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Cyclical behavior of crude oil markets and economic recessions in the period 1986–2010

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ABSTRACT

For at least one century, crude oil has been one of the most important commodities for the worldwide economic activity. Important technological innovations, including chemical transformation processes and transportation systems, have been based on the availability or not of crude oil. In this way, a close understanding of the crude oil market dynamics should provide insights in important aspects related to potential directions of technological change for both improving crude oil transformation efficiency and substitution by alternative energy sources. This paper studies the dynamics of the crude oil price for the period from 1986 to 2010. To this end, the entropy time-asymmetry is computed along the price trajectory. Empirical results indicated the presence of a non-regular cyclical behavior with a dominant period of about 4.5 years. Some evidences pointing toward a comovement of entropy time-asymmetry peaks with major US economic recessions are found, suggesting a tight relationship between macroeconomy and crude oil prices. The results are discussed in terms of the major economic events that occurred in the upward and downward cycle periods and potential implications for the design of energy policies.

1. Introduction

Crude oil is one of the most important commodities for the global economy. The current global reserves of crude oil are estimated to be at about 1.3 trillion barrels, whereas annual oil consumption is around 31 billion barrels (CIA factbook). Crude oil is used as one of the most important energy inputs after chemical transformations to produce fuels for almost every transportation sector. Some residuals from the chemical transformation of crude oil are used in thermoelectric installations for the production of electrical power. On the other hand, given its content of a wide variety of hydrocarbon compounds, crude oil is the main source of basic bricks (e.g., linear and aromatic hydrocarbons) for the manufacturing of intermediate and final products used in everyday economic activity. In this way, the crude oil production and commercialization mechanisms should reflect, to some extent, the intensity and structure of several sectors of contemporaneous economy. Coccia [1] has remarked that energy metrics based on crude oil consumption support the monitoring of energy and economic system performances in order to design effective energy strategy and political economy interventions focused on the competitive advantage increase of countries in modern economies.

At least in the last century, crude oil has been one of the motors for technological innovation in transportation, energy and chemical sectors [2]. The massive use of automobiles and the fabrication of domestic and industrial goods along 20th Century cannot be conceived without the technological developments oriented to exploit crude oil as a primary source of energy and manufacturing commodity. On the other hand, the perceptions in recent years that cheap crude oil reserves and production is in

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the downturn phase of the Hubbert curve [3] and the use of crude oil products accelerated the climate change [4] have motivated intense research on new technologies for crude oil substitution by, e.g., non-conventional oil sources [5]. However, recent studies have suggested that full crude oil substitution will last about 100–150 years [6,7]. This means that the usage and trading of crude oil and secondary products will be affecting, either positively or negatively, the outcome of the technological innovation by designing more efficient transformation processes or exploiting and developing other energy sources.

Given its central importance for the global activity, there is a long history of research in the characterization of the dynamics of crude oil markets. Many studies focused on the relationships between crude oil prices and economic activity (see, for instance, [8–16]). Some results point towards a direct effect of crude oil prices in the dynamics of economic activity. For instance, Hamilton [9] showed that all but one of the US recessions since the World War II have been Granger-preceded by dramatic price increments. Mork [17] extended Hamilton's results by showing that price asymmetry has an important effect in the directionality of the economy. Cuñado and Perez de Gracia [18] found that oil prices have permanent effects on inflation and short run but asymmetric effects on production growth rates. Oladosu [16] used empirical mode decomposition methods to show the eventuality of persistent oil price and economic decline following a long oil price run-up. Other studies have challenged the notion that movements of crude oil prices have significant effects in macroeconomy variables. For instance, it has been argued that oil price shocks are unlikely to induce a significative effect in the US macroeconomy [9,16] and that the adverse effects of positive shocks can be explained from the resulting tightening of monetary policy [19].

Summing up, the crude oil market is a complex system that is closely linked to modern economic and technological dynamics. As a complex system, different approaches and methods have been tried to explain observed phenomena, model price dynamics and optimize trading mechanisms. In this way, it should be accepted that no single methodology is sufficient to study crude oil markets and so a variety of theories and methods should provide a more comprehensive view of the system structure and dynamics. The importance of studying the crude oil market dynamics relies on the fact that, as crude oil still one of the most important energy sources, some important insights in the evolution of social change can be drawn from the study of the structure and evolution of the crude oil market.

This paper uses entropy time-asymmetry analysis, an approach borrowed from information theory, to study the dynamics of crude oil prices. By the effects of shocks and regime changes, the crude oil market can be considered as operating out-of-equilibrium conditions. In this way, the application of entropy time-asymmetry concept to characterize the effects of shocks and intrinsic dynamics can provide interesting results that have not obtained with previously used empirical methods. The empirical results reported in this paper for the period from 1986 to 2010, obtained from a sliding window implementation of the entropy algorithm, can be described as follows:

- The time-asymmetry fluctuations present a dominant period of about 4.5 years, which is within the range of the so-called Kitchin inventory cycles [20]. To the best of our knowledge, no previous work has reported the existence of such a cycle in the dynamics of crude oil prices.
- The peaks or downward segments of the entropy time-asymmetry cycles are in comovement with the occurrence of major economic recessions in the scrutinized period. After the occurrence of an economic recession, the entropy time-asymmetry exhibits a gradual decrement to negative values associated with a contraction of the market complexity.

Further analysis reveals that the in-phase behavior of entropy time-asymmetry and recessions is not constrained to recession periods, but it extends to the 85% of the analyzed period. The rest of the paper is organized as follows. Section 2 describes the entropy methodology and the extension to the standard approximate entropy algorithm [21] to compute time-asymmetries in time series. Section 3 describes the data. Sections 4 to 5 describe and discuss the results. The last section provides the main conclusions of the paper.

2. Approximate entropy

Entropy is a widely used concept to quantify disorder and uncertainty of dynamic systems. Microscopically, entropy can be related to the number of configurations that a system can reach for a very large set of trajectories. In this way, Shannon and Kolmogorov-Sinai entropy concepts are oriented to characterize the gain of information by providing a measure of disorder and uncertainty. In particular, the Kolmogorov-Sinai entropy is an index which indicates the exponential rate at which information is obtained as long as the system is dynamically perturbed. That is, entropy per unit time is related to the minimum number of bits (digits or nats) required to record the time series during one time unit. The application of these concepts requires, in principle, an infinite data series with infinitely accurate precision and resolution [22]. However, measurements for real systems are sampled with resolution ε and sampling time T_s, which involve only finite data series. Pincus [21] introduced the approximate entropy statistics to quantify regularity of time series of finite length. The approximate entropy (AE) computations are based on the likelihood that templates in the time series which are similar and remains similar on next incremental comparisons. Time series with large AE must have substantial fluctuation of irregularity. Given its simplicity from both conceptual and algorithmic standpoints, AE has found sound application in many science and engineering fields, including physiology [21,23], geosciences [24] and financial systems [25]. A typical application of entropy analysis is to use the algorithms to compute a regularity measure on a time series and then to use that computed value to classify the time series as being of one type or another.

The AE computation algorithm can be described as follows [21]. Consider a finite time series of length N sampled at small time intervals T_s,$\{X_i\}=\{x_1, x_2 \ldots, x_N\}$, where $x_i = x(t_0 + iT_s)$. The length N defines a time scale $\tau = NT_s$. Introduce two m-dimensional