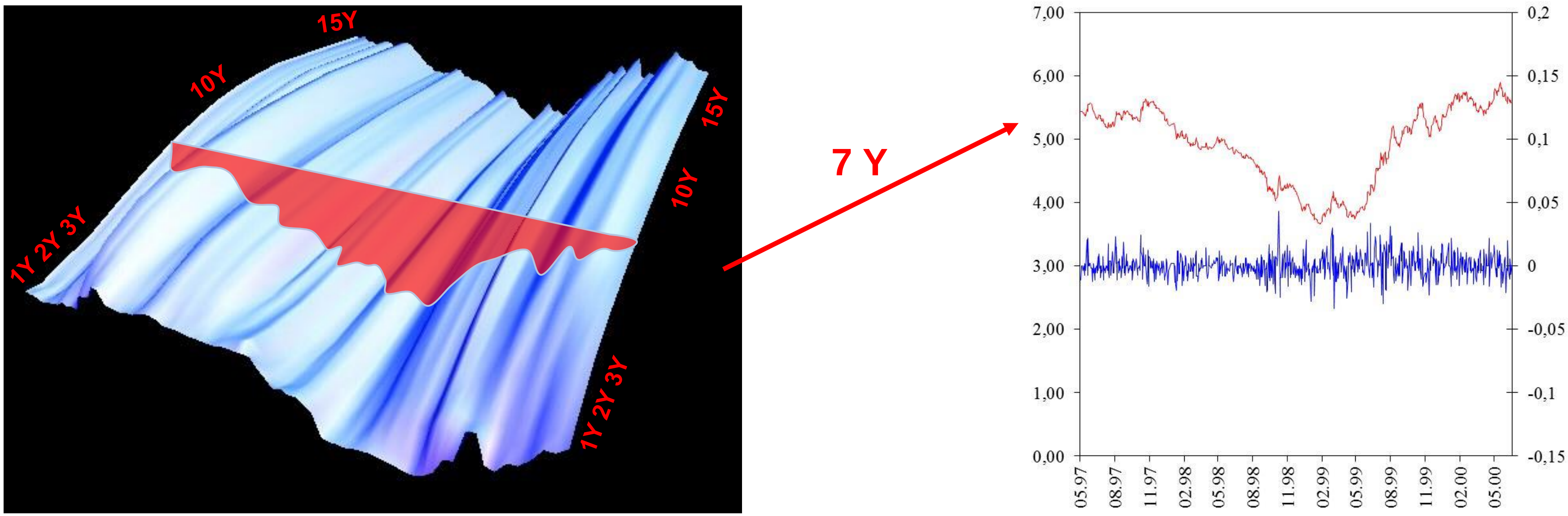

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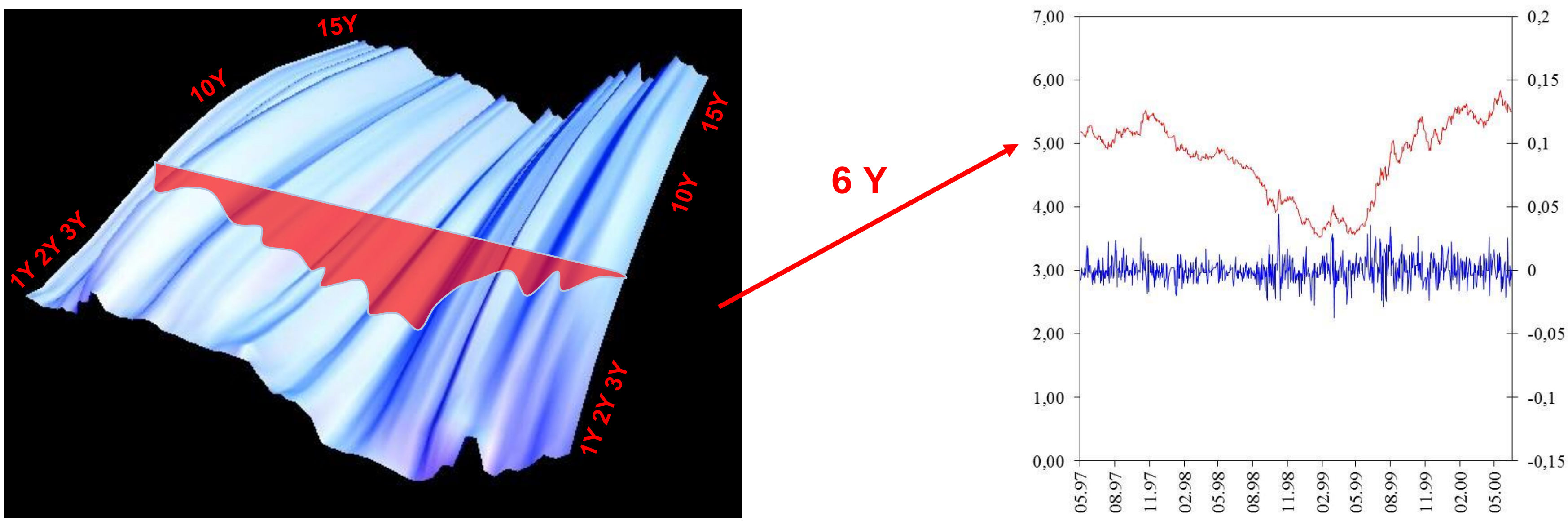

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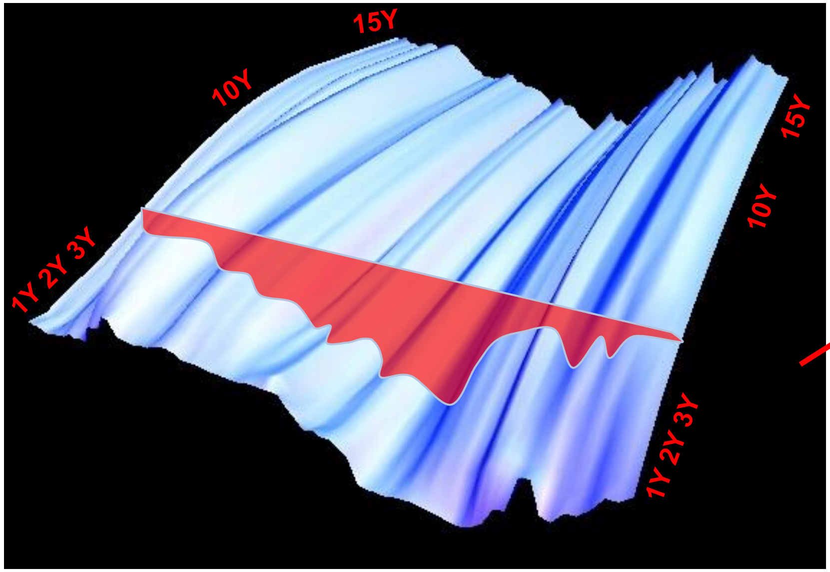
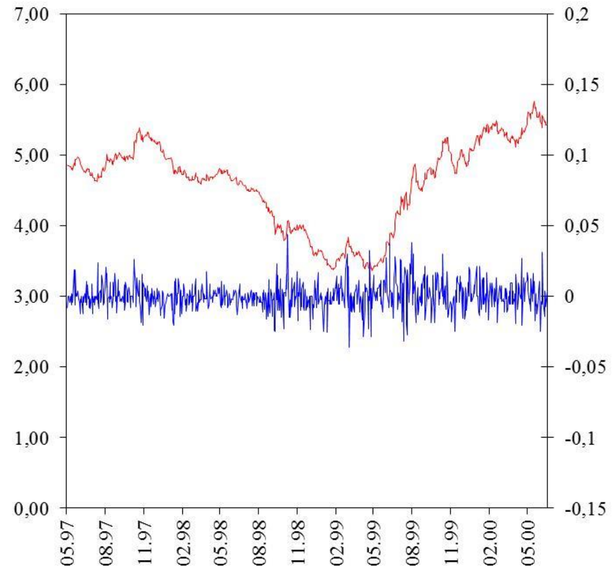


5 Y



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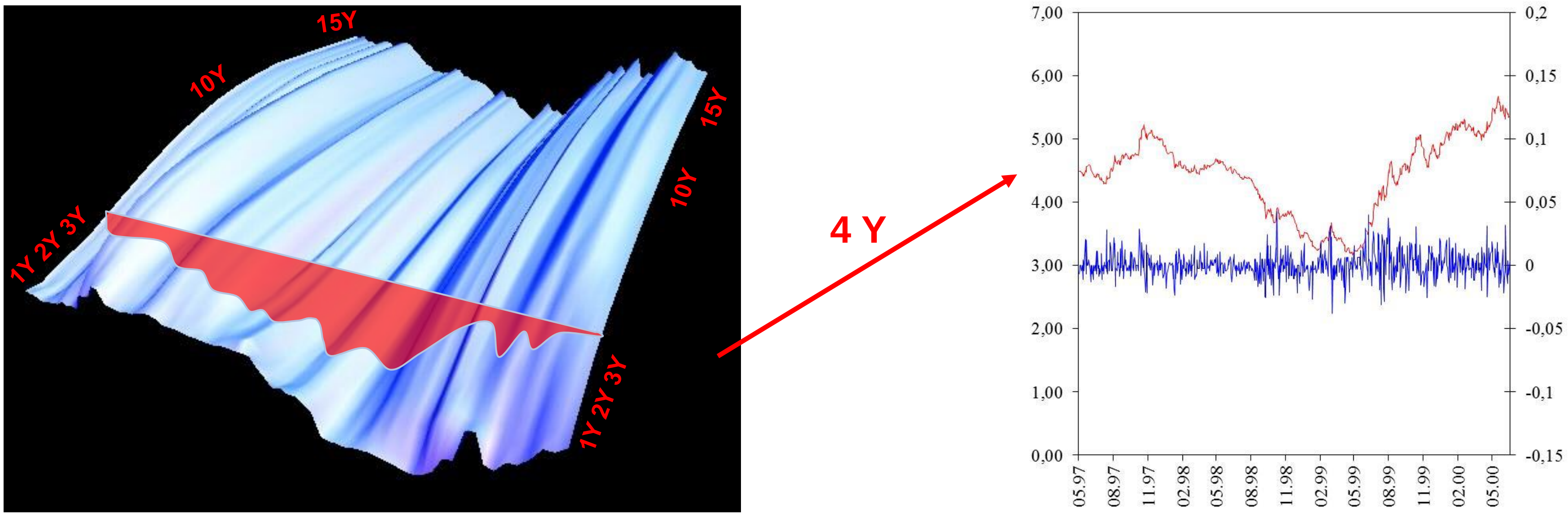

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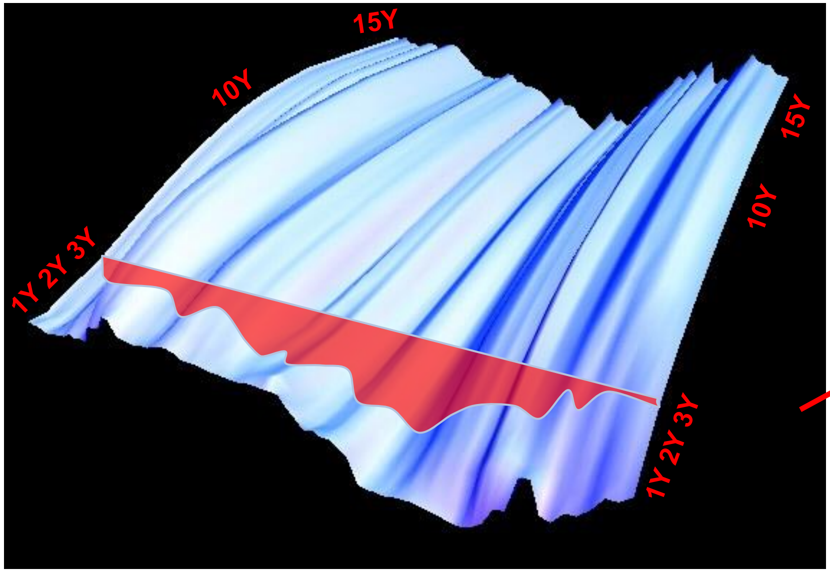

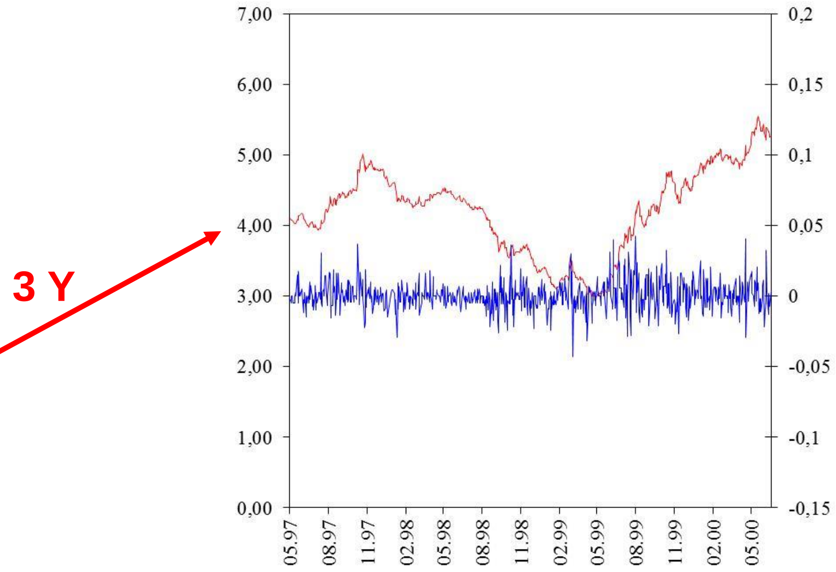

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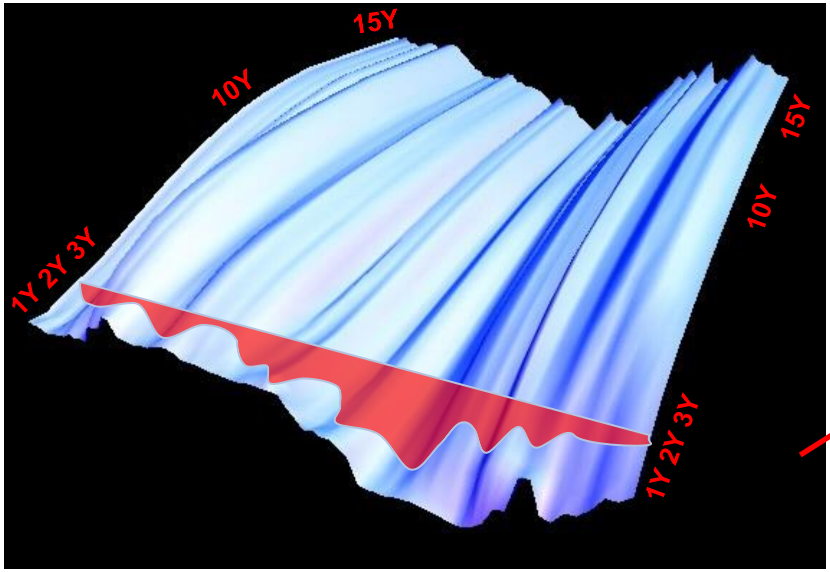

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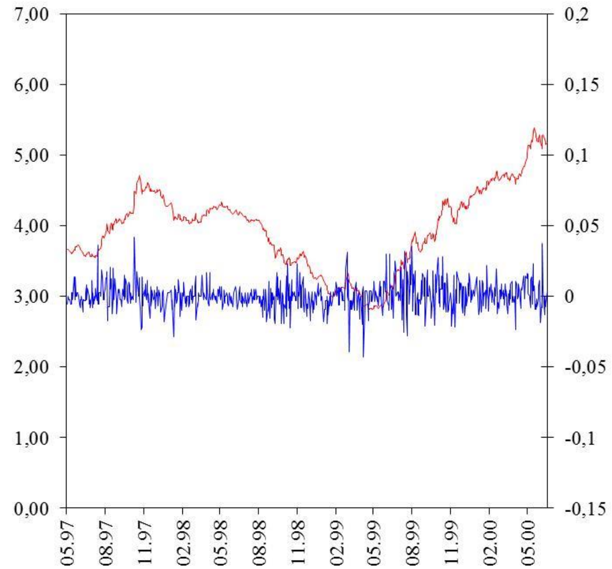

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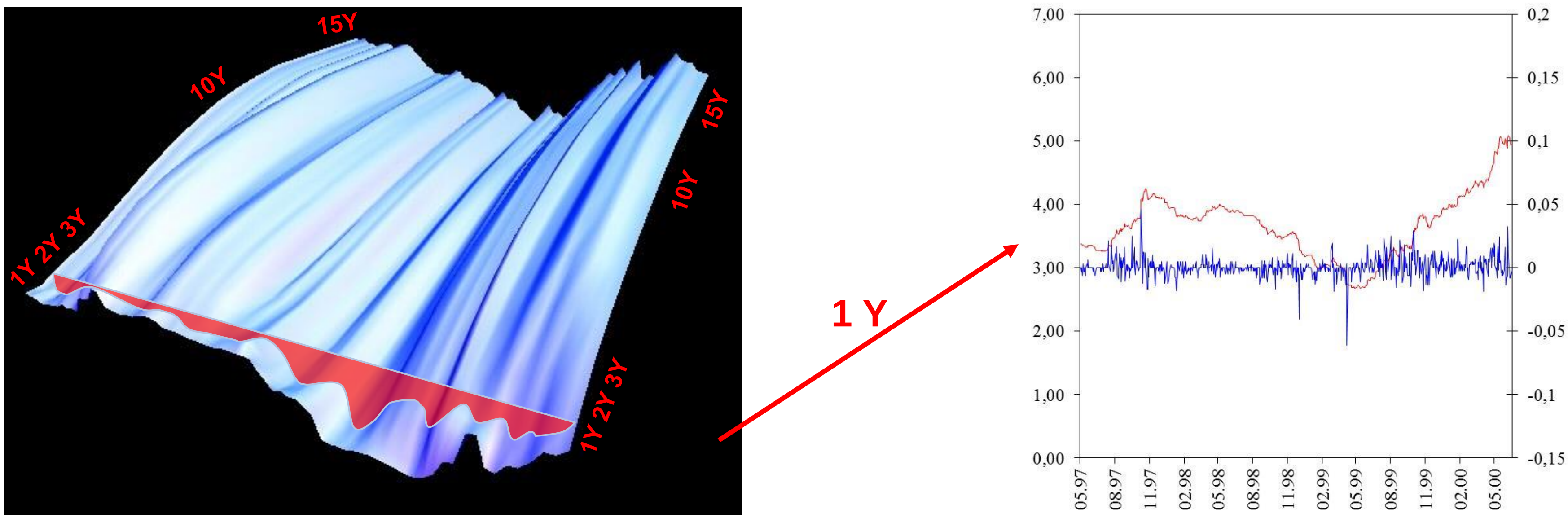

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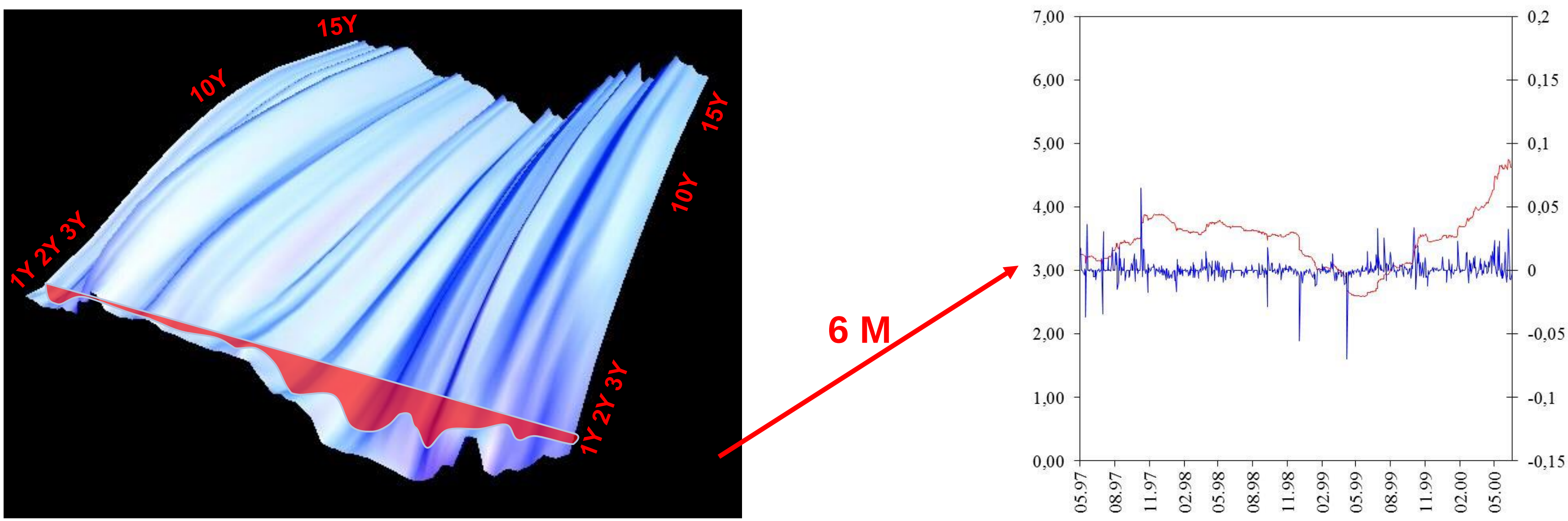

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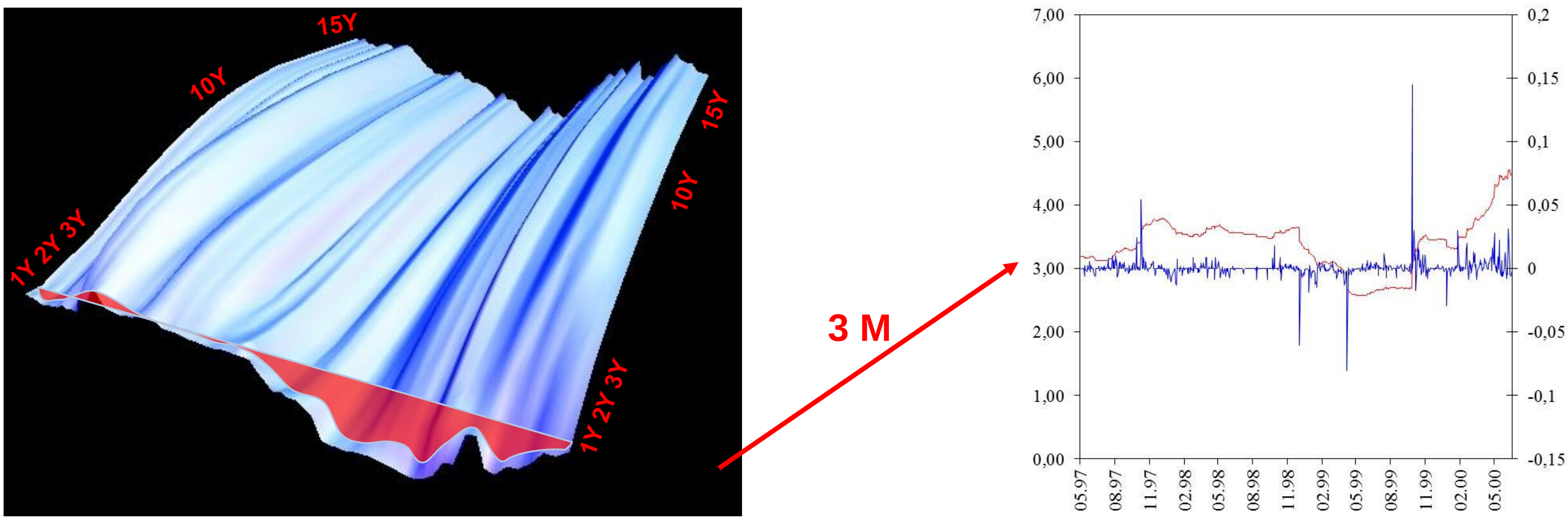

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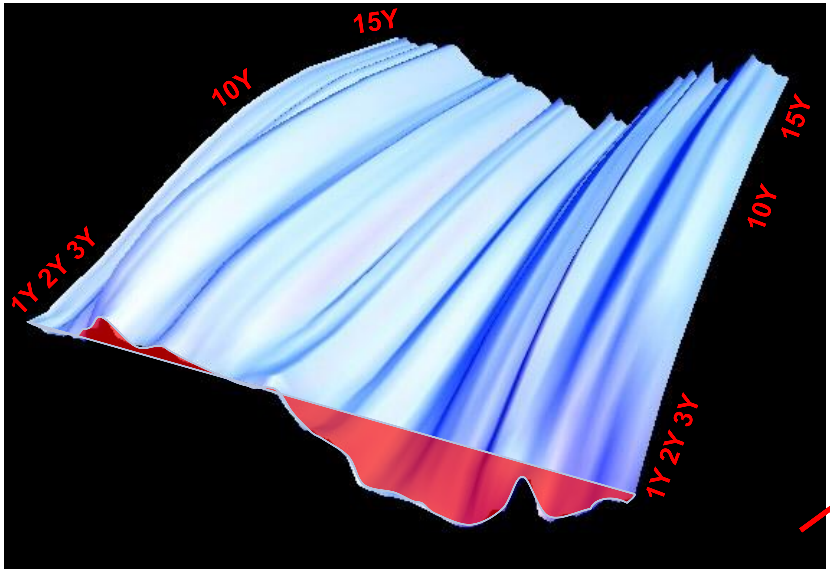
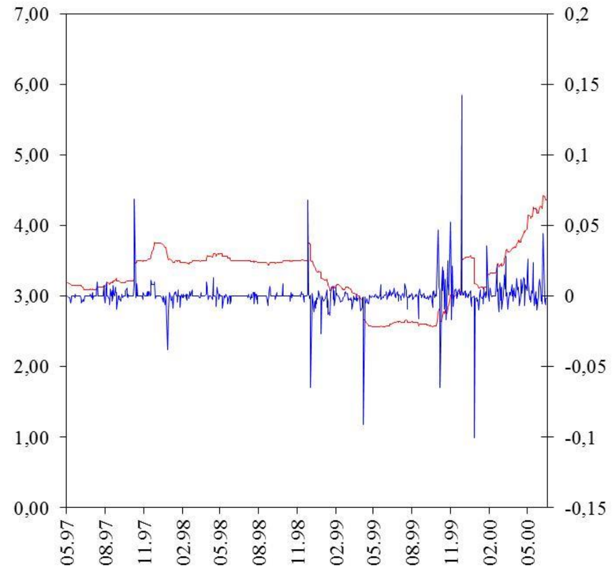


1 M



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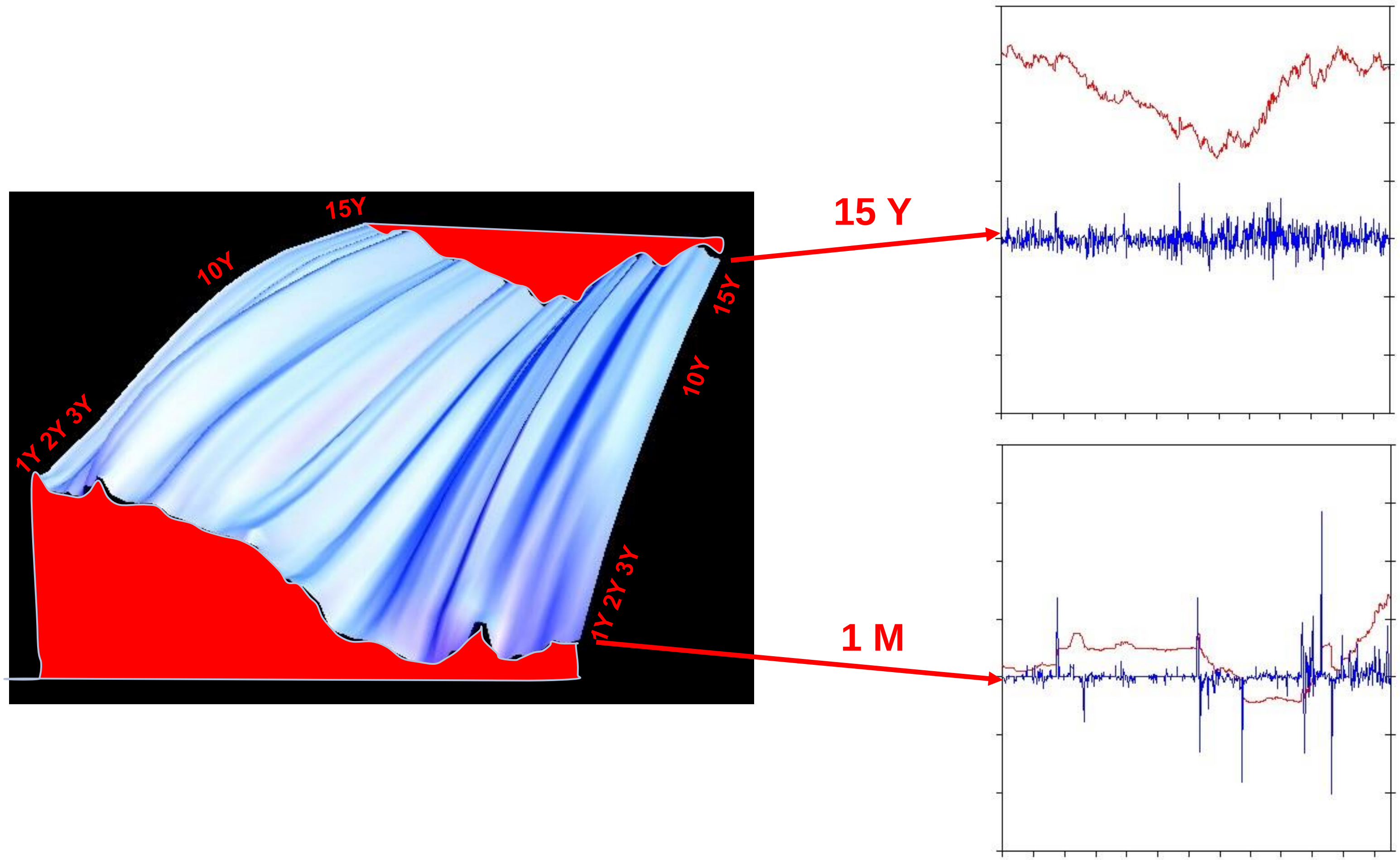
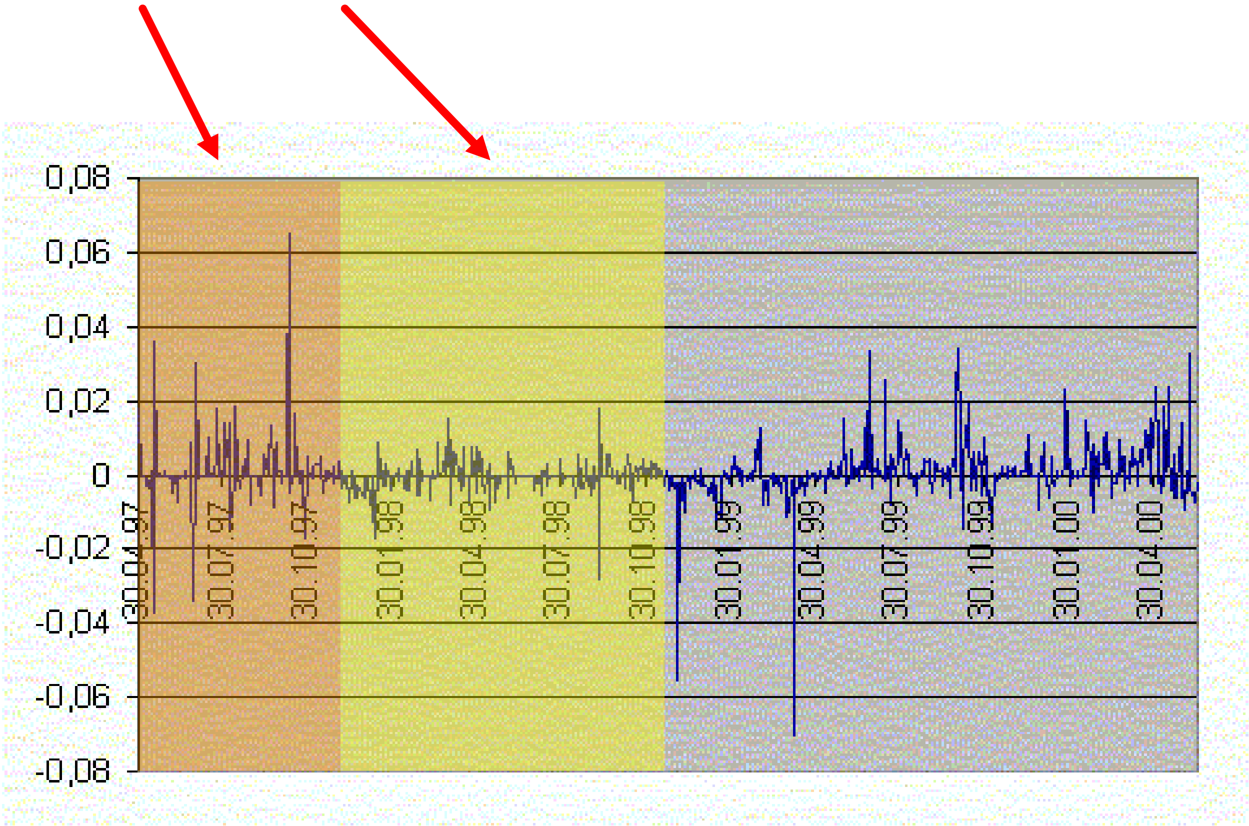


The change in interest rates follows no simple statistics

Phenomenology of financial time series

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



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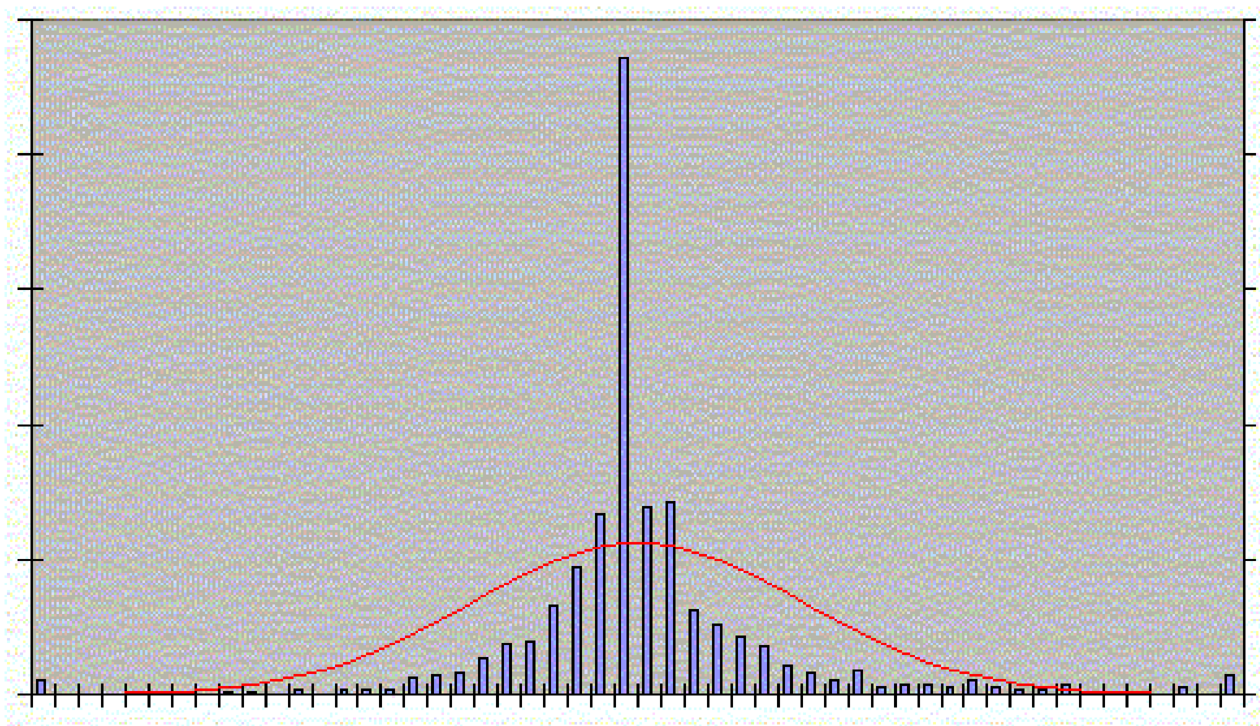
Phenomenology of financial time series

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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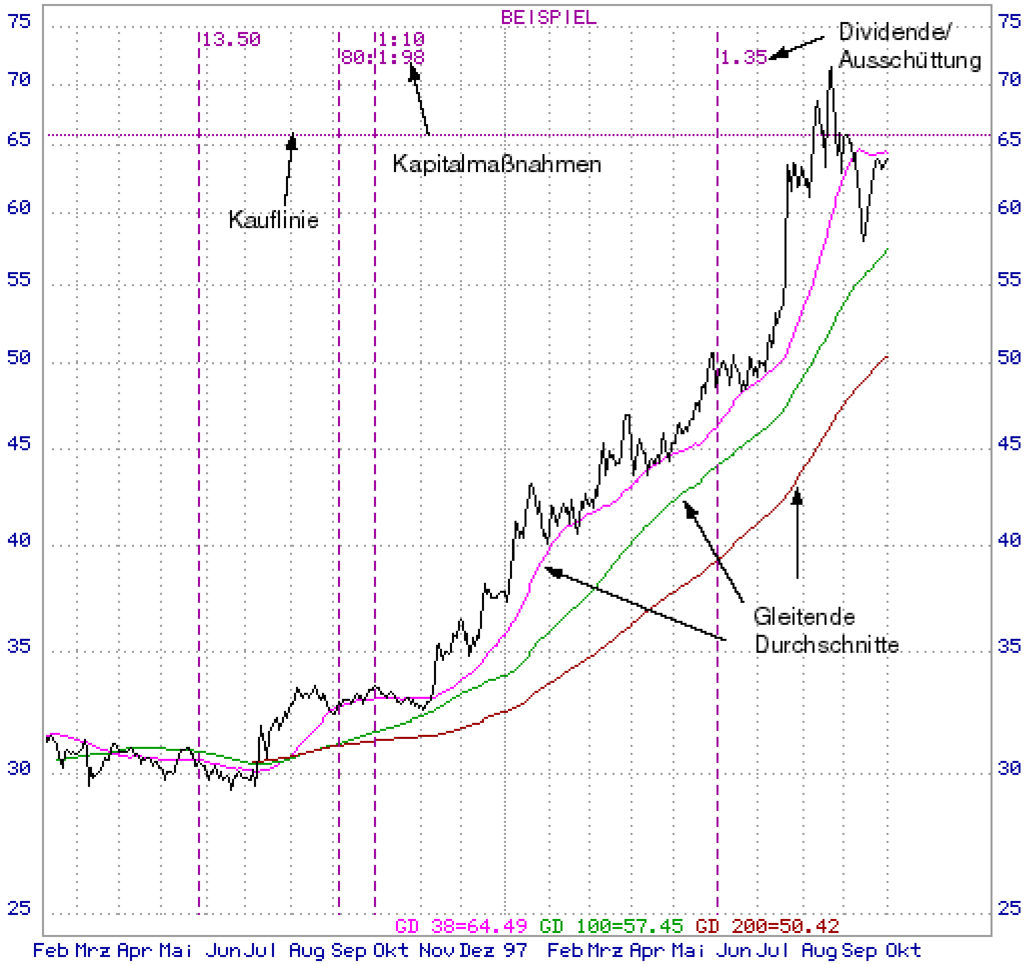
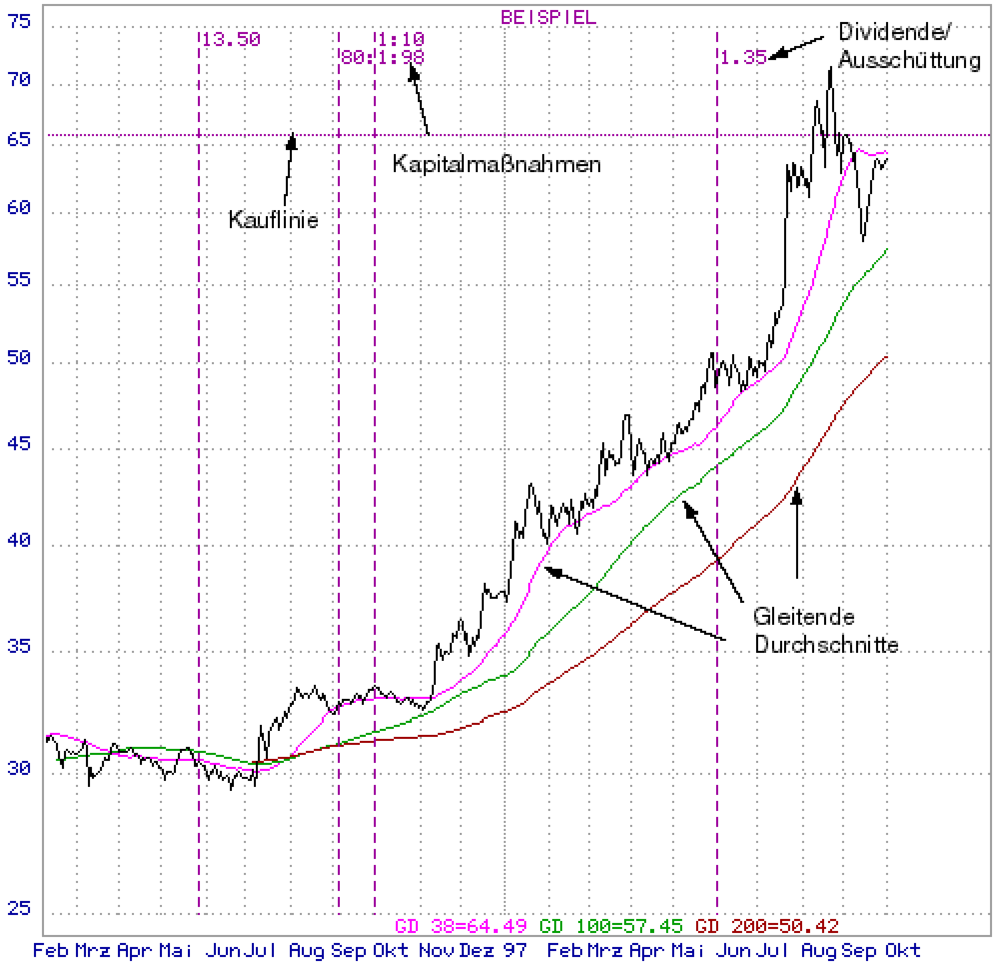
How to “explain” the curves – Different approaches



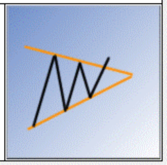
Can we see patterns?

How to “explain” the curves – Different approaches



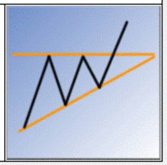
Symmetrisches Dreieck

Das symmetrische Dreieck zeigt die Unsicherheit von Optimisten u. Pessimisten im Markt.
Die Kraft der Bären lässt nach, und die Tiefs liegen immer höher. Auf der anderen Seite trauen, auch die Bullen sich derzeit nicht viel zu, und die Hochs liegen immer ein Stück tiefer.
Alle warten auf den entscheidenden Ausbruch.



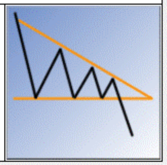
Steigendes Dreieck

Das steigende Dreieck zeigt an, daß die Bullen ihre Kräfte sammeln.
Noch können die Kurse einen bestimmten Widerstand nicht durchbrechen.
Doch nach unten lassen sie sich auch nicht mehr ziehen. So liegen die Tiefs immer ein wenig höher.
Dieses Kräftesammeln kann zwischen 6 u. 12 Wochen dauern.



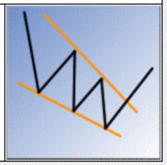
Fallendes Dreieck

Ein fallendes Dreieck entsteht, wenn es in einer Abwärtstbewegung immer wieder zu Zwischenerholungen kommt.
Die Hochpunkte dieser kurzen Aufwärtsbewegung liegen jeweils immer ein wenig niedriger las das vorangegangene Hoch.
Auf der anderen Seite ist der Abwärtsdruck nicht sehr stark.
Die neuen Tiefpunkte liegen gleichauf mit den vorherigen, so daß eine horizontale Unterstützung entsteht.



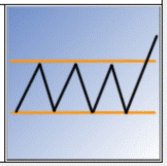
Bullisher Keil

Der bullishe Keil ist eine Bodenbildungs-Formation, die am Ende eines Abwärtstrend entsteht.
Der Abwärtsdruck lässt nach, und die untere Trendlinie wird flacher.
Auf der anderen Seite können sich die Bullen noch nicht durchsetzen.
Aus dieser Kombination entsteht eine Keil-Formation mit einem positiven Ausbruchs-Charakter.



Rechteck

Das Rechteck wird auch als Konsolidierungsphase oder Trading-Range bezeichnet.
Die Kurse legen nach einer starken Trendbewegung eine Pause ein u. bewegen sich, für eine Zeit zwischen einer festen Widerstands- und Unterstützungslinie seitwärts.
In dieser Phase wird Kraft getankt, um dann die Trendbewegung wieder aufzunehmen.



The “Euclidean geometry” approach

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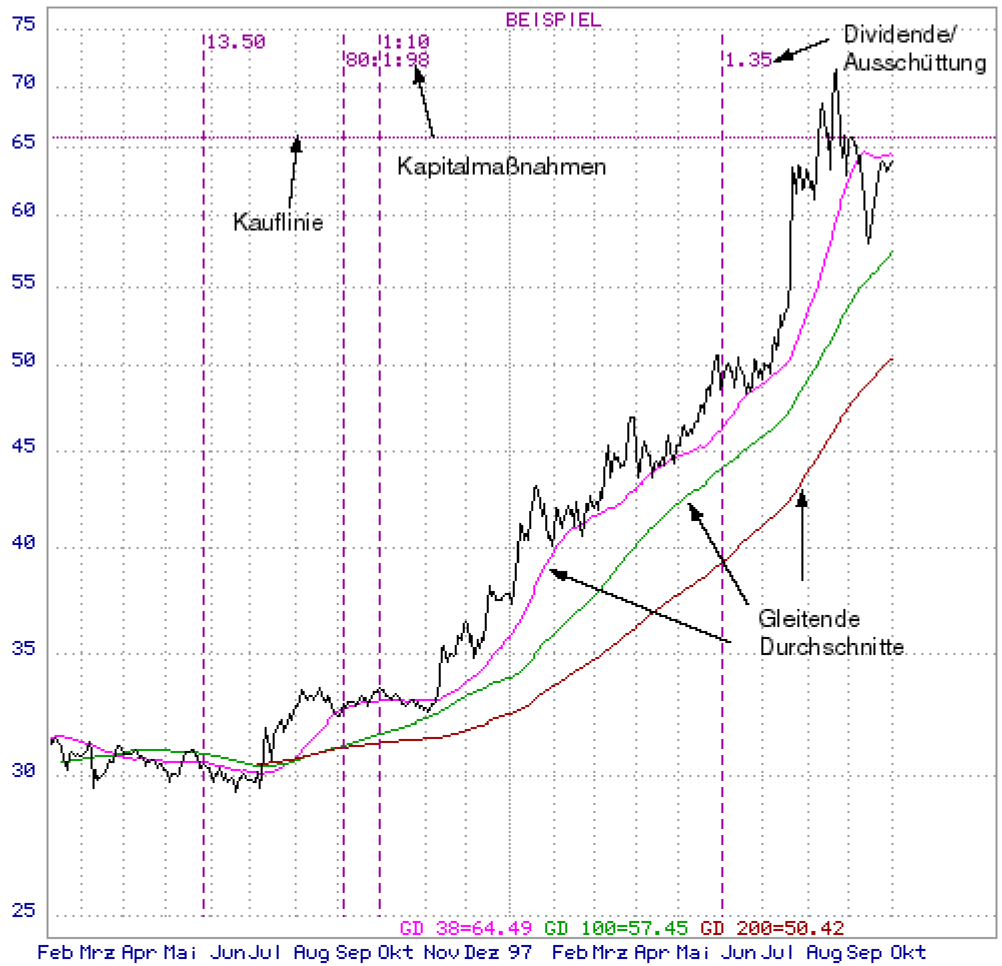
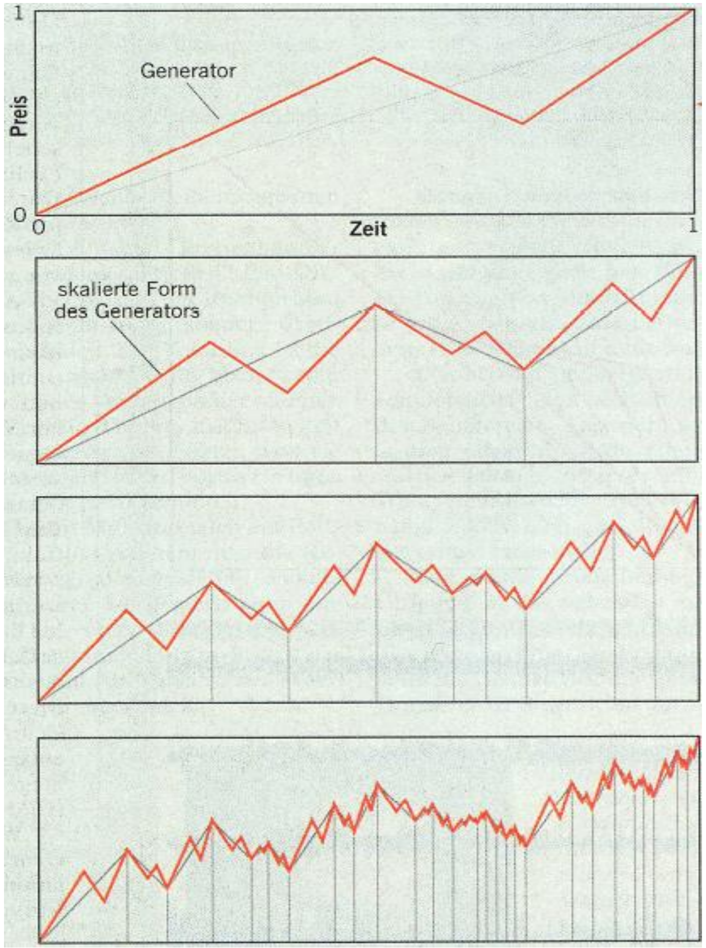
How to “explain” the curves – Different approaches





The fractal geometry approach

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How to “explain” the curves – Different approaches

Welche Kurve ist die gefälschte?

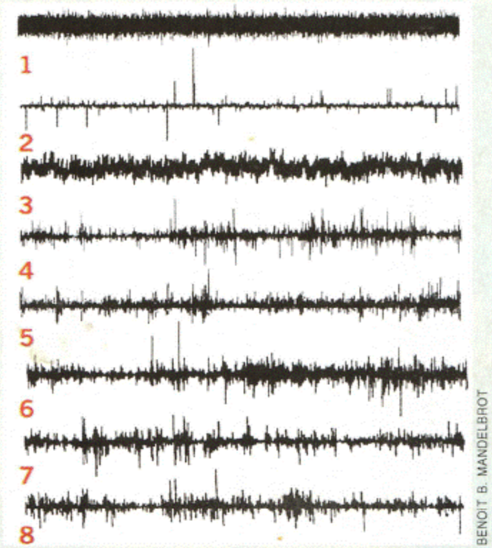
Wie gut können Multifraktale echte Preis-Charts wiedergeben? Vergleichen wir mehrere historische Preisverläufe mit ein paar künstlichen Modellen.

Die erste Kurve ist offensichtlich noch weit von der Realität entfernt. Sie ist außerordentlich einförmig und läuft auf einen konstanten Hintergrund kleiner Preisänderungen hinaus, wie das Rauschen beim Radioempfang. Die Volatilität bleibt gleichförmig, ohne plötzliche Sprünge. Wenn das die Aufzeichnung eines historischen Preisverlaufs wäre, würden sich die Veränderungen zwar von Tag zu Tag unterscheiden, aber die Monate würden insgesamt doch sehr gleichartig verlaufen.

Die ziemlich einfache zweite Kurve ist schon besser, denn sie zeigt viele plötzliche Zacken. Aber die stehen isoliert gegen einen unveränderlichen Hintergrund, in dem die Variabilität der Preise ungefähr gleich bleibt. Das ist bei der dritten Kurve besser getroffen; dafür zeigt sie keine urplötzlichen Sprünge.

Alle drei Diagramme sind mit bloßem Auge als unrealistisch zu erkennen. Woher stammen sie? Kurve 1 folgt einem Modell, das der französische Mathematiker Louis Bachelier (1870 bis 1946) im Jahre 1900 eingeführt hat. Die Preisveränderungen folgen einer Irrfahrt (*random walk*); dazu gehört die Glockenkurve, womit das Modell auf die Portfolio-Theorie hinausläuft. Die Kurven 2 und 3 ergeben sich aus Verbesserungsversuchen von Bacheliers Arbeiten. Die eine entspricht einem Modell, das ich 1963 vorgeschlagen habe (basierend auf Lévy-stabilen Zufallsprozessen) und einem, das ich 1965 publiziert habe (basierend auf *fractional Brownian motion*). Beide sind nur unter sehr speziellen Marktbedingungen sinnvoll.

Von den – wichtigeren – fünf unteren Diagrammen beruht wenigstens eines auf echten Marktdaten, und wenigstens ein weiteres ist ein computergeneriertes Beispiel meines letzten multifraktalen Modells. Bevor Sie weiterlesen, versuchen Sie, diese Charts richtig zuzuordnen! Ich hoffe, daß auch Sie auf die Fälschungen hereinfallen.



Tatsächlich sind nur zwei der Charts echte Marktdaten. Chart 5 stellt den Kurs der IBM-Aktie dar und Chart 6 den Wechselkurs DM gegen amerikanische Dollar. Die anderen Kurven (4, 7 und 8) ähneln ihren zwei echten Gegenstücken zwar stark, sind aber vollständig künstlich, erzeugt mit einer weiter verfeinerten Form meines multifraktalen Modells.

The fractal geometry approach

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

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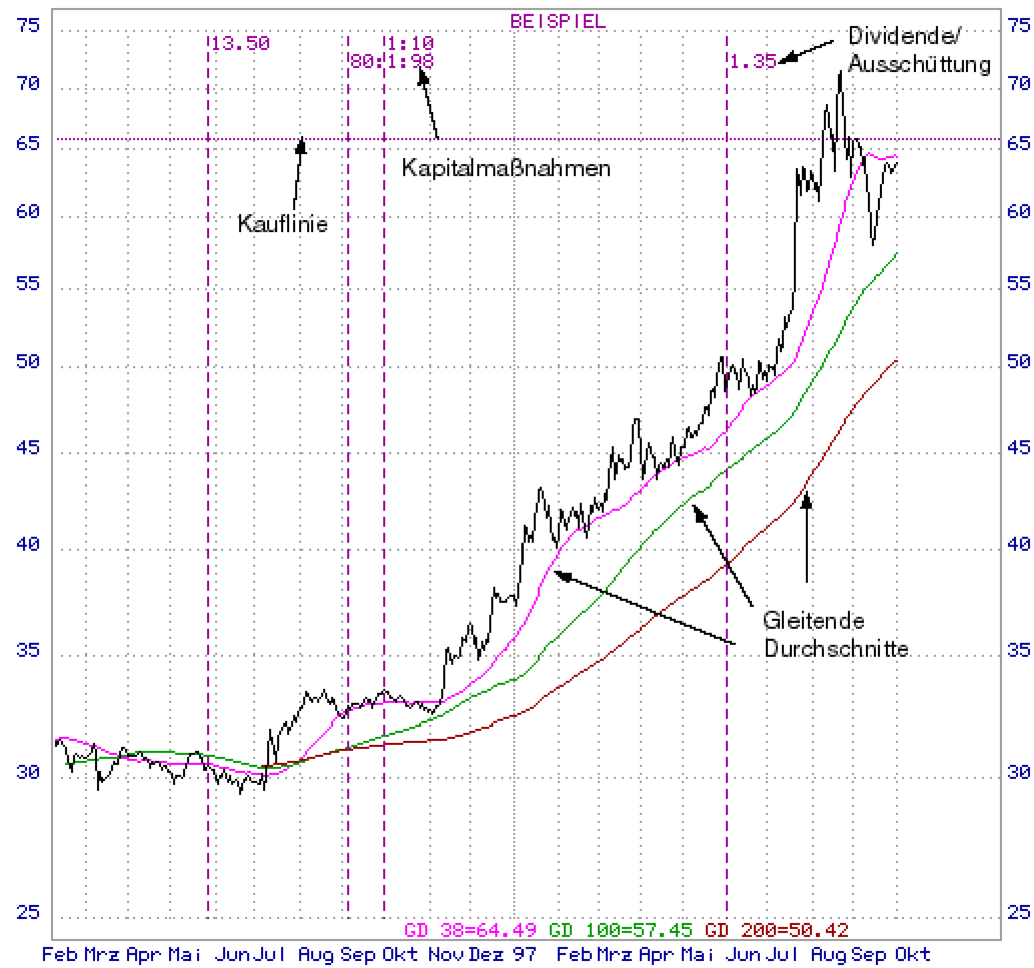
How to “explain” the curves – Different approaches



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: $Z^{-1} \stackrel{d}{=} \Gamma\left(\frac{2\beta}{\sigma^2}, -\frac{2\alpha}{\sigma^2} + 1\right)$

The stochastic approach

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How to “explain” the curves – Different approaches

Stochastic Calculus

$\cdot$	dW_t	dt	*Itô Formula*
dW_t	dt	0	$df(X_t) = f'(X_t)dX_t$
dt	0	0	$+\frac{1}{2}f''(X_t)(dX_t)^2$

$\text{var}\,W_t = t$; $\text{Cov}(W_t, W_s) = \min(t, s)$

Itô-Tanaka Formula for Local time

$$L_t^a(Z) = |Z_t - a| - |Z_0 - a| - \int_0^t \text{sgn}(Z_u - a)\,dZ_u \quad (63)$$

$$f(Z_t) = f(Z_0) + \int_0^t f_l'(Z_u)\,dZ_u + \frac{1}{2}\int_{I\!R} L_t^a(Z), \mu(da) \quad (64)$$

f_l' is the left-hand side derivative of f, measure $\mu = f''$ in the sense of distributions

Girsanov With $d\tilde{I\!P} \triangleq \exp(\sigma W_T - \frac{1}{2}\sigma^2 T)dI\!P$ $\tilde{W}_t - \sigma t$ is a Brownian motion under $\tilde{I\!P}$

American Option $V_0 = \sup_\tau I\!E[e^{-r_d\tau}g(S_\tau)]$ payoff g (maximize over all stopping times τ)

Rogers: $V_0 = \inf_M I\!E[\sup_t(e^{-r_d t}g(S_t) - M_t)]$ minimize over all martingales with $M_0 = 0$ and $\sup_t |M_t| \in L^1$

Doob-Meyer Decomposition Supermartingale $Y_t = Y_0 + M_t - A_t$, M a martingale and $A \uparrow$

Brownian Bridge $B_s|(W_r, W_t)$ on $r \le s \le t$

$$\sim W_r + \frac{s-r}{t-r}(W_t - W_r) + \sqrt{\frac{(s-r)(r-t)}{t-r}}\mathcal{N}(0,1)$$

Reflection Principle $M_T \triangleq \max_{0<t<T} W_t$

$$I\!P[M_T > m, W_T < b] = I\!P[W_T > 2m - b] \quad (65)$$

$$I\!P[M_T > m] = 2I\!P[W_T > m] \quad (66)$$

Martingale Representation Theorem (Δ-Hedge) Each martingale X can be represented by $X_t = X_0 + \int_0^t \delta(u)\,dW_u$ for an adapted δ

Lévy's Characterization A continuous martingale M with $M_t^2 - t$ being a martingale is a Brownian motion

Itô-Process: $dX_t = b_t, dt + \sigma_t\,dW_t$ for adapted b and σ

Semimartingale: $X_t = M_t + A_t$, where M is a local martingale and A is a càdlàg adapted process of locally bounded variation

Dambis / Dubins-Schwarz A continuous local $(\mathcal{F}_t)$-martingale is a time-changed Brownian motion: $M_t = W_{\langle M \rangle_t}$, where $\tau_u = \inf\{t : \langle M \rangle_t > u\}$ and W_{τ_u} is an $(\mathcal{F}_{\tau_u})$-Brownian motion

Bessel Process $R_t = |\mathbf{W}_t|$, the Euclidean norm of an n-dimensional Brownian motion

$$dR_t = dW_t + \frac{n-1}{2R_t}dt \quad (67)$$

$$dR_t^2 = 2\sqrt{R_t^2}\,dW_t + n\,dt \quad (68)$$

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How to “explain” the curves – Different approaches

Stochastic Calculus

$\cdot$	dW_t	dt	*Itô Formula*
dW_t	dt	0	$df(X_t) = f'(X_t)dX_t$
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$$f(Z_t) = f(Z_0) + \int_0^t f_l'(Z_u)\, dZ_u + \frac{1}{2}\int_{\mathbb{R}} L_t^a(Z), \mu($$

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P. Malliavin, A. Thalmaier,

Stochastic Calculus of Variations in Mathematical Finance,

Springer

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P. Malliavin, A. Thalmaier, Stochastic Calculus of Variations in Mathematical Finance, Springer

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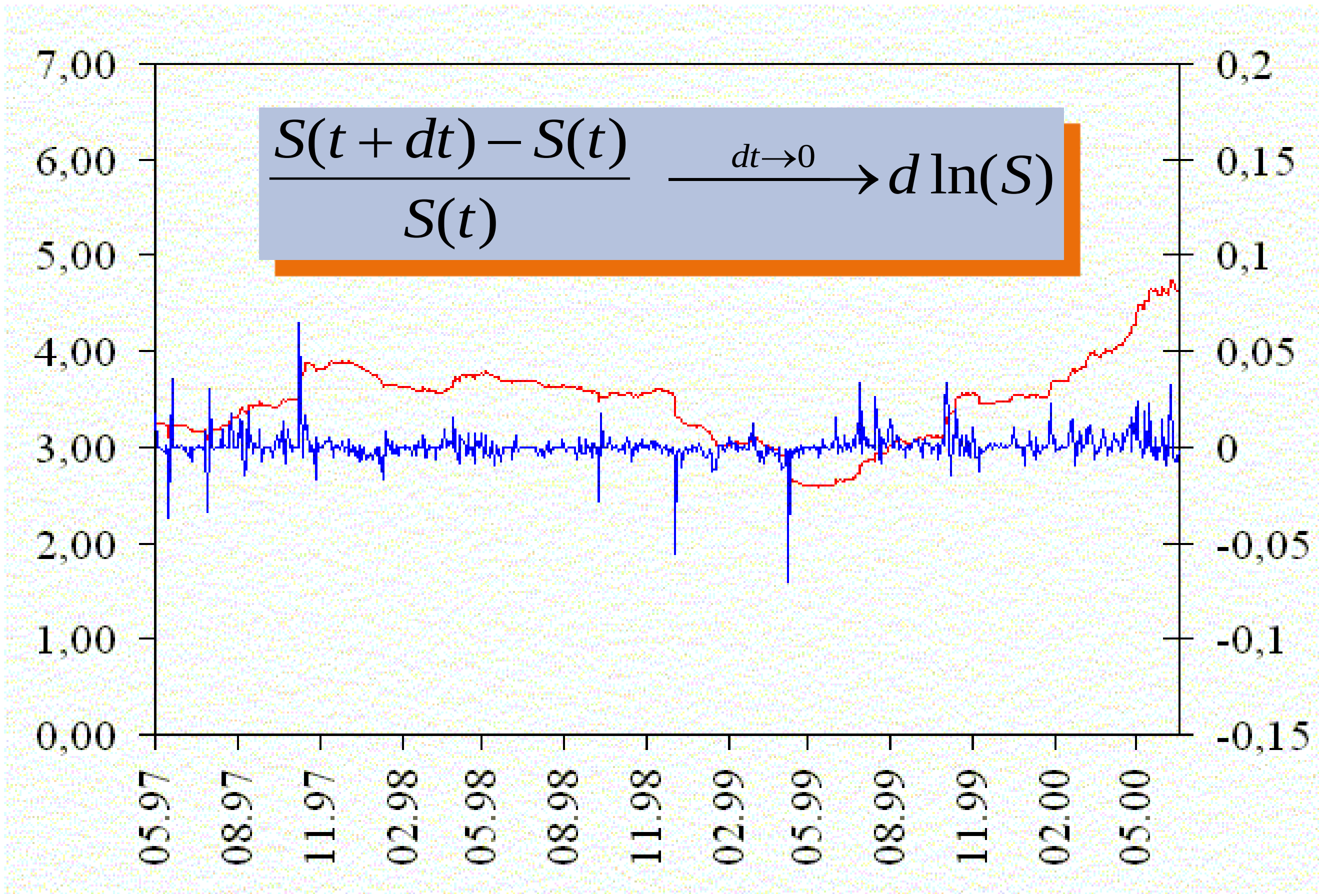
How to “explain” the curves – Different approaches

Modelling the logarithmical price change

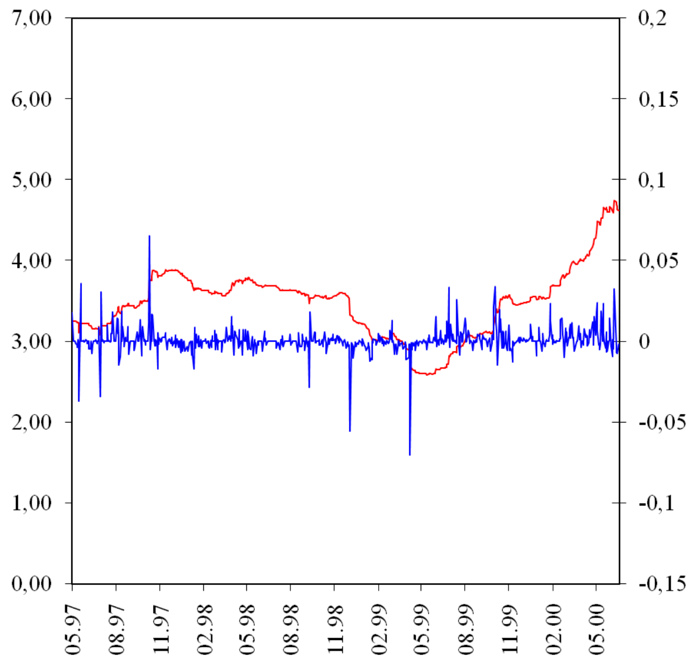
$$\frac{S(t+dt)-S(t)}{S(t)} \xrightarrow{dt \to 0} d\ln(S)$$



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)

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

Special case ARCH(1)

$$\begin{aligned} X_{\mathrm{t}}^2 &= (c_0 + c_1 X_{\mathrm{t-1}}^2) Z_{\mathrm{t}}^2 \\ &= c_1 Z_{\mathrm{t}}^2 X_{\mathrm{t-1}}^2 + c_0 Z_{\mathrm{t}}^2 \\ &= A_{\mathrm{t}} X_{\mathrm{t-1}}^2 + B_{\mathrm{t}} \end{aligned}$$

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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

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

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» 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):

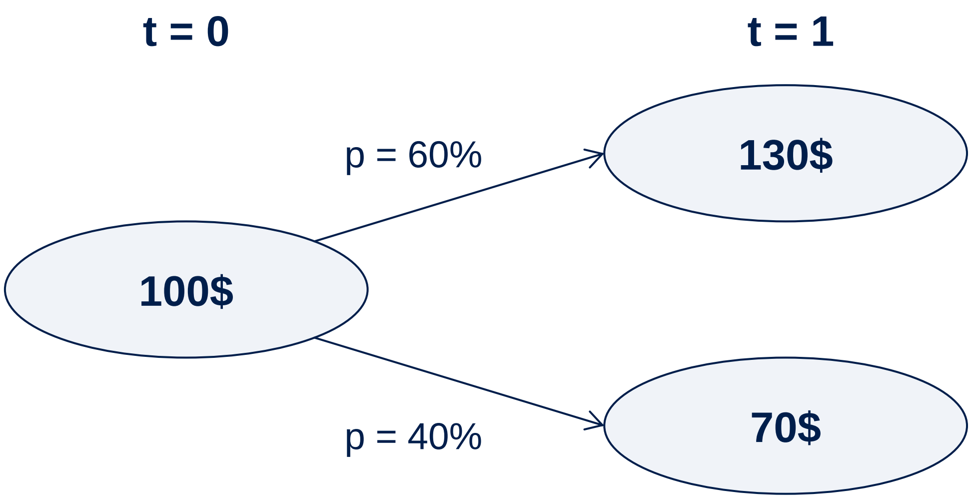
$$\log(\sigma_t) = c_0 + c_1 \log(\sigma_{t-1}) + \frac{c_2 \varepsilon_{t-1}}{\sqrt{\sigma_{t-1}}} + c_3 \left(\frac{|\varepsilon_{t-1}|}{\sqrt{\sigma_{t-1}}} - \sqrt{\frac{2}{\pi}} \right)$$

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

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% .

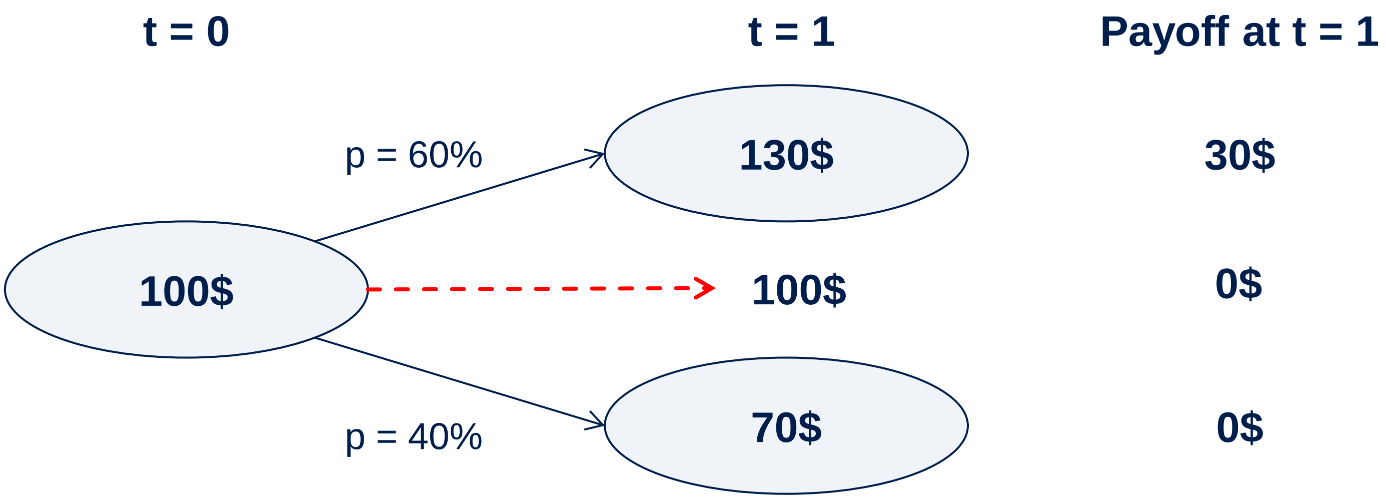


What is the fair price of such a contract today?

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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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 to… …d
im… …older
wi…

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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Stock price	Money spent		Money received		Profit
130$ (up)	» 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$**
100$					
(down)	» 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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Expected values based on empirical probabilities do not give the fair price!

					Profit
					3$
100$					
	» Buy ½ stock at t = 0:	**-50$**	» Initial contract:	**18$**	
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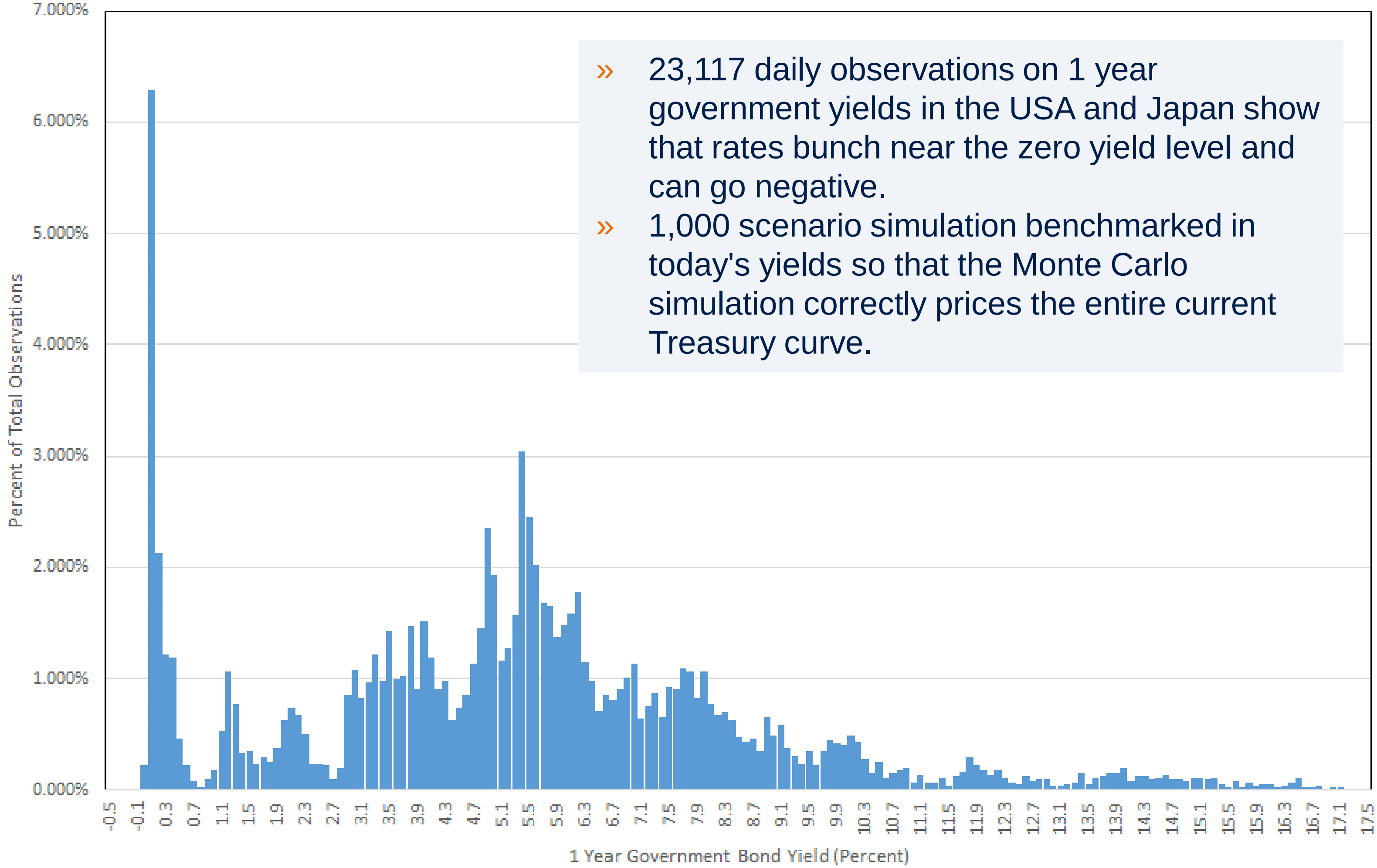
One thousand scenarios for the U.S. treasury curve

Distribution of 1 Year Government Bond Yields, USA, 1962 - 2015



» 23,117 daily observations on 1 year government yields in the USA and Japan show that rates bunch near the zero yield level and can go negative.

» 1,000 scenario simulation benchmarked in today's yields so that the Monte Carlo simulation correctly prices the entire current Treasury curve.

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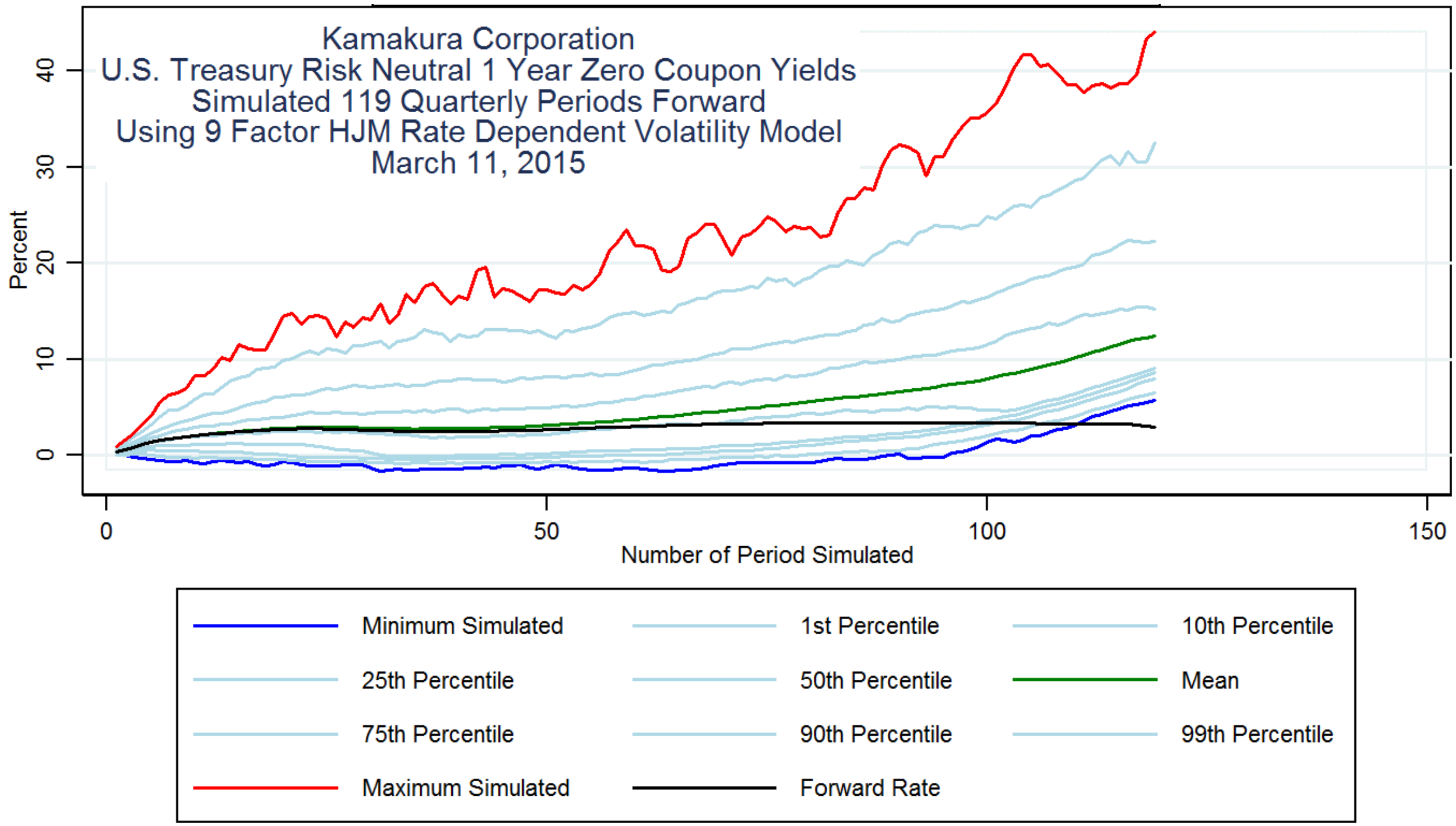
One thousand scenarios for the U.S. treasury curve



Source: Kamakura Corporation, U.S. Department of the Treasury

Good models are the essence of strategy and planning!

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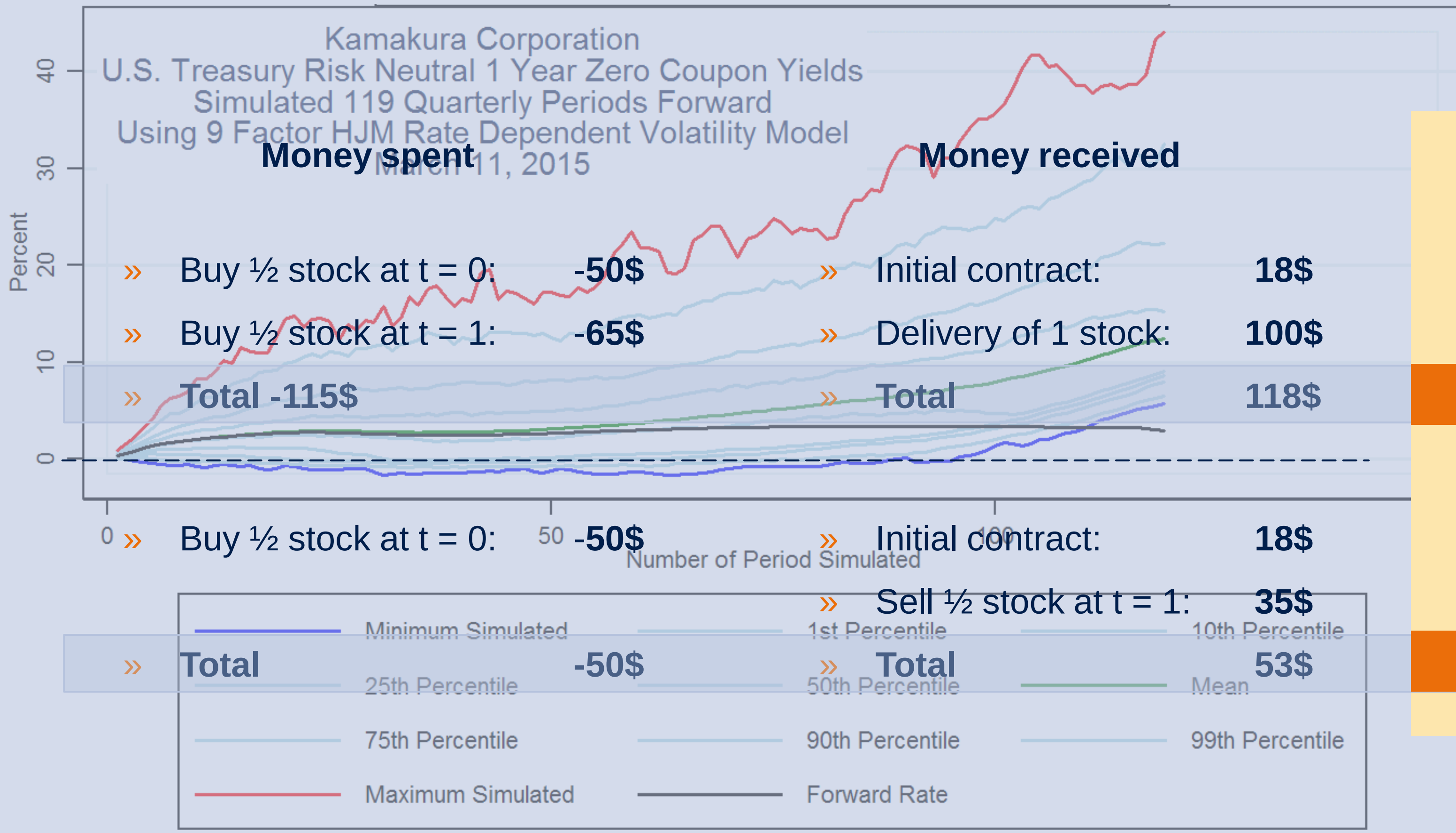
One thousand scenarios for the U.S. treasury curve (2/2)



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Good models are the essence of strategy and planning!

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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

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)

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 $\{n\} = n_1, n_2, \dots, n_L, \{k\} = k_1, k_2, \dots, k_L$ and

  $$\varphi_{\{n\};\{k\};O;M} = \frac{(a_1^\dagger)^{n_1} \dots (a_L^\dagger)^{n_L} (c_1^\dagger)^{k_1} \dots (c_L^\dagger)^{k_L} (o^\dagger)^{O} \dots (p^\dagger)^{M}}{\sqrt{n_1! \dots n_L!\, k_1! \dots k_L!\, O!\, M!}} \varphi_0$$

- φ_0 is the vacuum of the model: $a_j \varphi_0 = c_j \varphi_0 = p \varphi_0 = o \varphi_0 = 0, for\ j = 1, 2, \dots, L$

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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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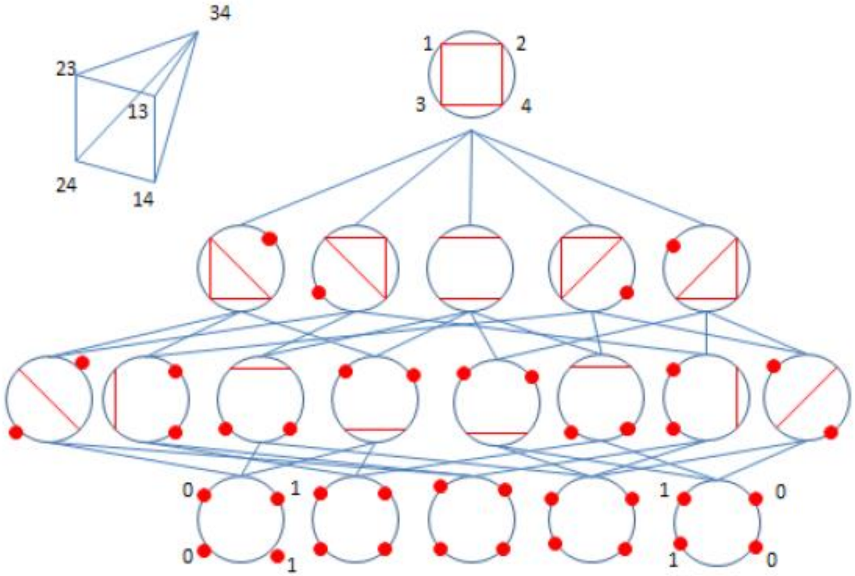
How to “explain” the curves – different approaches

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.



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

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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

d-fine

Known models in different domains of science

Chapman, Hall

Computational Neuroscience

A Comprehensive Approach

CRC Mathematical Biology and Mediscience Series

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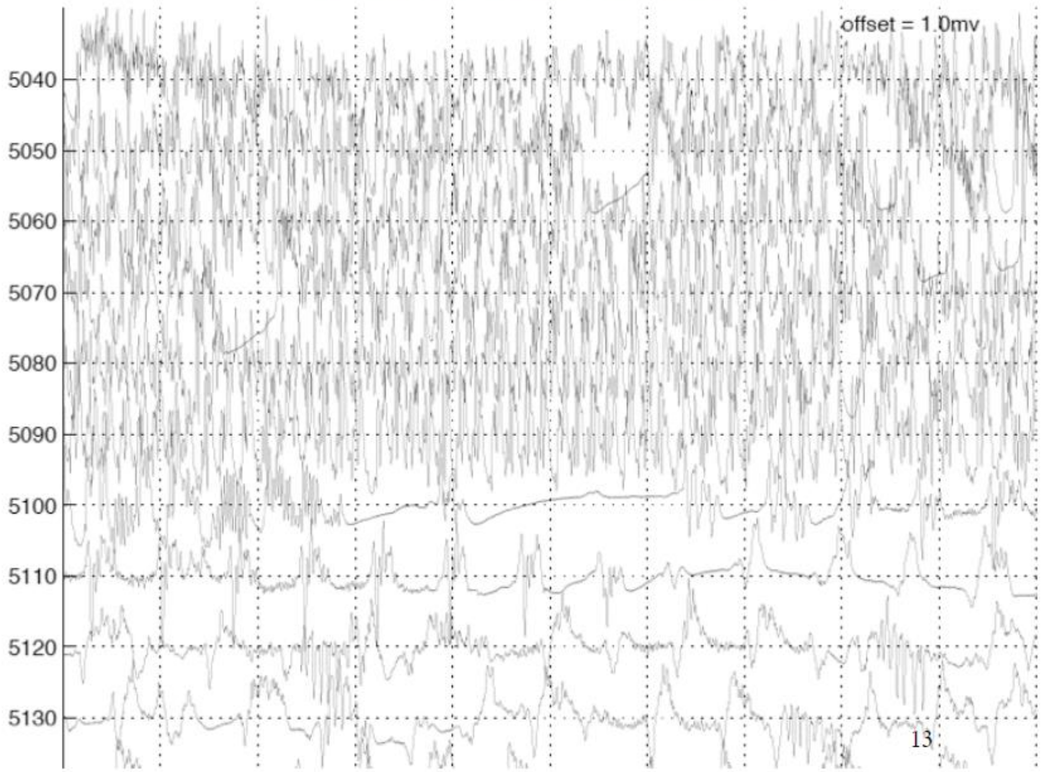
Mathematical/physical models in finance – The “patient” financial markets

Parallels between Earthquakes, Financial crashes and epileptic seizures
Didier Sornette



Didier Sornette

Neuron

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

See also:

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

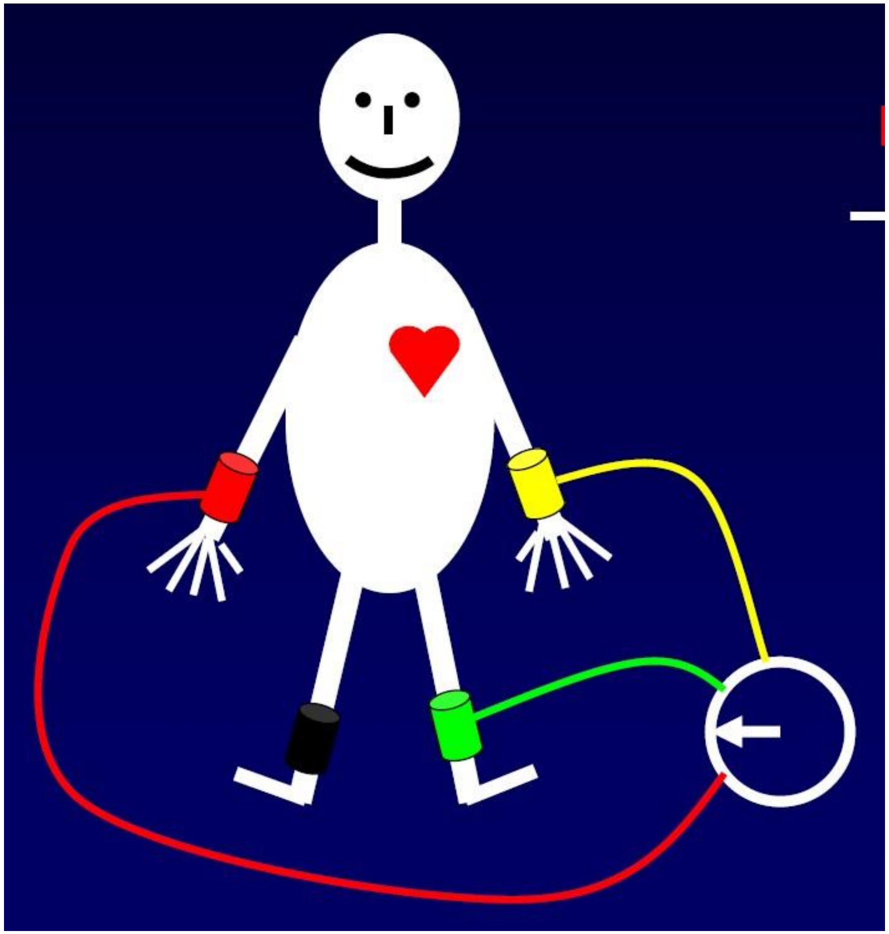
Epilepsy

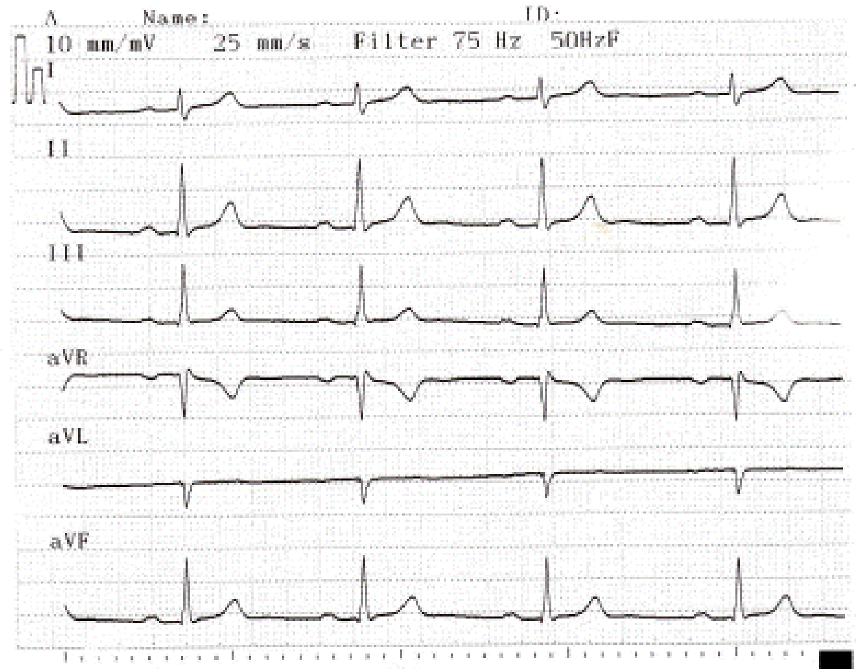
The Intersection of Neurosciences, Biology, Mathematics, Enginieering, and Physics

CRC Press

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

The “patient” financial markets





Our models “fit” in various fields of science

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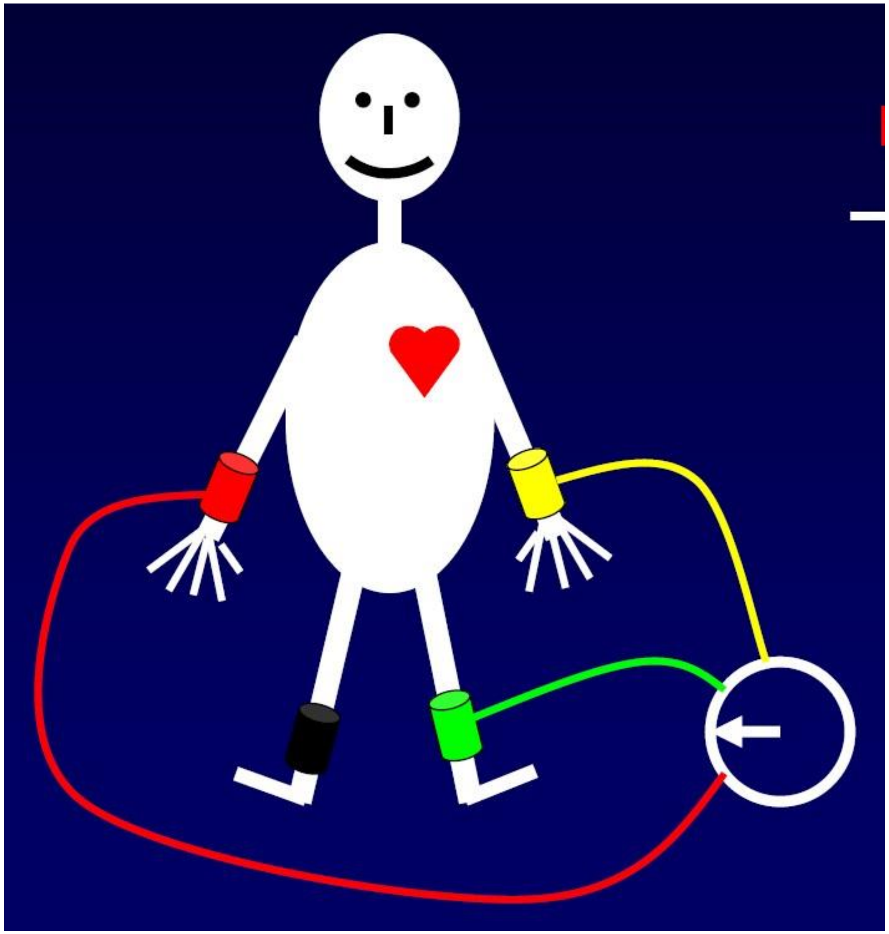
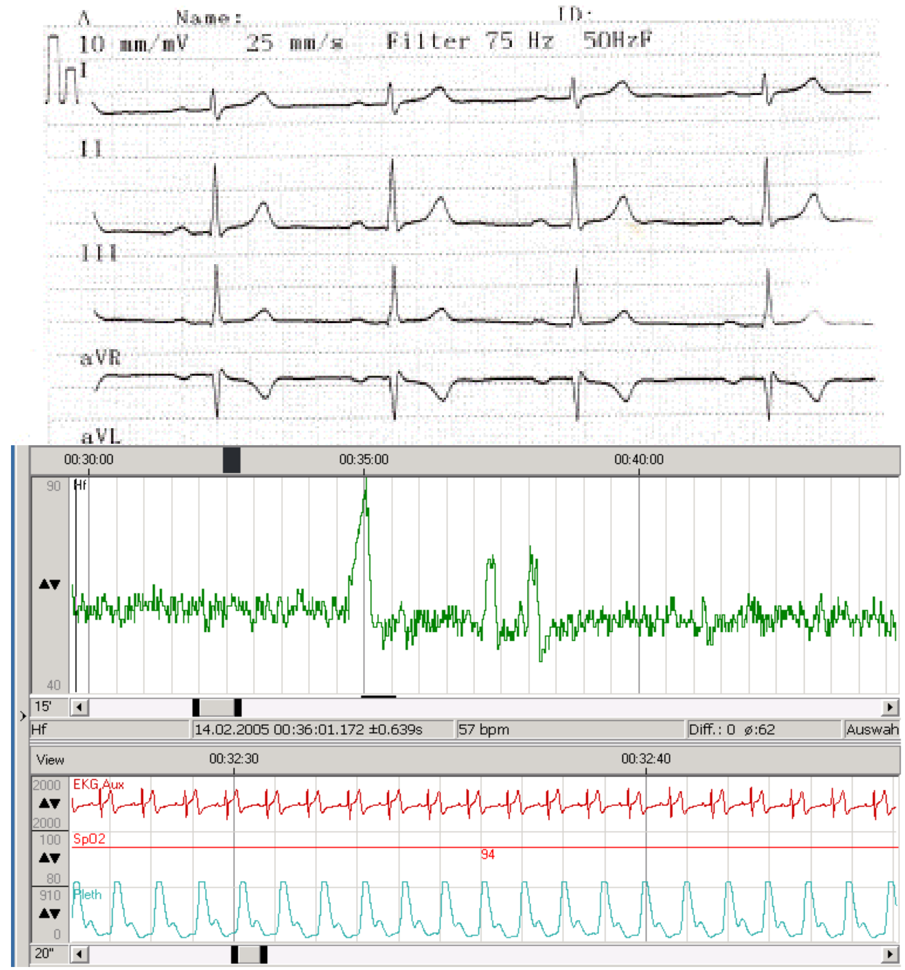
The "patient" financial markets





Our models "fit" in various fields of science

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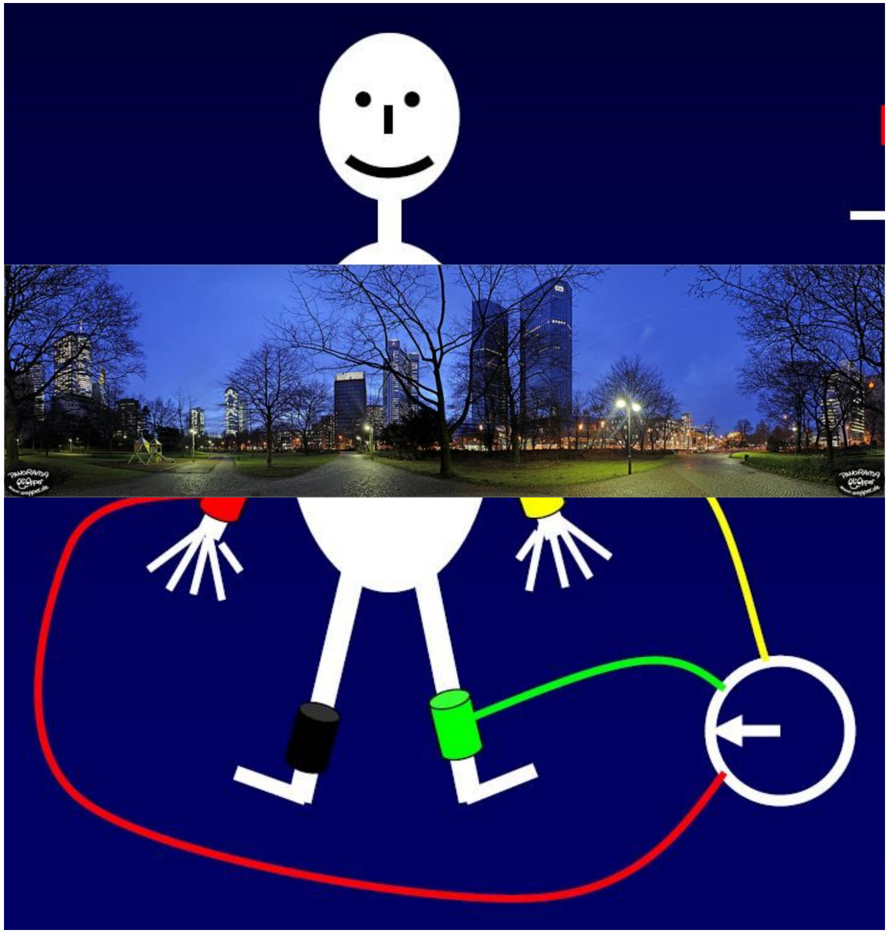
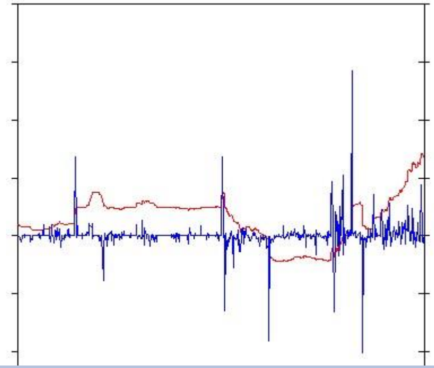
The “patient” financial markets





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

Photo source: © NH1977 / PIXELIO

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Physical models applied to financial markets – Implementation

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

CHAIR OF ENTREPRENEURIAL RISKS

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ETH Zurich - D-MTEC - Welcome to the Chair of Entrepreneurial Risks - Financial Crisis Observatory

Financial Crisis Observatory

- Description
- Highlights
- Is there an oil bubble?
- Pertinent articles
- Websites and Blogs
- Predictions
- Market Anxiety Measures
- RSS Feed
- The Financial Crisis: How Much Longer and Deeper?

Financial Crisis Observatory

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.

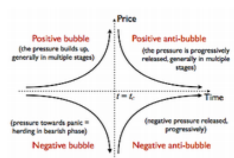
FCO Cockpit Syntheses

2015

- **1st February 2015: Synthesis report**
- **1st January 2015: Synthesis report**

2014

- **1st December 2014: Synthesis report**
- **1st November 2014: Synthesis report**
- **1st October 2014: Synthesis report and detailed calculations**
- **1st April 2014**
- **1st February 2014**



5 December 2013: Financial crisis risk monitoring and positive and negative bubble risk maps become available from the Financial Crisis Observatory.

30 September 2013

The graph prepared on 27 September 2013 shows subsequent evolution of TSLA stock price and our LPPL indicator.

Entrepreneurial Risks

FCO Blog

The FCO blog discusses how the system approach allows one to develop diagnostic methods and predictions of crises.

FCO RSS Feed

RSS

TOP

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The mechanics of the balance sheet – an engineers approach

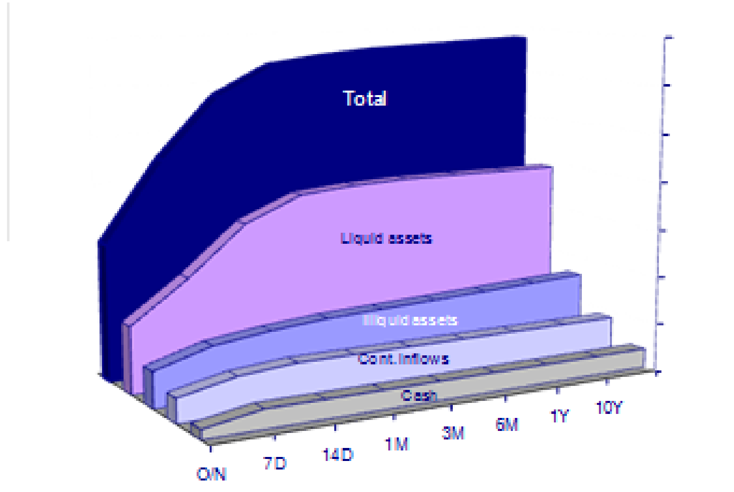
Mechanics of the balance sheet

Stylized Balance Sheet

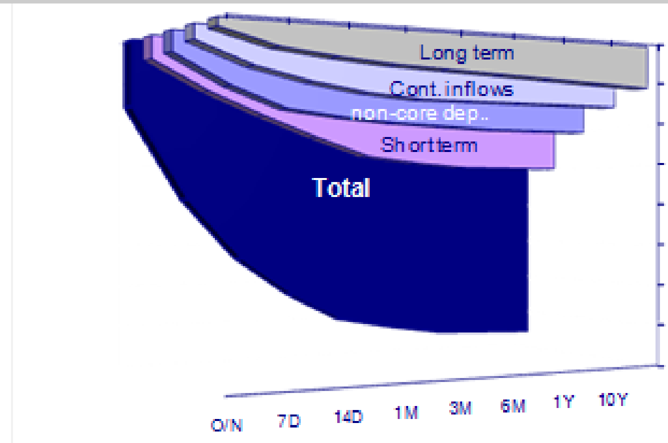
Assets	Liabilities
Cash balance	Short-term funding
Liquid assets (unencumbered)	Non-core deposits
	Core deposits
Illiquid assets	Long-term funding
	Share capital

Averaged balance sheet total of the big German banks: 490 bn Euros

Source: Bundesbankstatistik, July 2011



Cumulated outflows (cash ladder)



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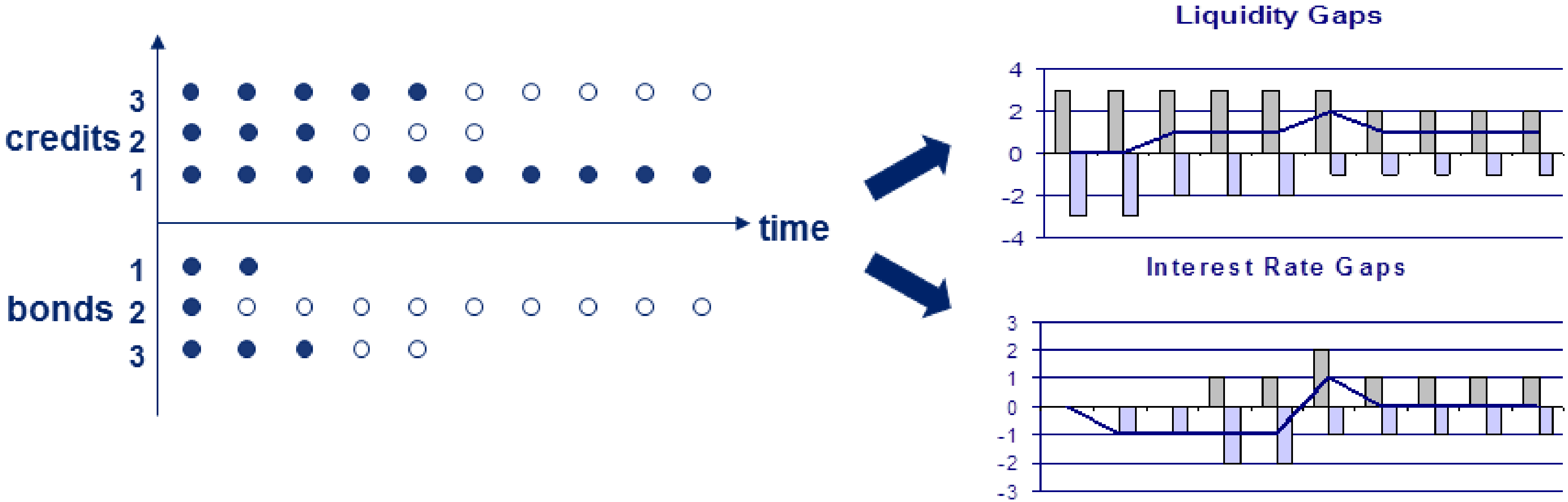
Consolidation: The ball model

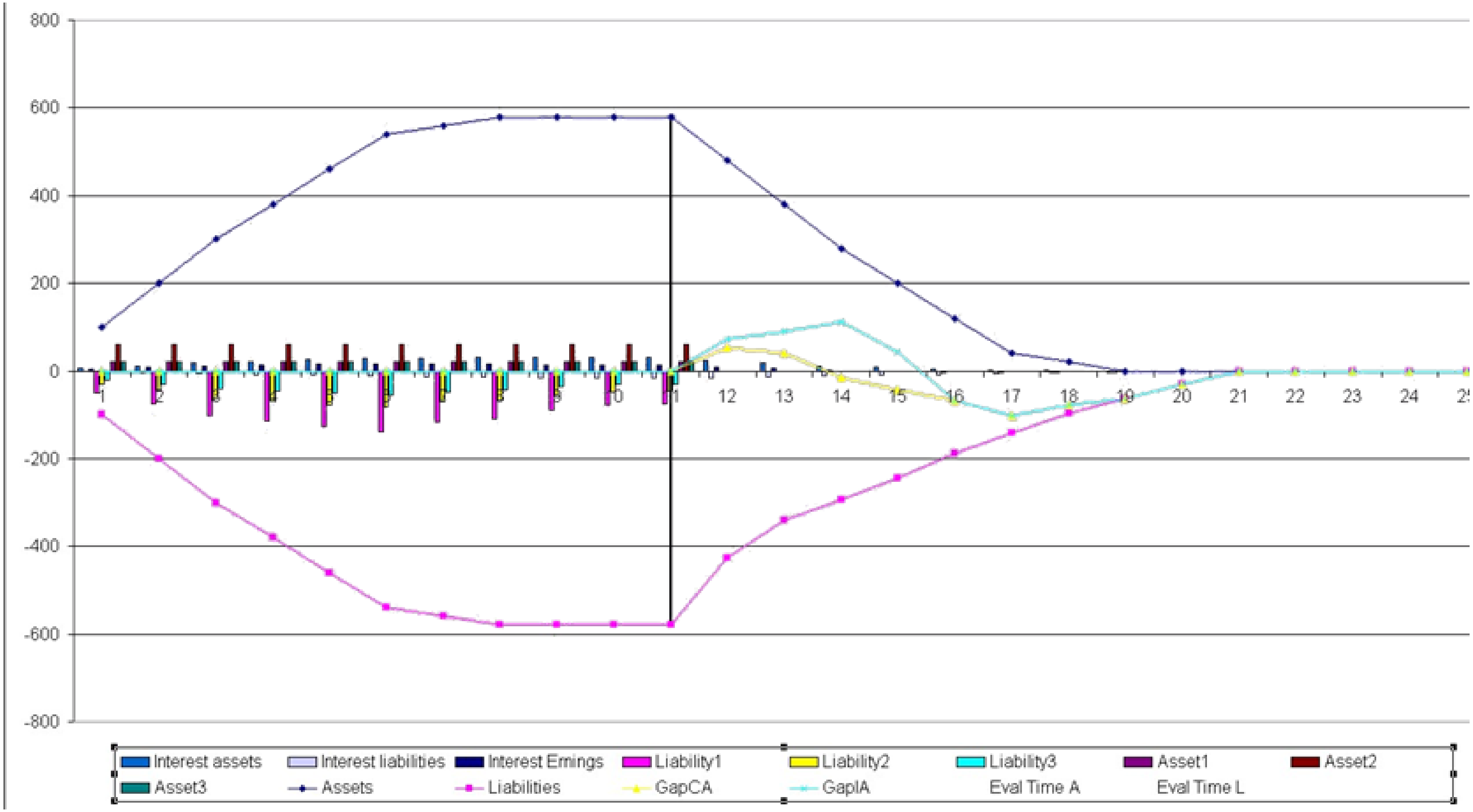
- **Purpose:** Simultaneous consideration of interest rate risk and liquidity risk



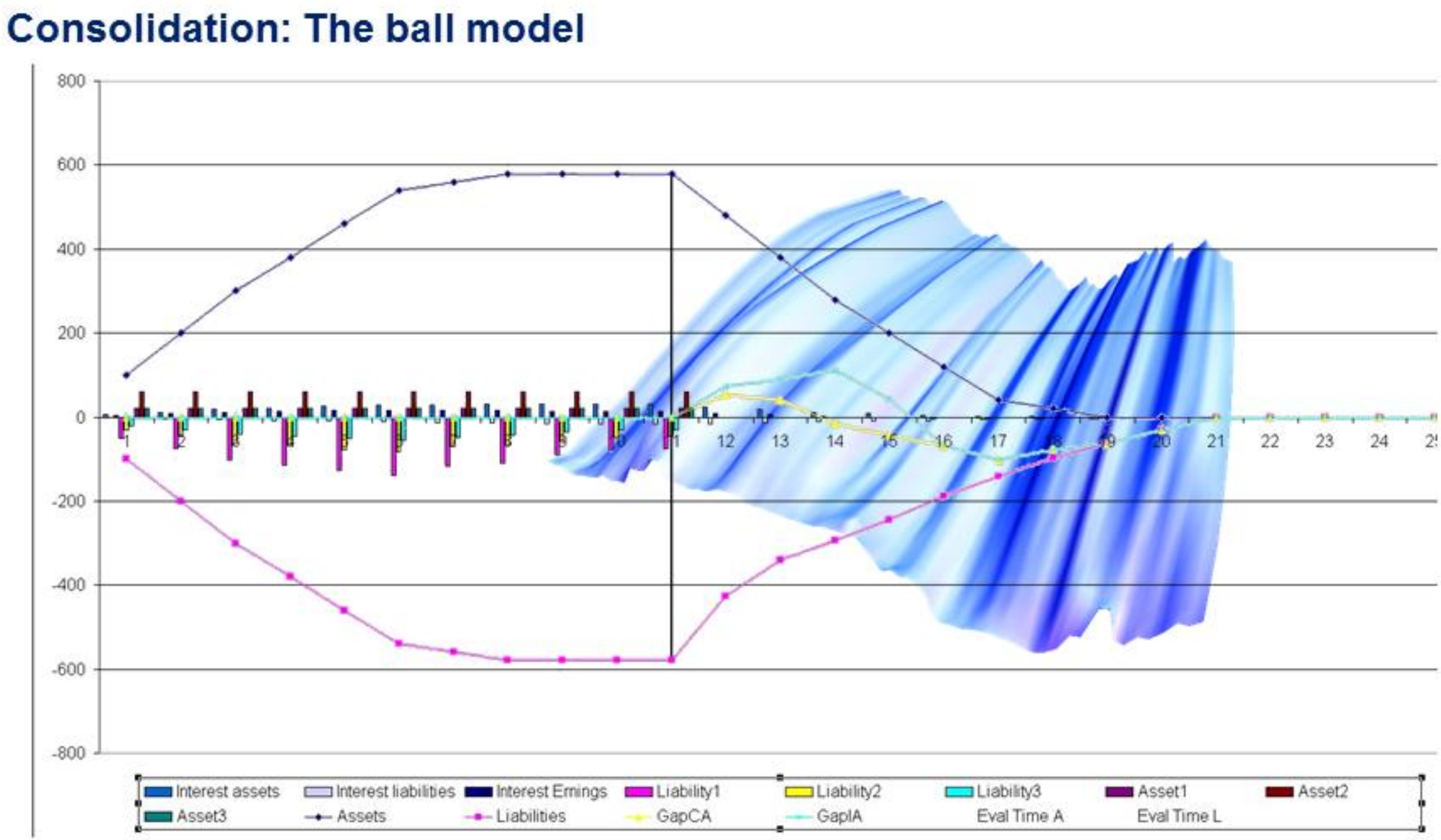
- ○ … capital commitment, no interest rate commitment
- ● … capital and interest rate commitment

The “bow wave” of the balance sheet

Consolidation: The ball model



The “bow wave” of the balance sheet



Cost reduction via canceling “waves”

» How can we achieve an optimal match between business structure, liquidity structure, and interest rate structure while taking into account their dynamics?

Photo source: www.Rudis-Fotoseite.de / pixelio.de

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Cost reduction via canceling “waves”

» How can we achieve an optimal match between business structure, liquidity structure, and interest rate structure while taking into account their dynamics?

Photo source: FotoHiero / pixelio.de

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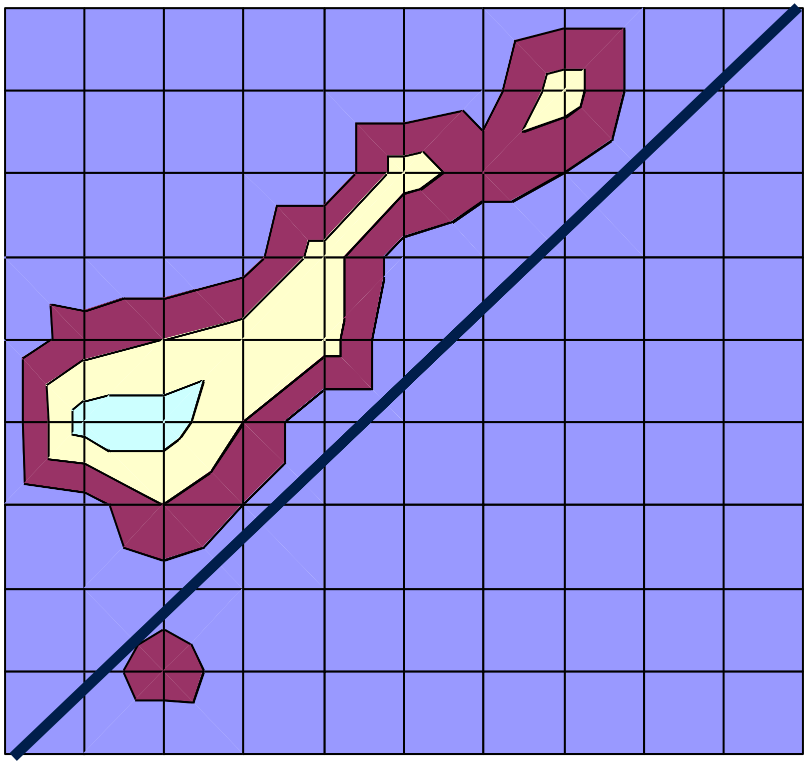
Cost reduction via canceling “waves”



» How can we achieve an optimal match between business structure, liquidity structure, and interest rate structure while taking into account their dynamics?

Photo source: FotoHiero / pixelio.de

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The costs of the crisis

SoFFin (Sonderfonds Finanzmarktstabilisierung)

Financial Market Stabilization Fund

guarantees of up to 400bn Euros

recapitalize or purchase assets for up to 80bn Euros

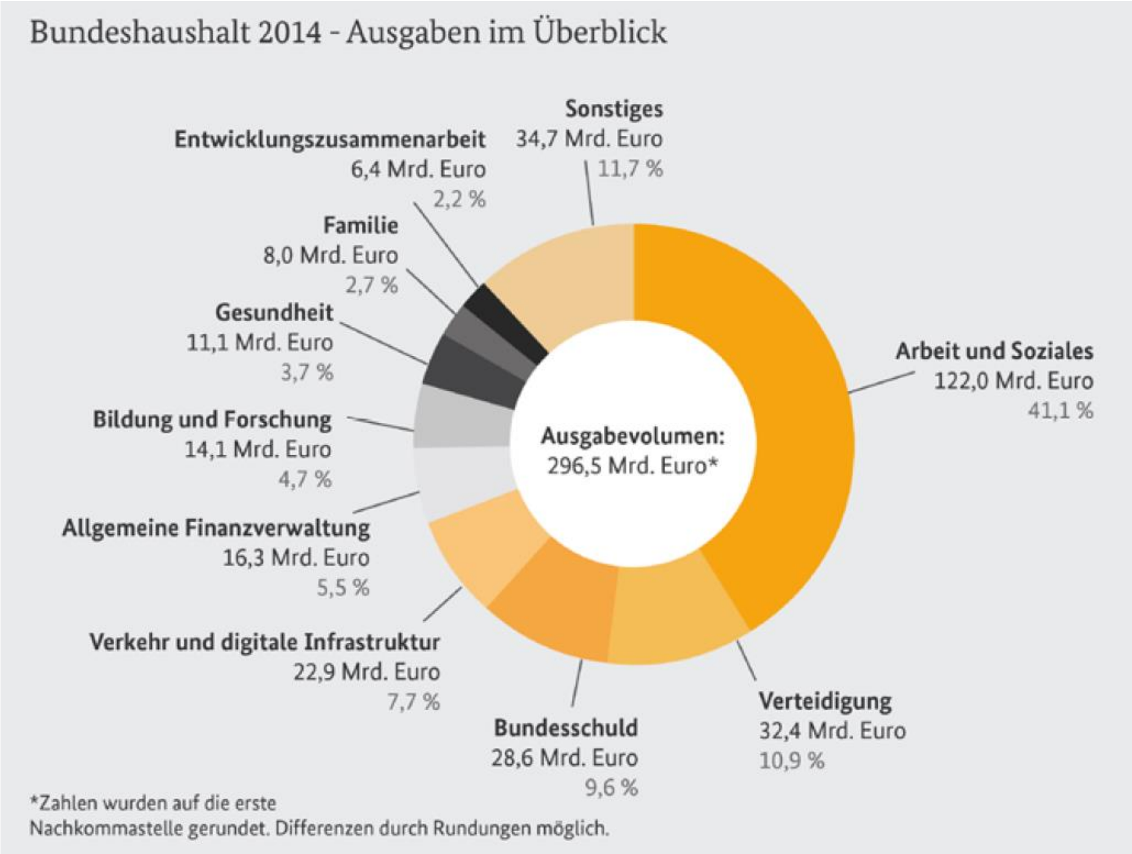
Accumulated losses of the SoFFin:

- 2009: 4.3 billion Euros
- 2010: 4.8 billion Euros
- 2011: 13.1 billion Euros
- 2012: 23 billion Euros
- 2013: 21.5 billion Euros
- 2014: 21.9 billion Euros

Equity recapitalizations (30.06.2012) :

- Aareal Bank AG: 0.3
- Commerzbank AG: 6.7
- Hypo Real Estate: 9.8
- WestLB AG: 3.0

296,5 billion EUR in 2014



Source: SoFFin Jahresberichte, http://www.fmsa.de/de/fmsa/soffin/Berichte/index.html

Source: Bundesministerium für Finanzen, Auf den Punkt - Bundeshaushalt 2014, August 2014

Visualizing US debt – 1

100 dollars

Source: Die Welt / August 2011

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Visualizing US debt – 2

10.000 dollars – average years income world wide

Source: Die Welt / August 2011

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Visualizing US debt – 3

1 million dollars

Source: Die Welt / August 2011

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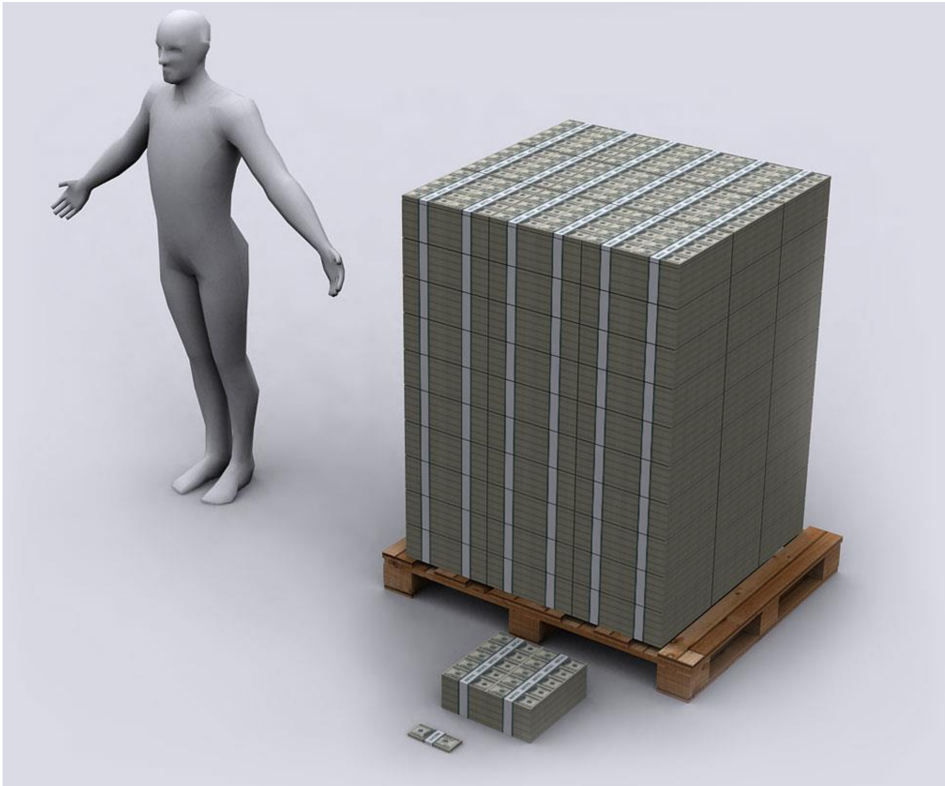
Visualizing US debt – 4



100 million dollars – This amount can be transported on a europallet

Source: Die Welt / August 2011

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Visualizing US debt – 5

1 billion dollars – 10 europallets, not easy to transport

Source: Die Welt / August 2011

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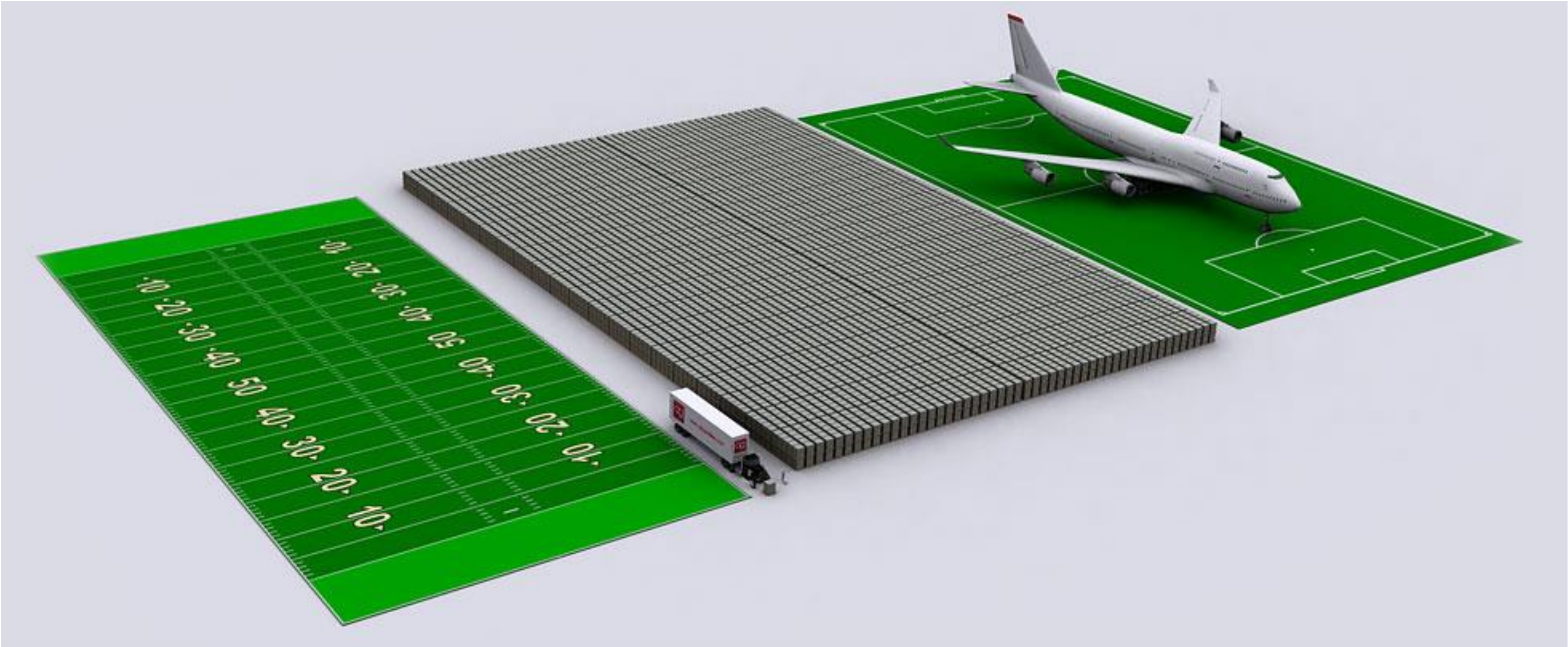
Visualizing US debt – 6



1 trillion dollars – in comparison to an American Football field or a Boeing 747

Source: Die Welt / August 2011

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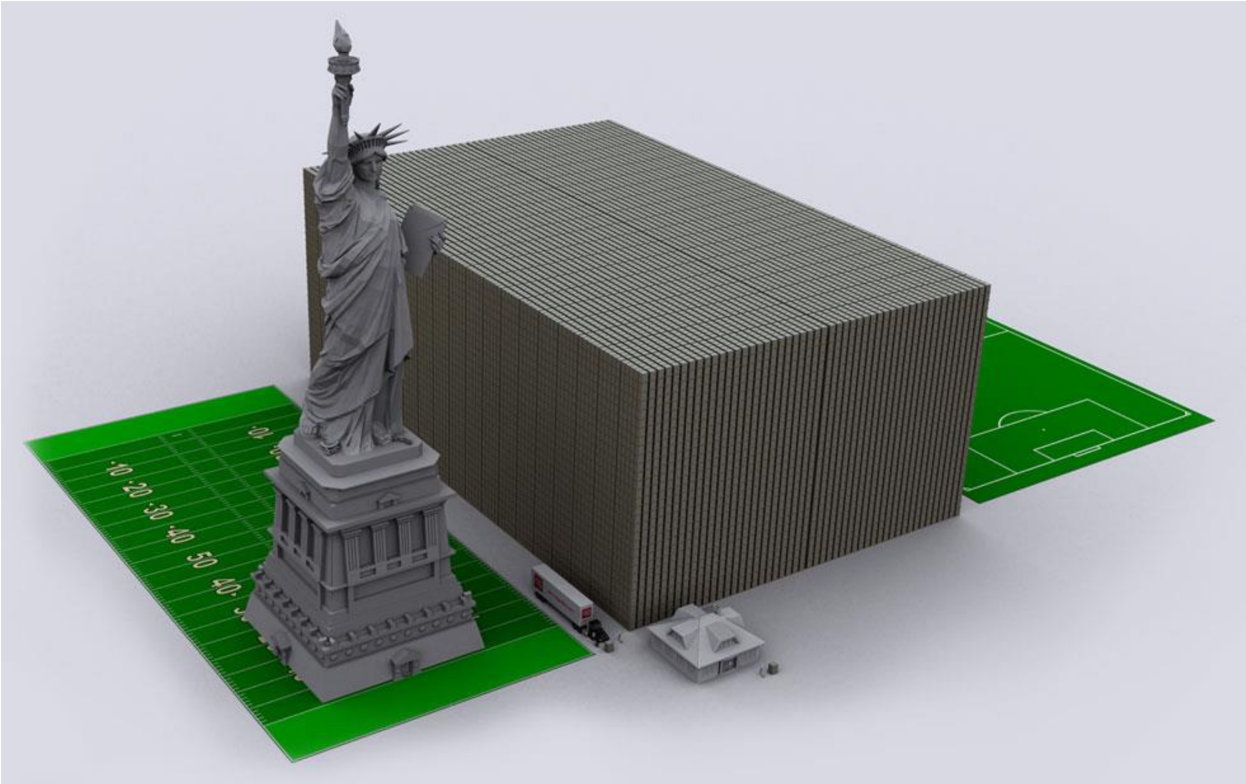
Visualizing US debt – 7



15 trillion dollars – represents the forecasted national debt of the USA at the end of 2011

Source: Die Welt / August 2011

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Visualizing US debt – 8

114,5 trillion dollars – sum of all unsecured obligations of the USA – i.e. national debt, including pensions, social services and private debt

15 trillion dollars (5 trillion dollars held by foreigners, 1,2 trillion dollars held by China)

Source: Die Welt / August 2011

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Visualizing US debt – 8

114,5 trillion dollars –

There are 10^{11} stars in the galaxy. That used to be a huge number. But it's only a hundred billion. It's less than the national deficit! We used to call them astronomical numbers. Now we should call them economical numbers.

Richard Feynman (1918–1988)

15 trillion dollars (5 trillion dollars held by foreigners, 1,2 trillion dollars held by China)

Source: Die Welt / August 2011

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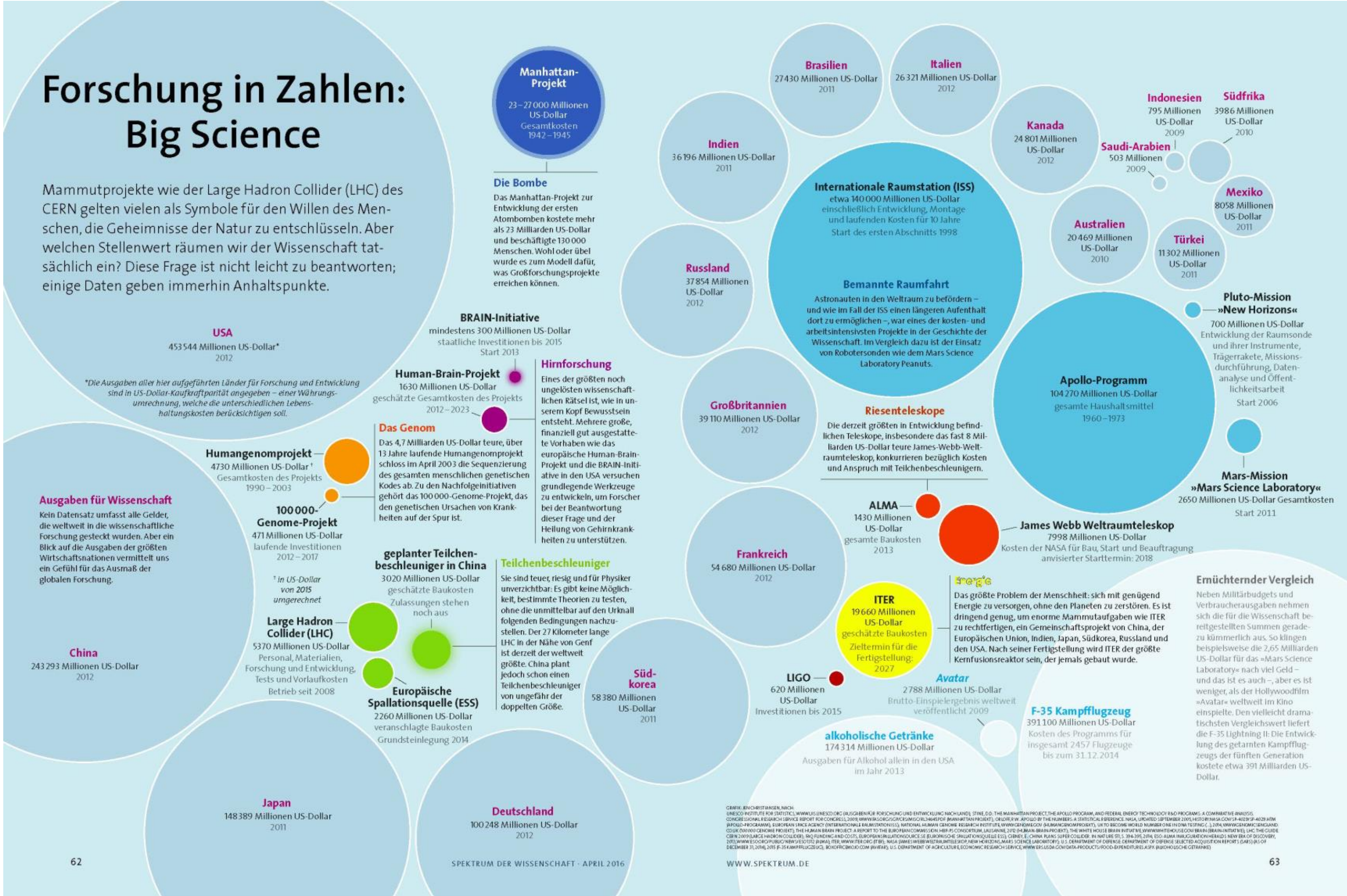
Cost of science (budget)

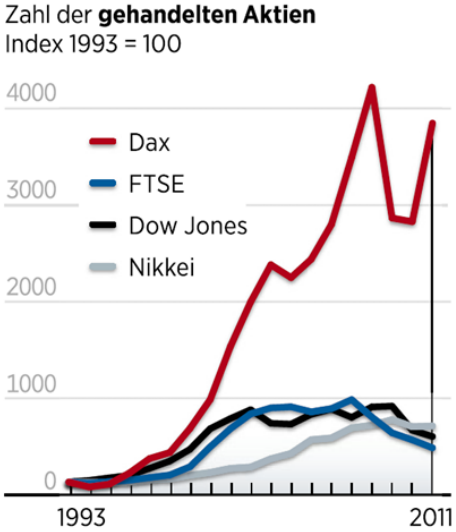


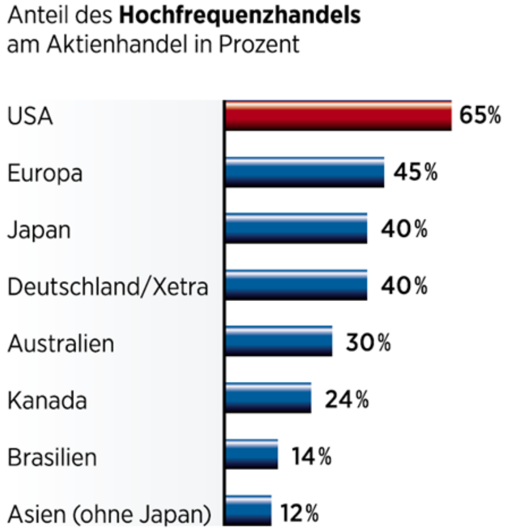
Spektrum der Wissenschaft April 2016

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





Source: Handelsblatt 2012

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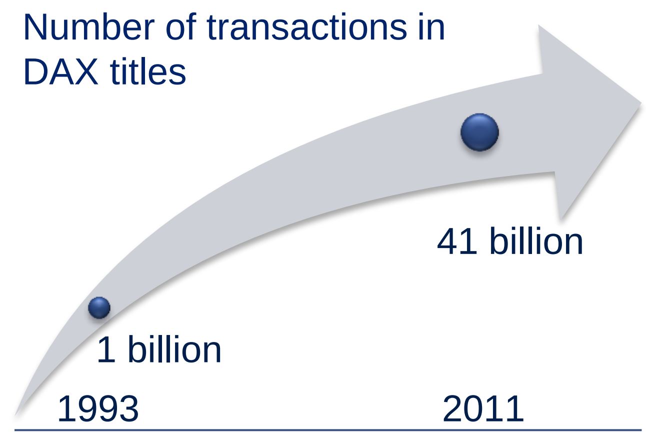
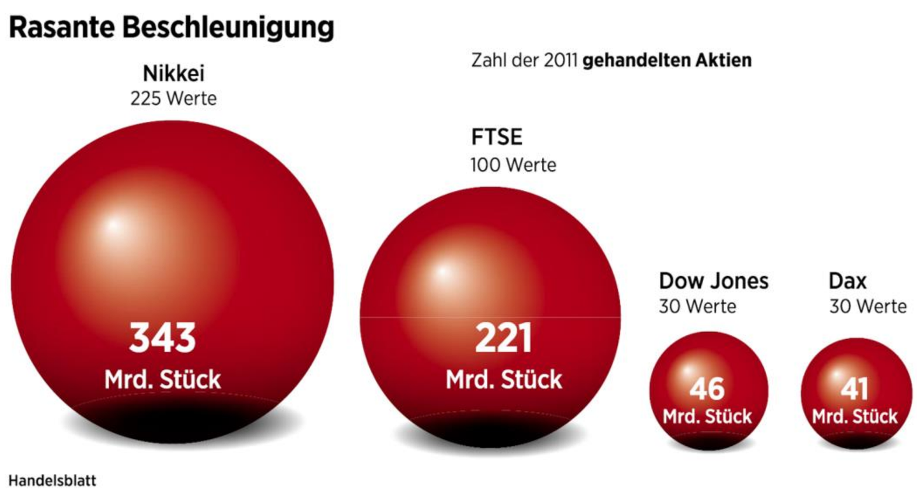
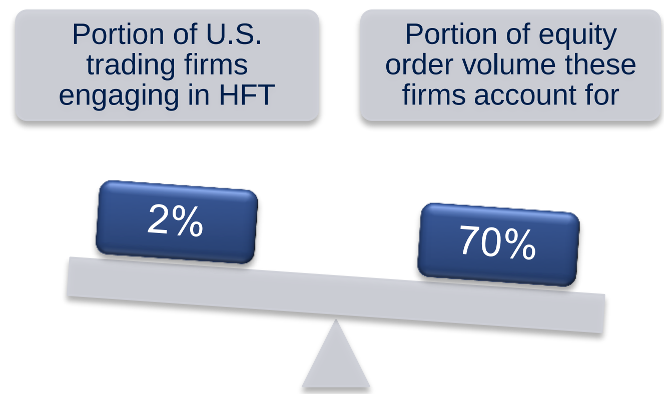
Volume of high frequency trading

- 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







Source: Handelsblatt 2012

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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.

Source: Handelsblatt 2012

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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 … Exch… nd the C… Trad… conc… 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

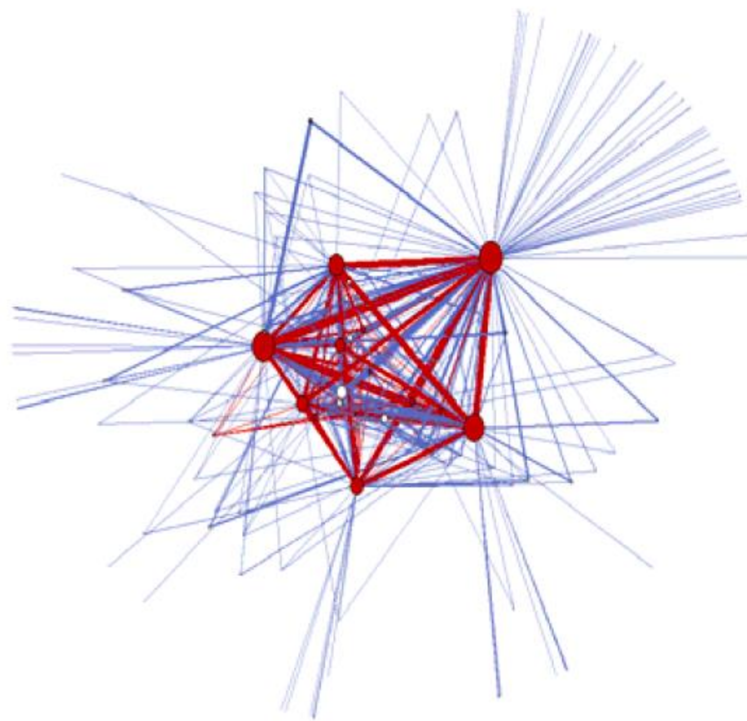
Source: Handelsblatt 2012

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



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

Network topologies of interbank payments

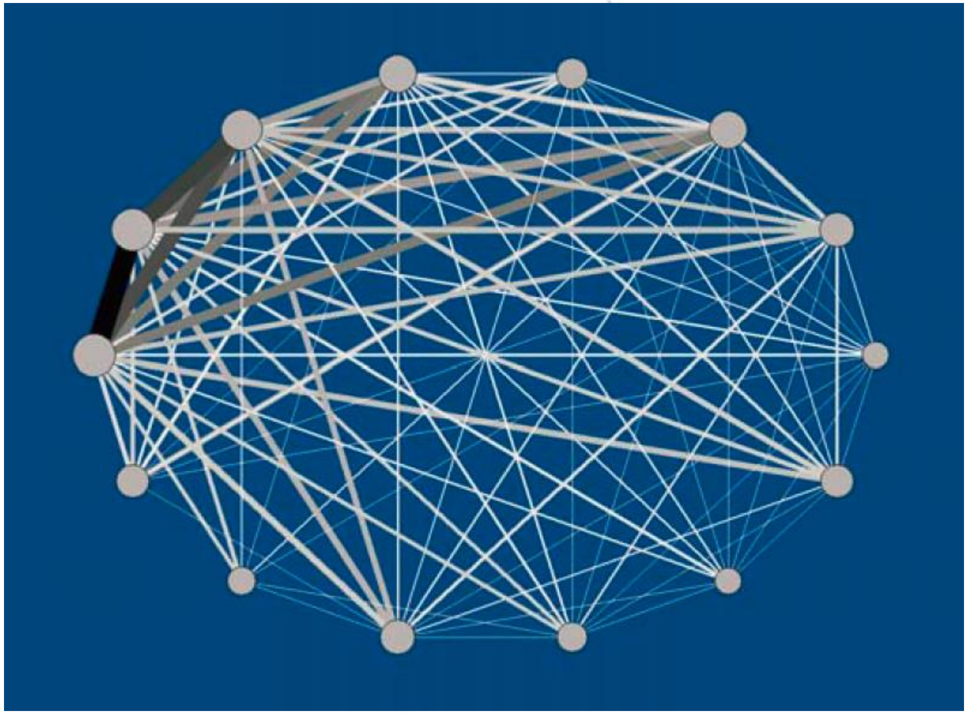
CHAPS: Clearing House Automated Payment System

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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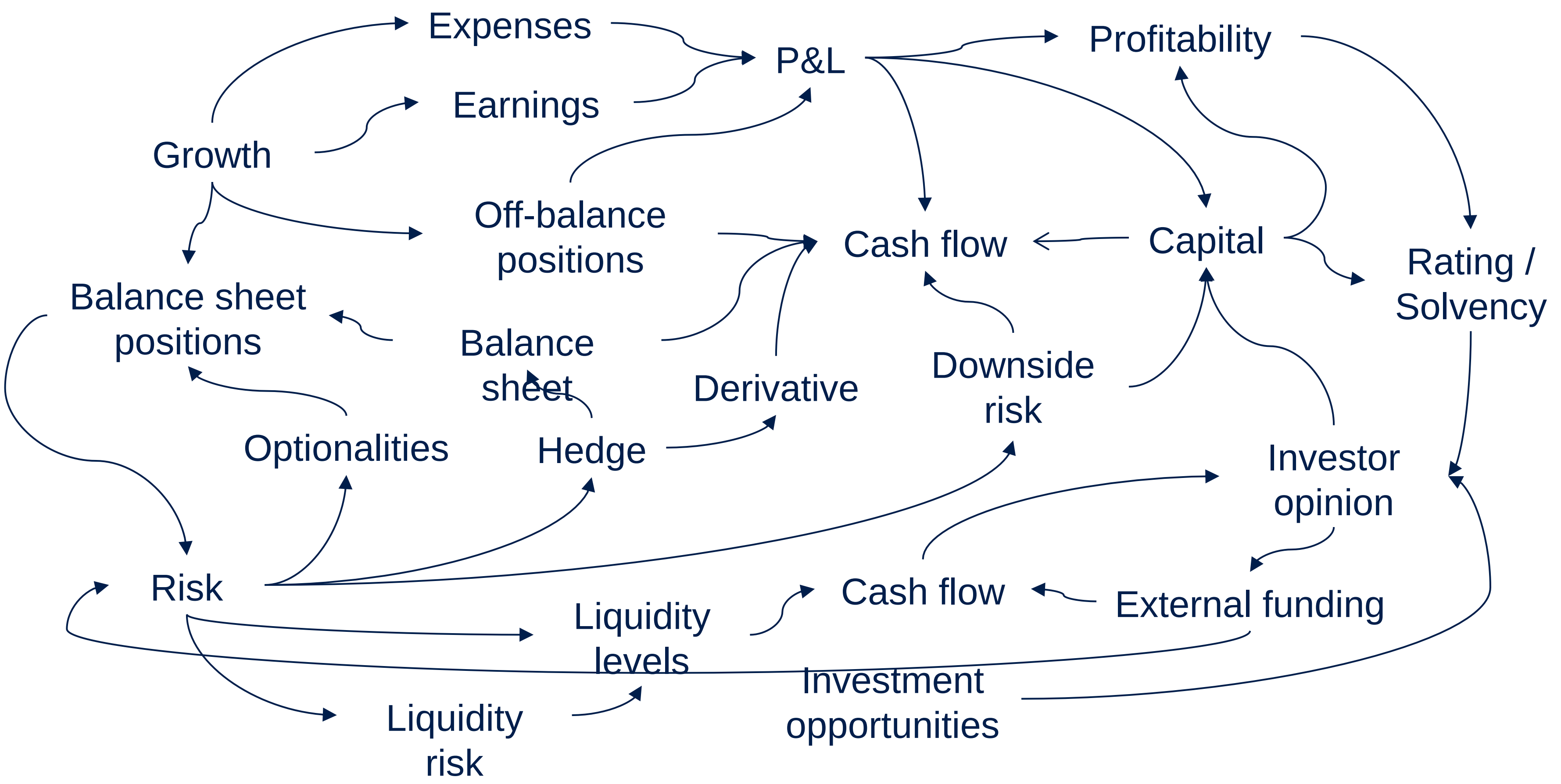
Economics and banking – a complex network of dependencies



From: Managing Liquidity in Banks, R. Duttweiler, 2009

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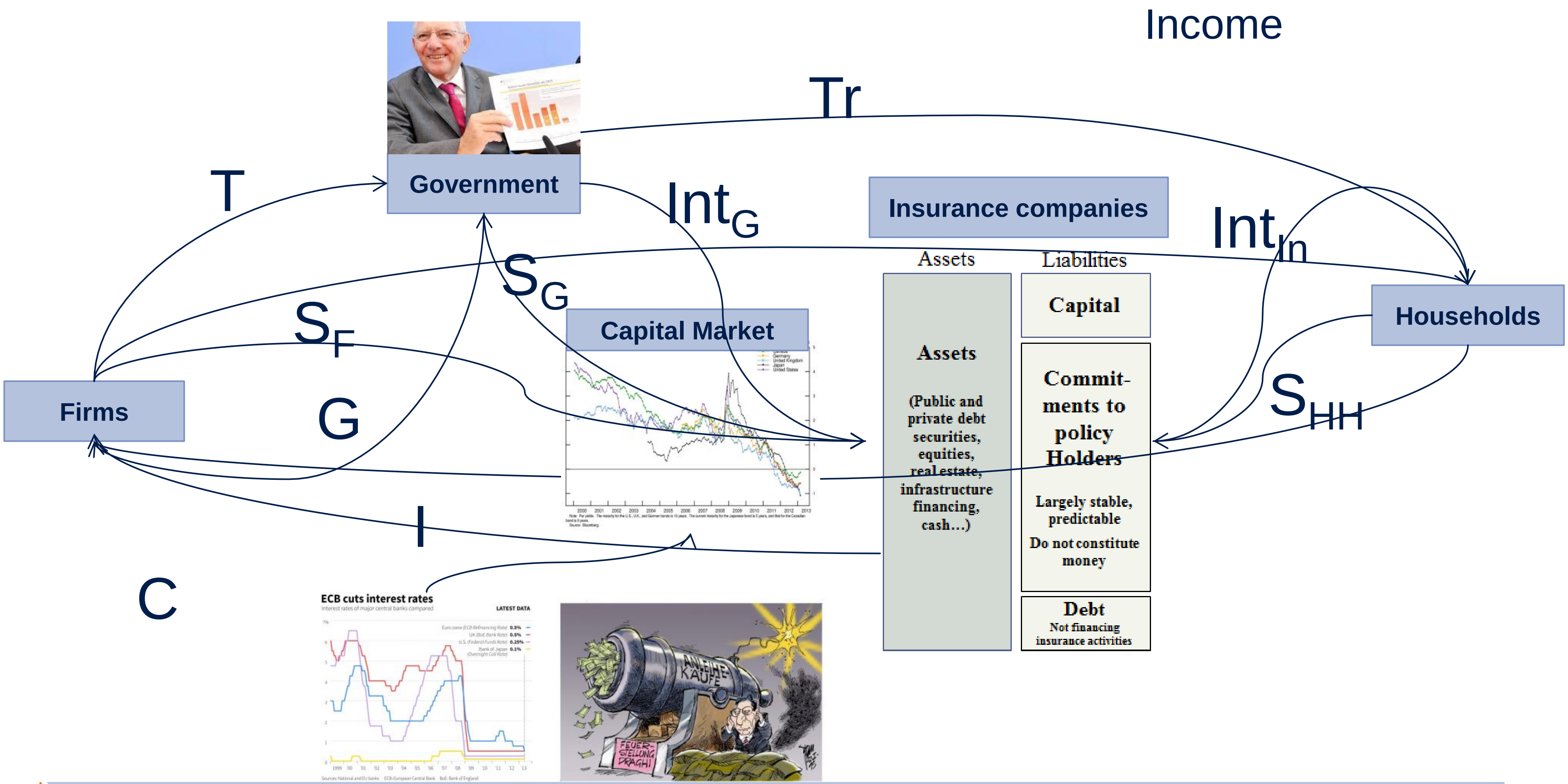
Complexity and networks: Economy and insurance companies



Insurance companies form a vital part of the macroeconomic flow chart

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Complexity and networks: All of us are affected

www.bild.de

– Seite 4

– SPORT

PENNY.

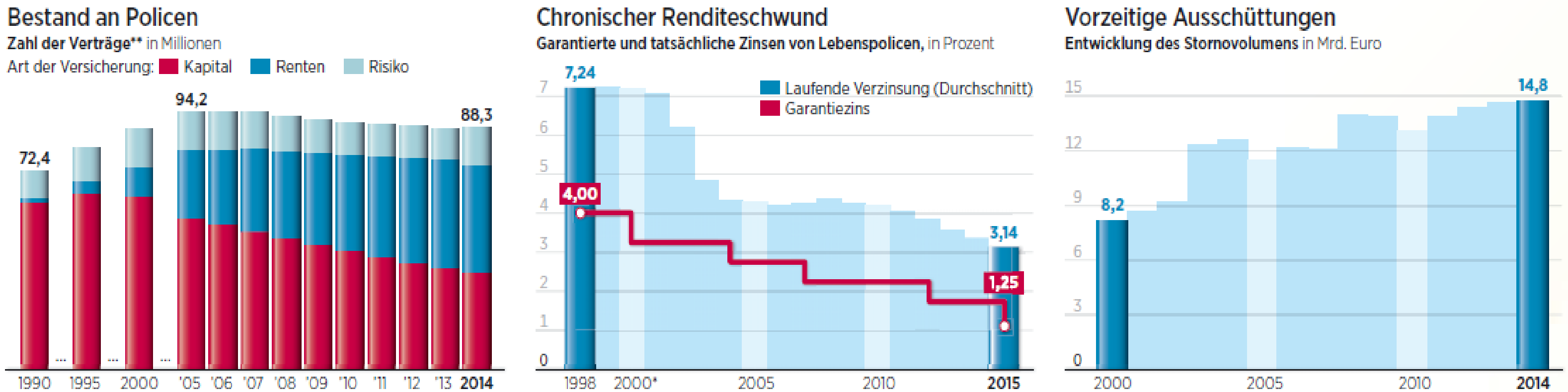
Gültig bis Samstag, 18.4.2015

Wegen Mini-Zins! IWF warnt vor Zahlungsunfähigkeit

Geht meine Lebens-Versicherung pleite?

Der Internationale Währungsfonds (IWF) schockt Verbraucher mit einem aktuellen Bericht: Lebensversicherer könnten „existentielle Probleme" bekommen, weil sie Kunden mehr Zinsen versprochen haben, als sie tatsächlich erwirtschaften können. Ob Versicherern sogar die Pleite droht, was das für Kunden bedeutet, was sie jetzt tun können – Seite 9.

Lebensversicherung in Zahlen – die Luft wird dünner



Handelsblatt | *Hauptversicherungen; **2000: bis Juni 4 %, ab Juli 3,25 %
Foto: blickwinkel | Quellen: GDV, Morgen & Morgen

Source: bild, Handelsblatt

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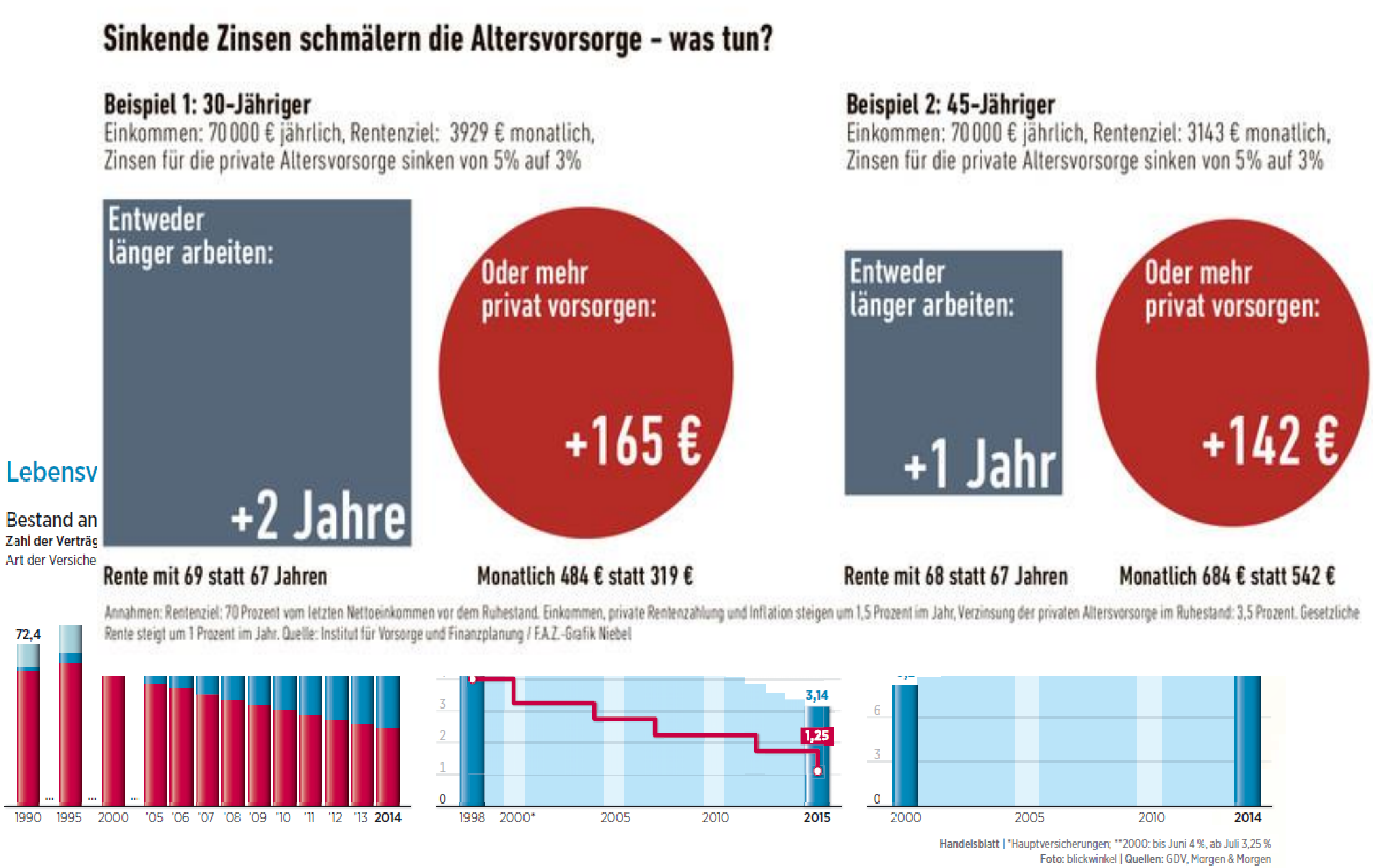
Complexity and networks: All of us are affected



Source: bild, Handelsblatt, FAZ

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Collecting and processing information

Digital economy is founded on data

Photo source: en.wikipedia.org

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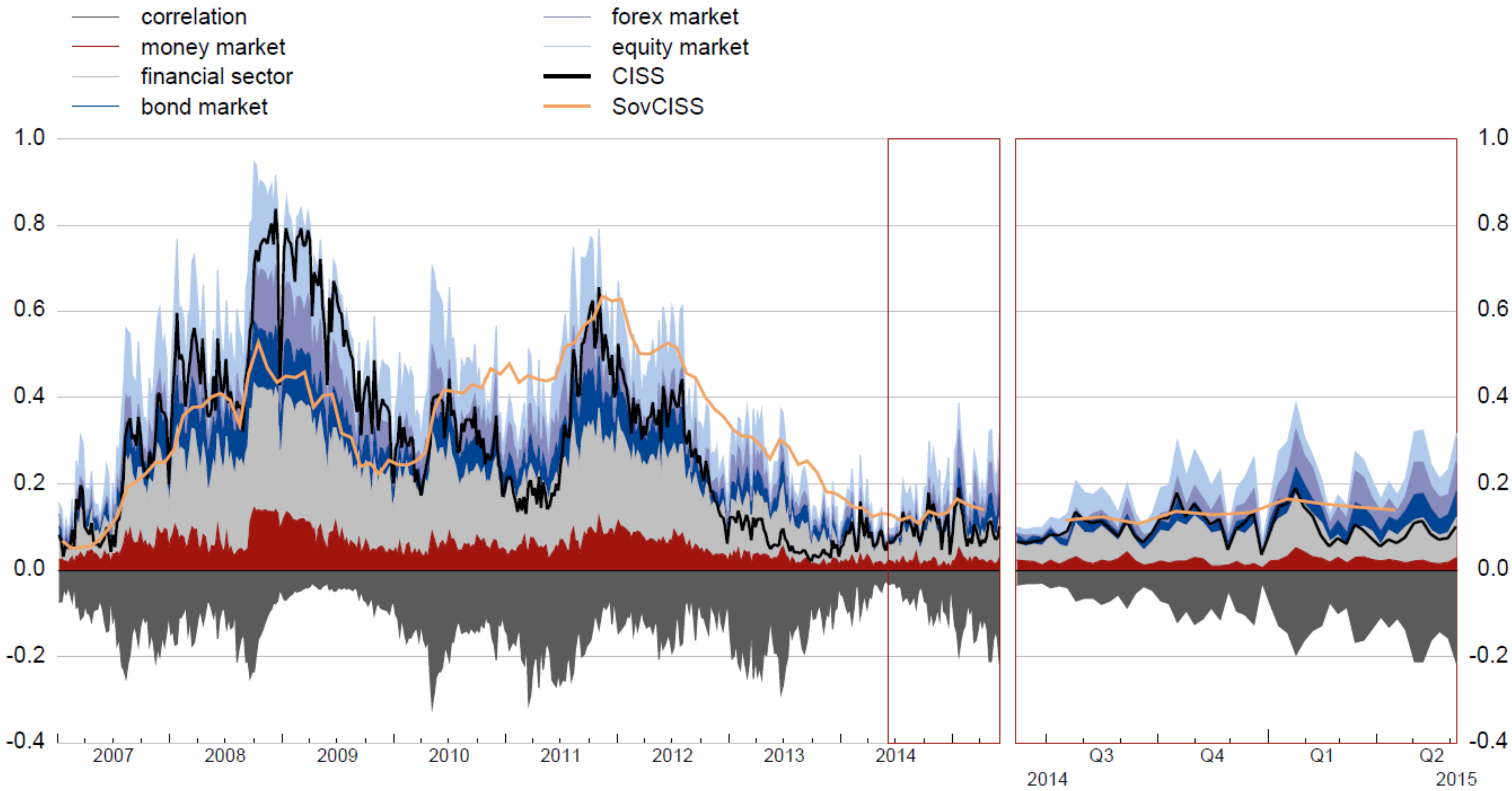
Combating the crisis: Is the financial and European debt crisis over?

» CISS = Composite Indicator of Systemic Stress



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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Watson, we need your help!

Mensch gegen Computer: Bei der populären US-Quizshow „Jeopardy!“ siegte die IBM-Maschine. Jetzt hat sie einen neuen Job

Wall Street heuert „Watson“ an

Super-Computer aus der TV-Quizshow „Jeopardy“ macht jetzt Banker arbeitslos

- Citigroup setzt schlaue IBM-Maschine bereits für Risikoanalysen und zur Kundenberatung ein

Source: WELT KOMPAKT, March 2012

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Watson, we need your help!

IBM

Watson wertet Daten von Apple-Nutzern aus

IBM will mit seinem selbst lernenden Computersystem Watson die Gesundheitsdaten von iPhone- und Apple-Watch-Nutzern analysieren – und die Ergebnisse Dritten anbieten.

von Patrick Beuth | 14. April 2015 - 11:35 Uhr

© Philippe Merle/AFP/Getty Images

iPhone und Apple Watch

Source: ZEIT Online

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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.

When things fall apart

**Vienna,
May 9th, 1873**

**New York, October
25th, 1929**

**Northern Rock,
September 18th, 2007**

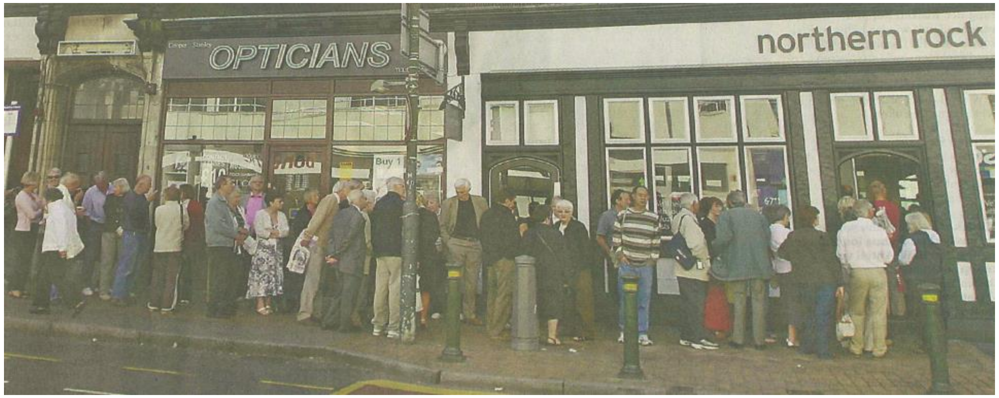

Photo source: en.wikipedia.org

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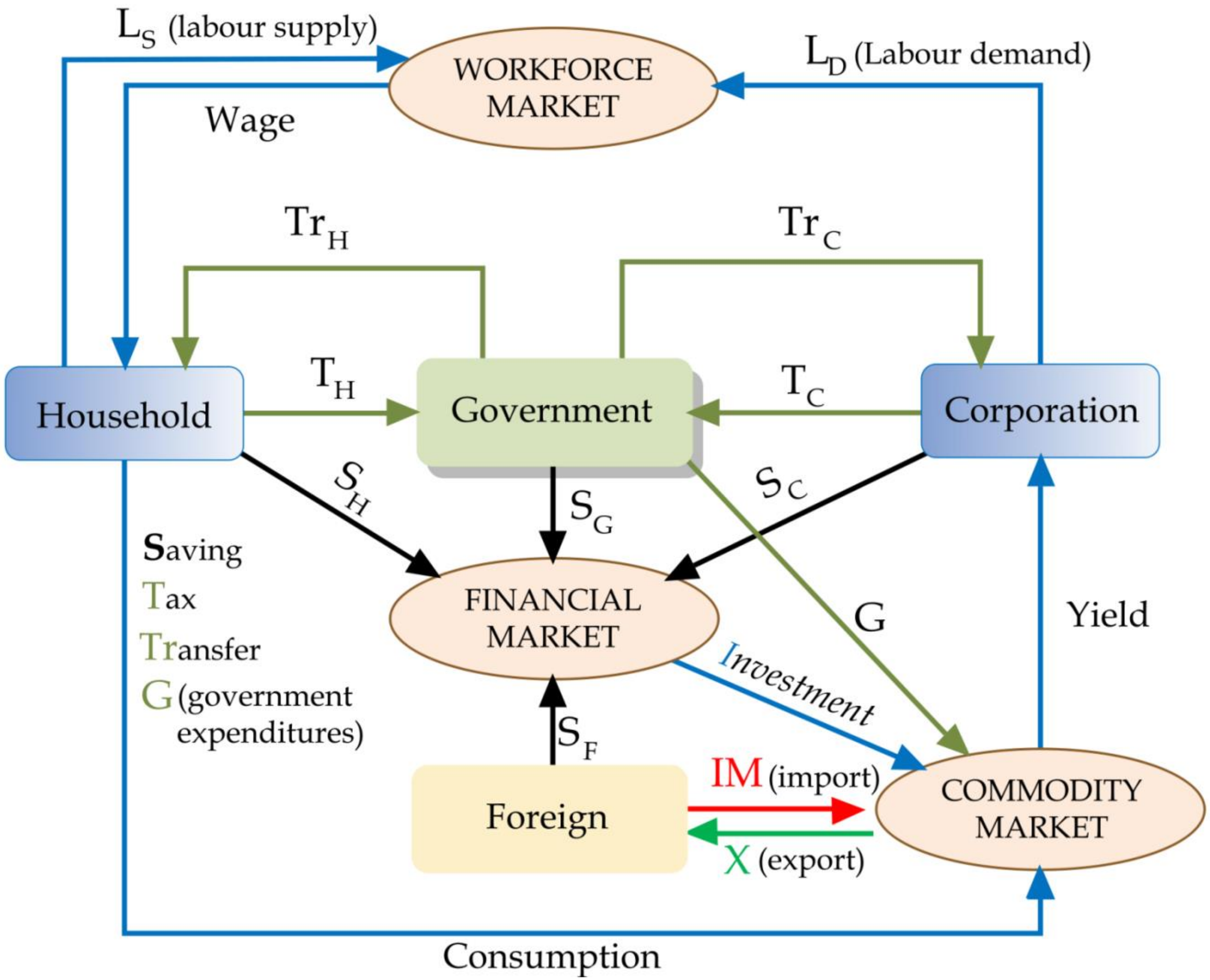
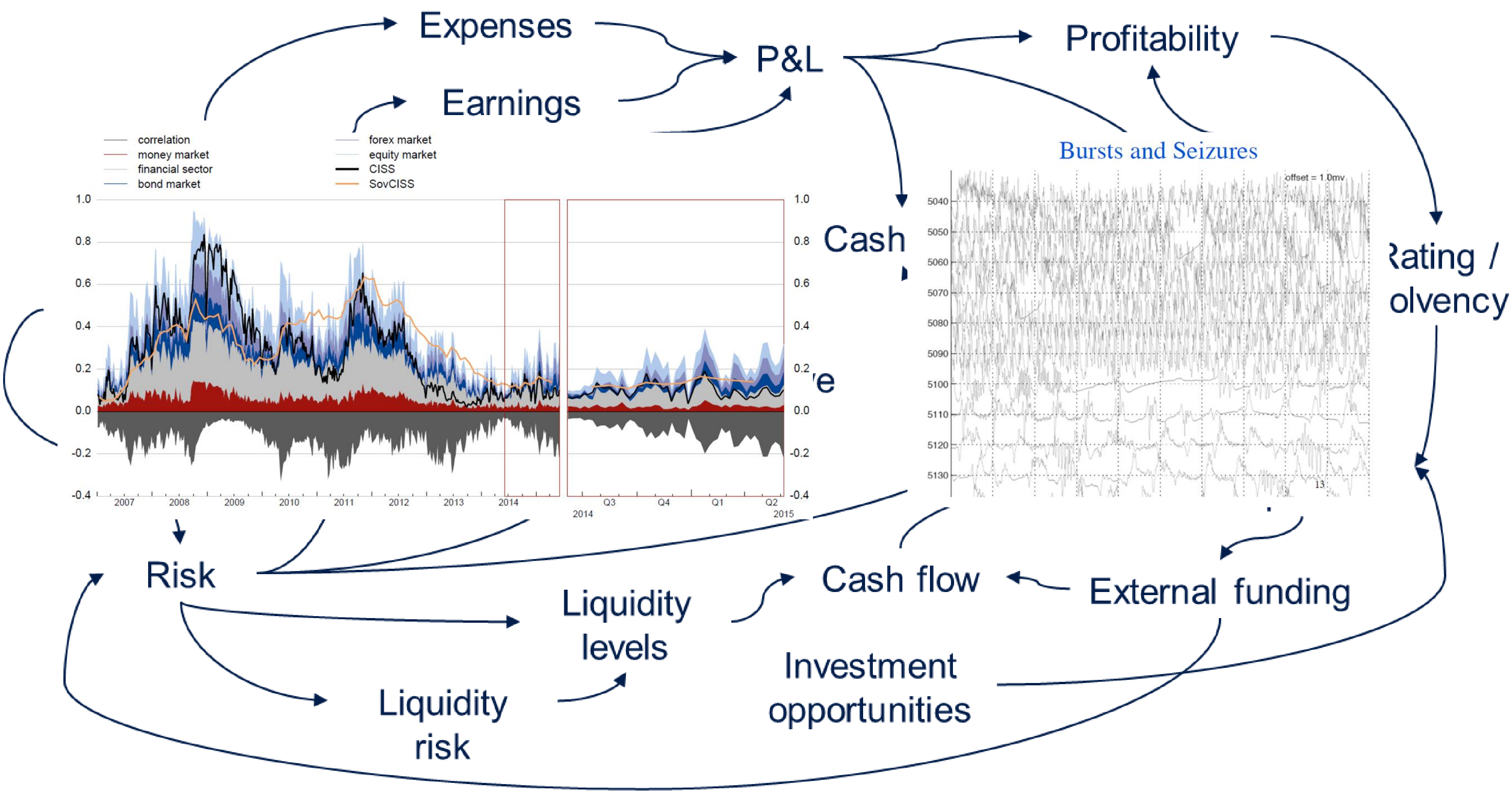
Economics and banking – a complex network of dependencies



Can human brains handle the amount of information?



From: Managing Liquidity in Banks, R. Duttweiler, 2009; European Systemic Risk Board (ESRB) Risk Dashboard; Didier Sornette, Neuron, Reviews on Cognitive Architectures, Vol. 86, Number 1, Oct. 2015

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The four “business dimensions”

Business Acumen

Global bank management

Liquidity risk

Greed

Fear

Modelling

Interest rate risk

Risk
duty of due care

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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

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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Partner

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