Shock Propagation Across the Futures Term Structure: Evidence from Crude Oil Prices

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a) motivations underlying the research

To what extent are commodity prices interconnected across the futures curve? Where in the term structure do shocks originate – and which other parts of the term structure do they reach? Is the direction of price shock propagation stable over time? We seek answers to those questions.

b) short account of the research performed

We investigate market integration and the propagation of price shocks empirically through the prism of information theory. Our laboratory is the New York Mercantile Exchange's (NYMEX) market for West Texas Intermediate (WTI) light sweet crude oil futures. This market provides an ideal setting for our analysis: among all commodity markets in 2000-2017, WTI futures boast the highest level of trading activity together with the greatest number of far-out delivery dates.

First, we use the concept of "mutual information" to investigate futures market integration across maturities. When two variables are interdependent, the mutual information measures the amount of entropy that is reduced (i.e., the amount of uncertainty that is resolved) compared to the case where the two variables are independent. Computing the mutual information between contracts is thus analogous to assessing their integration or return co-movements. Our approach, however, does not require making assumptions about the relationship between the variables.

Second, we investigate the propagation of price shocks across the futures term structure, relying on the concept of "transfer entropy" (Schreiber, 2000) that allows for dynamic analyses and for the determination of directionality. We introduce the concepts of "forward" and "backward information flows" and ascertain if price shocks evolve from short-term to long-term maturities or *vice versa*. Our approach is non-parametric and accommodates non-linearities – a key advantage given prior evidence that shock propagation dynamics are non-linear.

Finally, we utilize net transfer entropies to define a new metric that lets us construct a novel type of directed graph linking all the maturities in the term structure. The latter comprises hundreds of components that may interact in various ways. Graph theory provides a powerful visualization tool – as well as a means to detect anomalies – for our high-dimensional data. We use our directed graphs to examine precisely where the information entropy is transferred in the futures price system, and how far across the term structure it flows in practice.

c) main conclusions

We find large variations over time in the amount of mutual information shared by WTI futures with different delivery dates. In general, intermediate-maturity contracts (six months to two years) share relatively more mutual information than other contracts do. For all contracts, the

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levels of cross-maturity mutual information increases dramatically after 2003 (amid tight crude supplies, a dramatic growth in long-dated crude oil futures trading, and the onset of commodity markets' financialization) and reaches a peak at the top of the oil price boom in summer 2008. It falls back sharply in 2012 (to pre-2005 levels) and drops further in 2013 and 2014 (to pre-2002 levels). It has since recovered dramatically. Taken together, these term-structure findings point to a puzzling re-segmentation by maturity of the WTI market in 2012-2014.

On average in 2000-2017, contracts up to 21 months emit more information entropy than do further-out futures. A dynamic analysis, though, reveals that the amount of entropy emitted by other parts of the curve is non-trivial and can be high at times. Moreover, the overall direction of the entropy transfers is not stable over time. In particular, an analysis of information entropy flows that run "forward" (i.e., from near-dated to further-out maturities) *vs*. "backward" (i.e., from backdated to nearer-dated contracts) shows that the backward flows are actually *higher* than their forward counterparts in 2008, i.e., during a 12-month period encompassing the peak of the 2007-2008 oil price boom and the subsequent price collapse after the Lehman crisis.

The average directed graph, estimated for 2000-2017, supports a conventional view of how a futures market operates – specifically, the notion that price shocks are thought to form in the physical market (here represented by short maturities) and transmit to the paper market (here made up of further-out contracts). Yet, we also find that intermediate maturities send out information entropy to further-dated contracts as well as to near-dated ones. Furthermore, a dynamic analysis shows that there are sometimes major changes in the organization of cross-maturity connections. The biggest such rearrangement is in Fall 2008, with the direction of the information flows "flipping" entirely (i.e., originating at the far end of the curve and reaching even the shortest maturities). While this kind of reverse information-flow pattern is theoretically conceivable, our analysis provides the first empirical evidence of their existence.

d) potential benefits, applications and policy implications of the work

New research using regulatory trading data is needed to ascertain whether the re-segmentation of the WTI market in 2012-2014, which we document in this paper, stems from physical-market developments (maybe those that caused a concomitant surge of the Brent-WTI price spread) or, alternatively, if it is due to some key market participants' pulling back from the back end of the WTI futures curve (perhaps due to the onset of costlier regulatory requirements).

Next, new micro-founded dynamic theoretical models are needed, in which multiple futures maturities trade simultaneously, in order to generate the bi-directional information flows across the term structure that our analysis reveals. On the empirical side, the methodology we propose raises tantalizing possibilities of applications in the realm of return predictability.

Finally, a debate has long raged regarding the extent to which the financialization of commodity markets is responsible for the 2007-2008 crude oil price boom. Extant bubble studies focus on the spot or nearby futures prices. Our finding that the three nearest-dated WTI futures turn almost silent during that entire episode and, instead of emitting information, start receiving net entropy transfers from even the furthest-out contracts, indicates that any analysis of the 2007-2008 boom/bust should consider the possible impact of financialization on all the components of a term structure — not just its front end.