Information flows in the term structure of commodity prices

Delphine Lautier, Franck Raynaud

Chair Finance and Sustainable Development
Fime Research Initiative
University Paris-Dauphine
Ecole Polytechnique Federale de Lausanne

Seminaire Fime - FDD March 28, 2014

Motivation

Financialization and integration of commodity markets raise questions:

- Hedging function of the futures markets: relation between the physical and the paper markets?
- Price discovery function of the markets: what about the informational content of the prices?

Empirical analysis :

- Most important commodity futures market : American crude oil, 2001-2011
- Analysis of maturity linkages: all available maturities, from the 1rst to the 84th months (i.e. 34 maturities)
- Information flows between prices returns associated to each maturity (1740 pairs of maturities)
- Methodology: information theory and graph theory

Results raise theoretical questions, on the segmentation theory and the Samuelson effect.

Methodology (1/2): Information Theory (Shannon,1948)

Entropy: Degree of uncertainty associated to a variable.

- Considering a random variable X (price returns) and its corresponding distribution $p(x)$, the entropy of X is:
$$H(X) = -\sum_x p(x) \log p(x)$$
- Conditional entropy: the remaining entropy of X if the values of Y are known
$$H(X|Y) = -\sum_{x,y} p(x,y) \log p(x|y)$$

Mutual information: Reduction of entropy of one variable when the other variables are known

$$M(X,Y) = H(X,Y) - H(X|Y) - H(Y|X)$$

Information transfer: Information emitted / information received

- The value of X at $t+1$ *depends* on the value of Y at t
Entropy rate: $h_1 = -\sum p(x_{t+1}, x_t, y_t) \log p(x_{t+1}|x_t, y_t)$
- The value of X at $t+1$ *does not depend* on the value of Y at t
Entropy rate: $h_2 = -\sum p(x_{t+1}, x_t, y_t) \log p(x_{t+1}|x_t)$
- Entropy transfer from X to Y: $T_{X \to Y} = h_1 - h_2$

Methodology (2/2)

Advantages:

- Model free methodology; holds also in the case on non linearity
- Gives rise to interesting quantities

Measurements:

- Total amount of information send from (respectively received by) the maturity M to (from) all others i:

$$T_{M_s} = < T_{M \to i} >_i$$

  $<>_i$ is the average over all maturities, except M.

- The forward flow ϕ_f (respectively backward flow ϕ_b) is given by:

$$\phi_f = \sum_{X<Y} T_{X \to Y}$$

Analysis through the graph theory: high dimensional analysis

- Graph: nodes stands for price returns (one node per maturity); links stand for directionality.
- Survival ratios used to analyze the stability of the graph

$$\bar{S}_R(t) = \frac{1}{N} D_{XY}(t) \cap \bar{D}_{XY}$$

Mutual information (MI)

Synchronous moves in the prices : MI reflects market integration

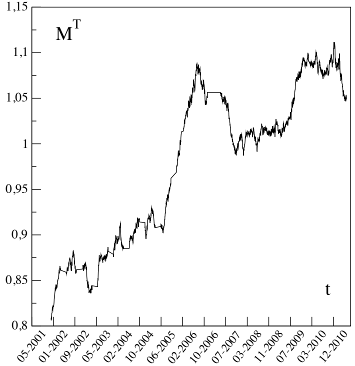

Figure: MI shared by all maturities.

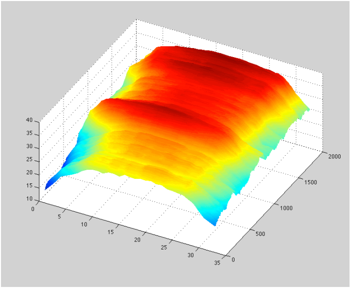

Figure: MI per maturity

More intense cross maturity linkages: market segmentation diminishes.
Asymmetry in the average MI: it is higher on the long-term.

Information flows: static analysis

Information emitted (in black) and received (in red) by each maturity

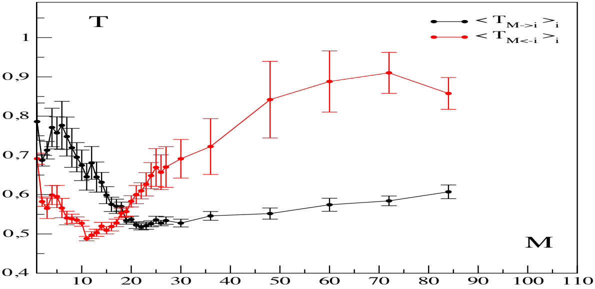

Figure: Average information transfer between maturities, 2001-2011

Market segmentation is not necessarily the same for the information emitted and received.

Information flows: forward and backward flows

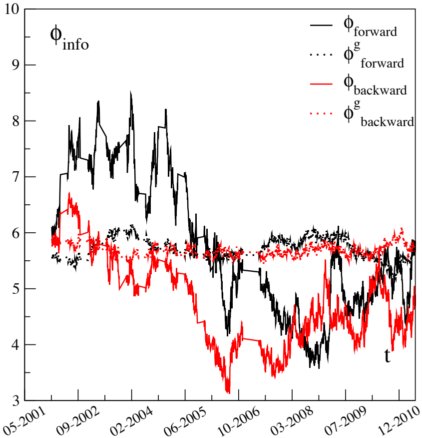

Figure: Information transfer between maturities, 2001-2011

Directed graph and its dynamic properties

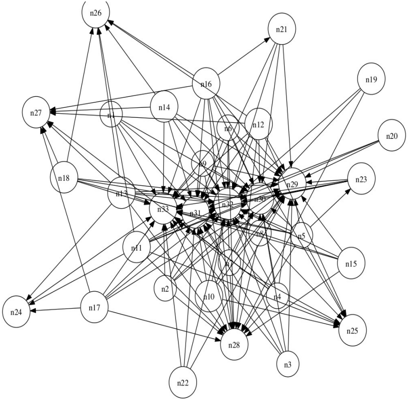

Figure: Directed graph

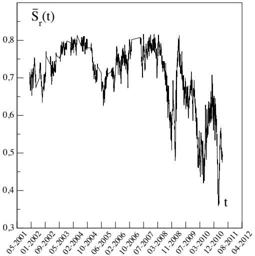

Figure: Survival ratios

Conclusion (1/2)

Main findings

- The information shared by futures contracts with different delivery dates is increasing;
- On average on the period, short-term maturities emit more information than long-term ones;
- Today, this is less obvious: price movements can now propagate as easily in the forward direction as in the backward one;
- The direction of information flows is less and less stable.

This raises theoretical questions.

- Segmentation theory
- Samuelson effect

Conclusion (2/2)

Samuelson effect (1965):

- Short-term prices are more volatile than long-term ones. A shock coming from the physical market affects mainly the nearby contract price. It has an impact on succeeding prices that decreases as maturity increases.
- Forward flows are the natural direction for the propagation of prices shocks: the volatility comes from the physical market; it is transmitted to the paper market.

For a reappraisal of the Samuelson effect:

- Today backward flows are becoming important: shocks can come from the paper market.
- This is not necessarily due to speculation and financial activity
- Sudden changes in the physical conditions expected in the long run
- The expectations of the operators are embedded in the prices of deferred futures contracts.

Reappraisal of the Samuelson effect : an intuition

Bessembinder et al (1996)
Notations:
- Prices shock u_t:

$$u_t = \ln \left(\frac{S_{t+1}}{E_t[S_{t+1}]} \right) \quad (1)$$

In this setting, prices shocks always appear on the physical market, on the *current* spot price.
After a shock has impacted the physical market at t, the operators expect it to influence prices in T.
- Rate of revision in the expectation, "elasticity":

$$\epsilon_{t,\tau} = \frac{\ln \left(\frac{E_{t+1}[S_T]}{E_t[S_T]} \right)}{u_t} \quad (2)$$

Equilibrium relationships on the physical and the futures markets

For the futures market:

$$F_{t,T} = S_t \exp\left(cc_t(T-t)\right) \tag{3}$$

where cc_t is the net cost of carry.
For the physical market:

$$E_t[S_T] = S_t \exp\left((cc_t + \pi)(T-t)\right) \tag{4}$$

where π is the risk premium associated to the holding of the commodity.
Propagation of prices shocks from the physical to the paper markets:
From (3) we can write:

$$\Delta F_{t,T} = \pi + u_t \epsilon_{t,\tau} \tag{5}$$

Thus:

$$Var[\Delta F_{t,T}] = \epsilon^2_{t,\tau} Var[u_t] \tag{6}$$

Introducing long term shocks(1)

Suppose that L is the longest maturity on the paper market. There is a shock $v_{t,L}$ on this maturity:

$$v_{t,L} = \ln\left(\frac{F_{t+1,L}}{E_t[F_{t+1,L}]}\right) \tag{7}$$

This shock is transmitted along the prices curve; there is a backward move. At the intermediate maturity L-M:

$$v_{t,L-M} = \ln\left(\frac{F_{t+1,L-M}}{E_t[F_{t+1,L-M}]}\right)$$

If it is transmitted in a proportion η, we will have:

$$\eta_{t,L-M} = \frac{v_{t,L-M}}{v_{t,L}} \tag{8}$$

η can be seen as an elasticity in the maturity dimension.

Introducing long term shocks(2)

If the shock goes until the spot market we will have:

$$\eta_{t,0} = \frac{u_t}{v_{t,L}}$$

Introducing this relation into equation (6), we obtain:

$$Var[\Delta F_{t,T}] = \epsilon^2_{t,\tau} \eta^2_{t,0} Var[v_{t,L}] \quad (9)$$

If market integration is strong, $\eta_{t,0}$ tends towards 1.
There might be backward flows, coming from the paper market and still, a prices behavior that is alike the Samuelson effect.