Oil price spikes and crashes – How does recent history fit with some popular modeling approaches?

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Motivation in a nutshell

: Price development crude oil WTI

source: EIA

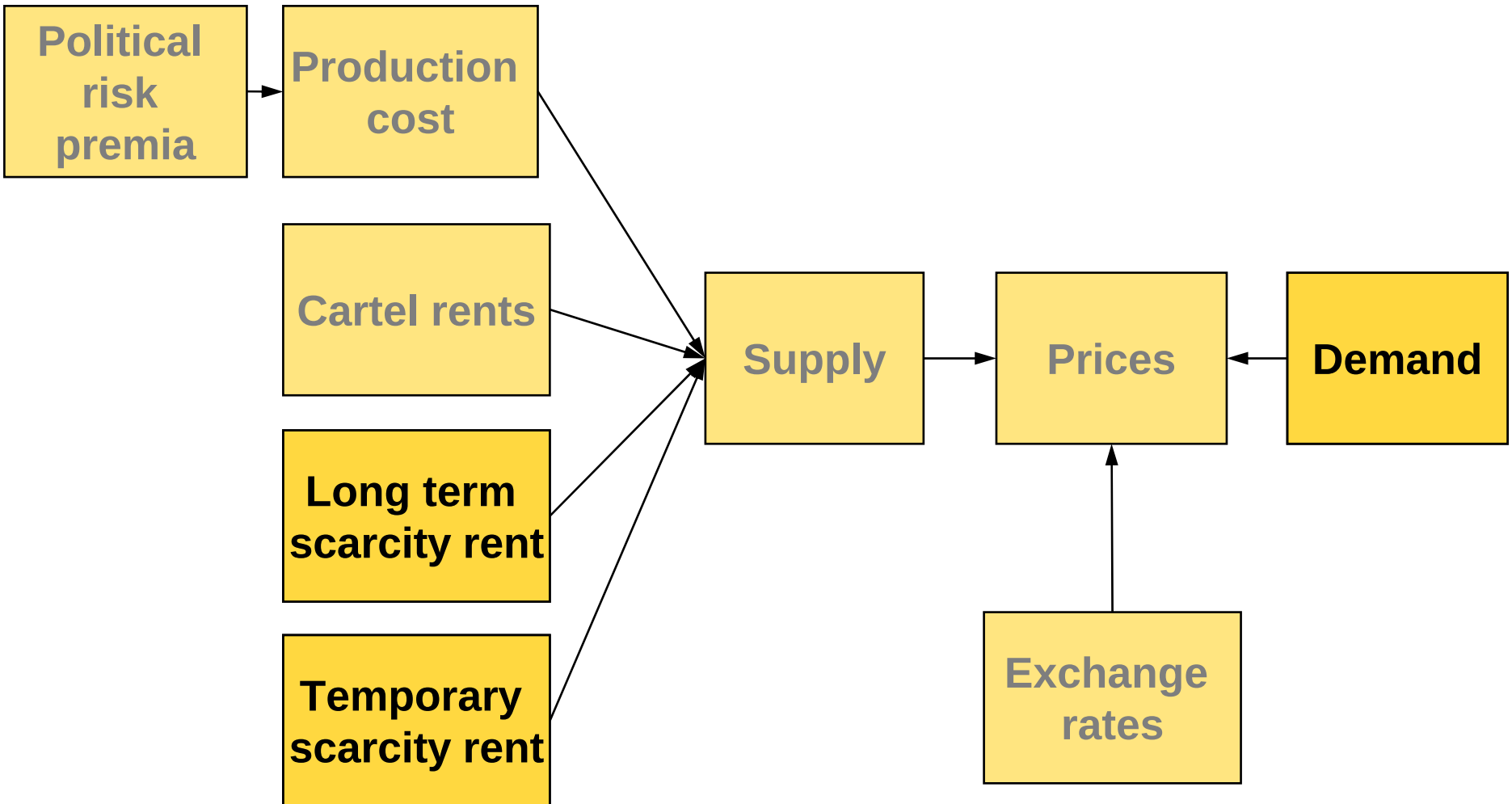
Motivation – a few more words

- Oil prices have been investigated for decades
  - Seminal work already by Hotelling (1931)
- Recent fluctuations of oil prices have sparked again interest in oil price modelling
  - E.g. Hamilton (2009)
- Oil price forecasts in the longer run seem to be almost impossible
  - best forecast for price in five years: today‘s price (?!)
  - or price on today‘s future market

→ What should we tell our students?

→ **Prices change as new information arrives?**

Impacts on prices and new information

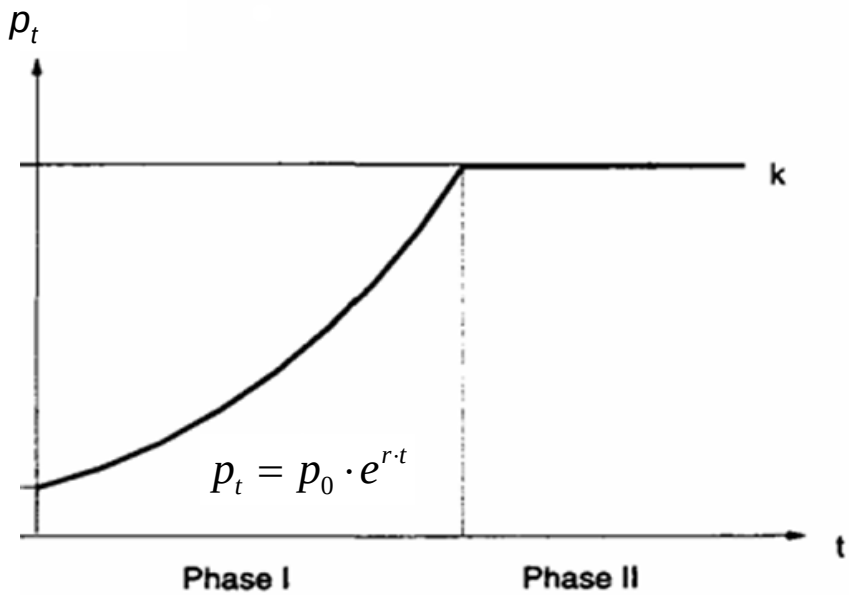


Overview

1. Introduction
2. Hotelling‘s model
3. Modern finance multi-factor models
4. Behavioural finance models
5. Hotelling‘s model revisited – time-to-build constraints
6. Final remarks

Hotelling‘s model

- Basic model:
  - Price follows an exponential price path $p_t = p_0 \cdot e^{r \cdot t}$
  - → Price level driven by demand patterns
- Multiple extensions
  - Inclusion of extraction costs
  - Monopoly or oligopoly
  - Technological changes
  - …
- Important extension: Backstop technology
  - Nordhaus (1973)
  - → Two-phase price development



Model considered

Hotelling model for oil with backstop technology

- World oil production (2005): 81 mb/d (BP 2009)
- Remaining resources (URR): 2450 bill. bl (IEA 2008)

  of which not yet proven reserves 1207 bill. bl (IEA 2008)
- Cost backstop technology: 1000 $/bl (current PV cost Germany)
- Interest rate (real): 5 % p. a. (<< hurdle rate majors)
- Growth rate demand (at constant prices): 2 % p. a.
  (av. 1.1 % since 1973)
- Price elasticity of demand: -0.2

→ Starting price: 54.0 $/bl (BP 2005: 54.5 $/bl)

Hotelling‘s model – new information arrival

Information update possible on:

- Expected costs of backstop technology
- Current and expected future demand
- Expected ultimately recoverable resources

Resulting prices ($\$_{2005}$/bbl)

New information	Low scenario (-50 %)	Reference	High scenario (+50%)
Backstop cost	33.2	54.0	71.5
Demand growth	41.0	54.0	67.9
Unproven reserves	81.6	54.0	38.3

→ Substantial impact,

→ but none can explain rise of prices by factor 7 between 1998 and 2008

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General model

- Based on efficient market hypothesis
- Use of information contained in timeseries of spot and future prices
- Change in prices explained as resulting from one to several stochastic factors plus some structural effects
  - e.g. storage or risk premia
- No price forecasting capabilities
- Use for volatility modelling and valuation
- Examples
  - Gibson & Schwartz (1990), Schwartz (1997), Cortazar & Naranjo (2006)

Model considered - Cortazar and Naranjo (2006)

Source: Cortazar, G., Naranjo, L. (2006): An N Factor Gaussian Model of Oil Futures Prices. In: The Journal of Futures Markets 26 (3), pp. 243 268

- General N-factor model, here 3-factors used
- Uses general latent factors instead of intuitively interpretable quantities
- Risk adjusted processes for latent factors

$$d\mathbf{x}_t = \left(-\mathbf{K}\mathbf{x}_t - \boldsymbol{\lambda}\right)dt + \boldsymbol{\Sigma}d\mathbf{w}_t$$

$\mathbf{x}_t$ … *state variables*

$\mathbf{K}$ … *mean-reversion parameters*

$\boldsymbol{\Sigma}$ … *diffusion parameters*

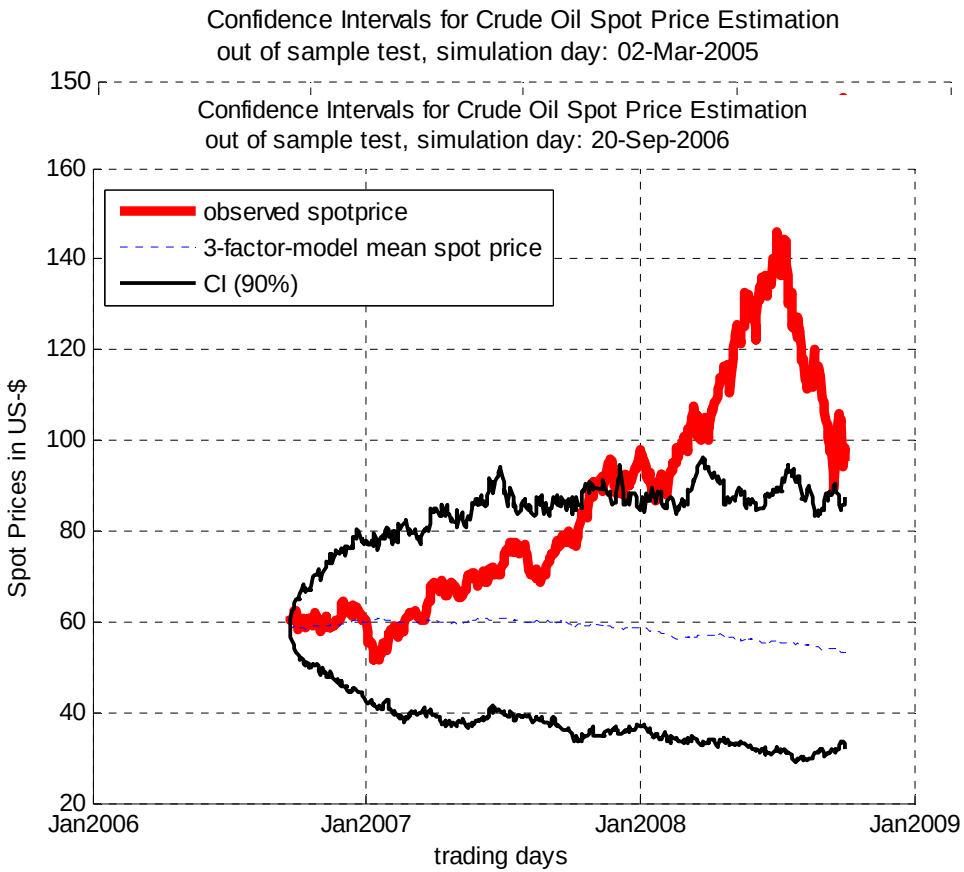
$\mathbf{w}_t$ … *Brownian motion*

$\boldsymbol{\lambda}$ … *risk premia*

→ Rolling estimation of parameters, from 2004 onwards

→ Then Monte-Carlo simulation of possible price developments

Multifactor finance model – new information arrival?



- Observed spot prices usually remain within 90 % confidence interval of simulations
- Yet both price peaks in August 2006 and in 2008 are outside the expected range

→ Either informational efficiency of markets not given

→ Or nature of incoming information changed fundamentally

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General considerations

- Broad variety of models
- So far limited applications to commodity models
- Common core of the approaches: impact of behavioural deviations from rational expectations
- E.g. Summers (1986), Tirole (1985) and others derived models for speculative bubbles
- Example for model on commodity market speculation:

  He and Westerhoff (2005)

Model considered – He and Westerhoff (2005)

Source: He, X.-Z., Westerhoff, F. (2005): Commodity markets, price limiters and speculative price dynamics. In: Journal of Economic Dynamics & Control 29, pp. 1577–1596

- Speculators in the market may be divided into:
  - Chartists: trend followers, believe in either bull or bear markets
  - Fundamentalists: consider deviations from the fundamental value
- The more the price deviates from the fundamental value, the more the chartists fear a price correction
  - → Share of fundamentalists increase

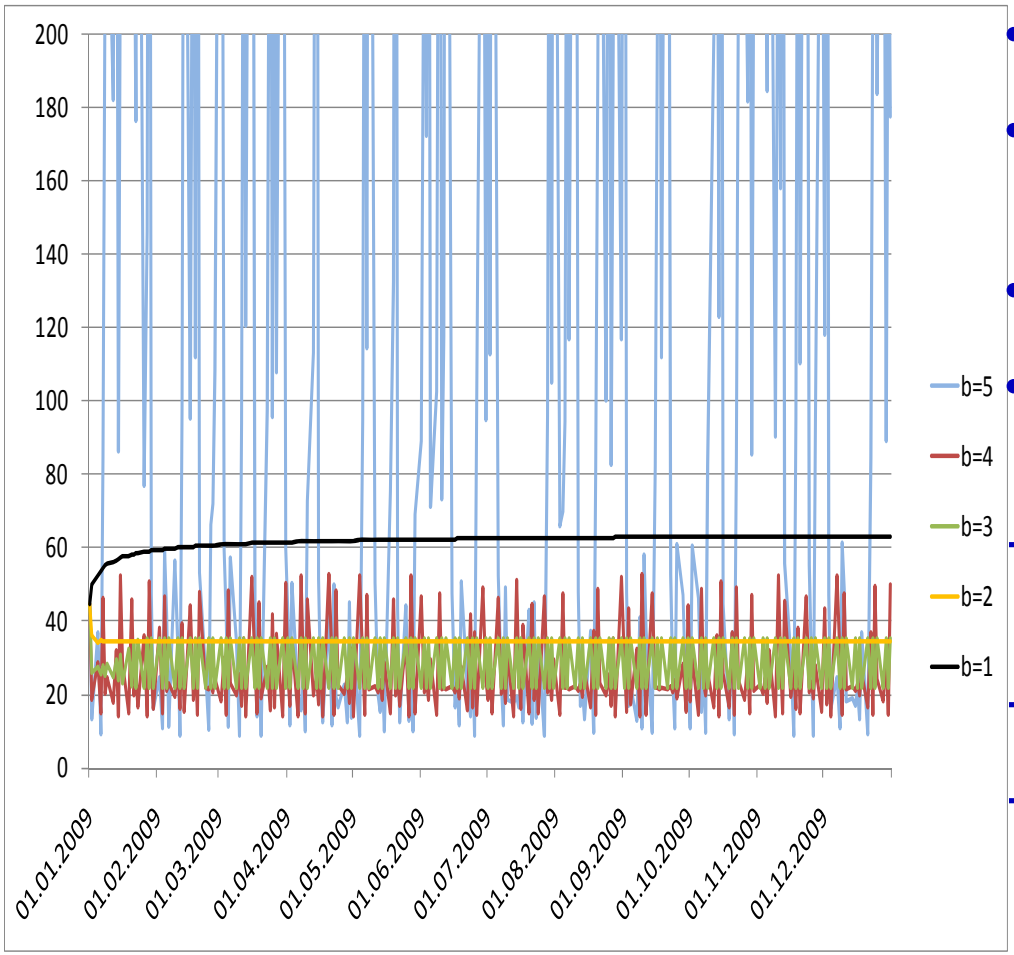
→ Overall non-linear price dynamics emerge

  - Depending on the parameter values, various attractors may emerge

$$S_{t+1} = S_t + a\left(m\left(F - S_t\right) - b\frac{\left(F - S_t\right)}{1 + d\left(F - S_t\right)^2} + c\frac{d\left(F - S_t\right)^3}{1 + d\left(F - S_t\right)^2} \right)$$

Behavioural finance model – new information arrival?

Price developments depending on reaction of chartists



- Deterministic model
- May explain short-term chaotic price patterns
- No long-term asset bubbles
- Long-term price uncertainty same as short term

→ Mechanical reaction to last observed price

→ As it is, clearly not adequate

→ But other behavioural models may be more promising

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General considerations

- Exploring and developing new oil fields requires up to 10 years time
- 10 years ago, oil price was at 12.72 $/bbl

→ Obviously limited incentives for exploration and development

→ In world with perfect information, further demand growth would have been anticipated

→ Combination of stochastic shocks (arrival of new information) and time-to-build induces risks of price shocks

→ short-term scarcity rent may impact prices

(Hotelling: long-term scarcity rent)

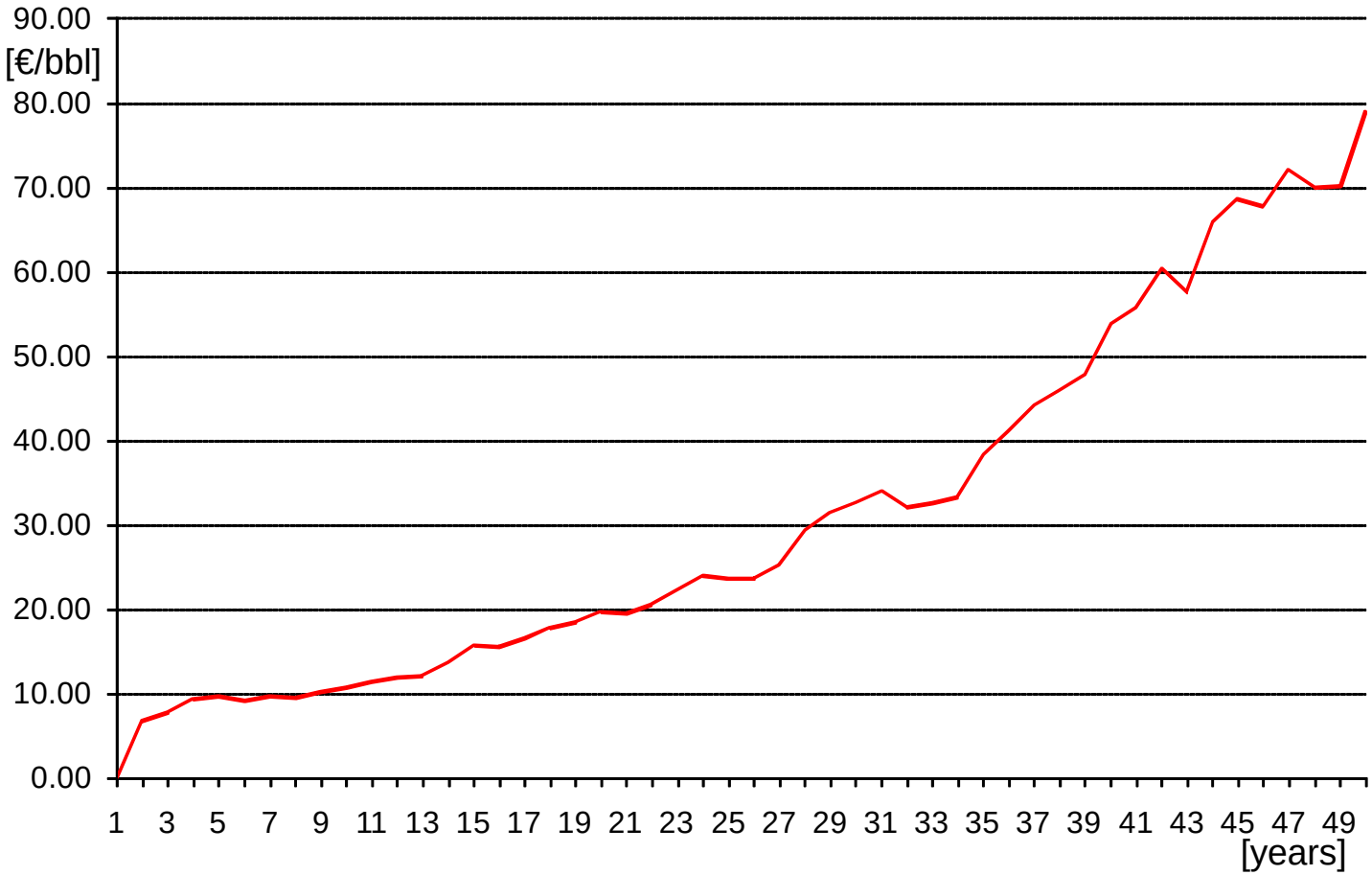
Model specification

- Model investigates short-term deviations from long term (Hotelling) equilibrium
- Demand growth is modelled as mean-reversion process
  - Standard deviation: 2 % p. a. (1973-2008 av.: 2.1%)
  - Coefficient autoregression: 0.5 (1973-2008: 0.44)
- Growth of supply is determined bei expected growth in demand, fixed 4 years in advance

$$S_{0,t} = S_{t-4}\left(1+g_{E,t-3}\right)\left(1+g_{E,t-2}\right)\left(1+g_{E,t-1}\right)\left(1+g_{E,t}\right)$$

- Other parameters almost identical with previous model
  - Backstop technology for seek of simplicity omitted
  - Short-term elasticities both for supply and demand 0.1

Price uncertainty under short-term fluctuations



→ Price uncertainty considerable, yet not sufficient for explaining

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More changes to come?

- 2006 to 2008 episode has been rather unique in oil history
- All models investigated are not capable of describing the observed spiking
- At least partly related to speculation
  - Self-reinforcing fundamental effects (costs of drilling) might be also relevant
- Fundamental models needed to gather insights
  - to disentangle new information and noise (real news and speculation)
  - to avoid future excessive speculative bubbles