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Regression analysis of historic oil prices: A basis for future mean reversion price scenarios

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ABSTRACT

We propose price forecasting algorithms based on regression analysis of historic oil prices over 150 years (1861–2012). From 1986 onward daily market prices allow more detailed analyses of the principal crude oil benchmarks (West Texas Intermediate [WTI] and Brent). The mean reversion price for a given time period corresponds to the marginal cost of supply. When supply and demand are out of equilibrium, spot prices move in a bandwidth bound at the bottom by cash cost of supply and at the top by the concurrent price of demand destruction. Short-term elasticity of demand is 0.015 (highly inelastic), and long-term elasticity of supply changed from 0.99 (highly elastic) during 1965–1983 to 0.39 (less elastic) during 1984–2012. We derive functions for the long-term equilibrium price and expand them into scalable equilibrium price functions for forecasting future price scenarios if “business-as-usual” is assumed. We also consider how two hypothetical black swan events (“unknown unknowns”) may affect the mean equilibrium price.

1. Introduction

The past decade included two unanticipated, steep oil price falls: one in late 2008 and early 2009, and a second that started in August 2014 and seemed to bottom out several times during 2015 but reached a new low in February 2016 to slowly rebound to about $50 per barrel at the end of 2016. Such price shocks tend to take oil and gas companies by surprise, impairing their business performance. As we document below, petroleum companies taking final investment decisions on mega-projects became accustomed to a decline in oil price volatility until mid-2014, and many assumed they could count on sustained high oil prices of $100 + /bbl well into the future.

For industry, the increased volatility of crude oil spot prices raises concerns and uncertainty about the appropriate reference price to use in approving new field development projects. Steeper commodity price swings lower the reference price, so that fewer of the screened projects will pass the corporate hurdle rate test. Commodity price shocks may affect the business planning and operations of petroleum companies in various ways:

- Past and current increases in the volatility of commodity prices increase uncertainty about what oil price should be used in estimations of net present value and internal rate of return to validate new investment decisions on long-term field development.
- Upward price shocks may convert contingent resources (hitherto uneconomic) into “proved reserves ready for future extraction,” merely in compliance with requirements to report reserves.
- Similarly but in the reverse direction, rapid price falls may decrease the nominal value of proved reserves in obligatory

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operational and financial reporting (e.g., to the SEC), affecting the company's balance sheet. Such decreases may even trigger bank borrowing base redeterminations and recall of revolving credit, leading to bankruptcy due to debt restructuring under Chapter 11 (and reemergence after restructuring, as has frequently occurred in the U.S. market over the past few years; see references in Section 5.1).

- Increased volatility in concurrent oil and gas prices increases the uncertainty range in fair-value assessments of oil and gas properties, making M&A price offers more dependent on forecasts of commodity prices.
- When spot price volatility decreases, projections of oil prices (and oil-indexed natural gas prices) stay in a narrower price deck, which tends to reduce concerns about future price volatility in corporate investment decisions.
- Oil and gas price movements are also relevant for hedging decisions of petroleum companies that use derivatives to mitigate adverse trends in future delivery prices.

The recent volatility of oil prices not only increases uncertainty about corporate earnings and project evaluations for companies, but also erodes tax revenue for governments (Weijermars, 2015). A better understanding of oil pricing mechanisms (micro-economics) is critical for anticipating their effects on the global economy (macro-economics) for as long as oil remains a major fuel in the world's pool of primary energy resources (Kumhof & Muir, 2012, 2014; Roeger, 2005). About 45% of 2015 global oil production is used to feed refineries that produce a range of transportation fuels (kerosene, diesel, gasoline, etc.). And, of course, oil is also used as fuel for electricity generation in power plants, as industrial feedstock, and as home heating fuel.

The steep 2014–2016 decline in oil spot prices has renewed industry awareness of the need to hedge the business against future oil price volatility. Oil price models provide essential support for decision-making in the upstream hydrocarbon industry. Numerous studies of oil price dynamics are available (Al-Qahtani, 2008; Alquist & Guénette, 2014; Alquist, Kilian, & Vigfusson, 2011; Baumeister & Kilian, 2012; Benes et al., 2012; Manescu & Robays, 2014; Miltersen, 2002; Pagano & Pisani, 2009). The idea of mean reversion of the oil price to a (varying) trendline has been discussed at length by Pindyck (1999). However, since that groundbreaking work, > 15 years of additional market dynamics have become available to be captured in time series. Our study provides equations for the mean reversion price (and restoration to the mean reversion price), including the recent period when major market agents caused short-term price shocks owing to supply-demand disequilibrium. The mean reversion price formulas established in our regression analysis of historic prices also update Slade's (1982) oil price regression. Our analysis accounts for the emergent share of unconventional resources (such as shale) in the global petroleum supply system, and for the general upward drift in the marginal cost of supply since the 1990s as extraction technology has become more costly. The regression analysis of historic oil prices over 150 years in our study places the development of the long-term mean reversion oil price in perspective. We derive equations for the time-dependent equilibrium supply rate by including the rising cost of marginal supply based on detailed price data available from 1986 onward.

Pindyck (1999, 2001) has emphasized that structural models of supply and demand can be linked to mean-reverting price trendlines only when the long-term marginal cost of supply is taken into account. Although many factors may affect marginal cost of supply, it rises when a resource gets scarcer and extraction technology innovations are slow in catching up. In spite of technology innovations, the cost of petroleum exploration and production gradually increases (Weijermars, Clint, & Pyle, 2014), because the bulk of conventional hydrocarbon resources remaining in the twenty-first century are located in physically and politically more hostile environments, and technology innovations that significantly reduce resource development cost occur relatively slowly. For example, deep-water and Arctic projects require expensive advanced technology. Increased political risk commonly means that a higher hurdle rate is adopted for project approval, so that only the larger deposits are extracted.

The current (2014–2017) low oil price regime is due to the oversupply policy of the dominant market firm (Saudi Aramco, backed up by its government owner and OPEC) in response to U.S. technology innovations during the past decade (i.e., fracking and horizontal drilling of shale formations; Weijermars et al., 2017; Weijermars, Sorek, Seng, & Ayers, 2017), which have added a significant new oil supply stream to the global market. How that development will play out and affect the future mean reversion price of oil can be further modeled from our analysis and the equations we derive.

This study is organized as follows. Section 2 details a comprehensive series of regression analyses (long-term, short-term) for the primary global oil price benchmarks (Brent and WTI). Certain subsections highlight decadal variations in price volatility and provide a basis for the updated mean reversion price trend-line for oil. The stark contrast between long-term and short-term price elasticity is highlighted here for the first time (Section 2.6). The long-term cost escalation is further analyzed in Section 3 and captured in our updated model for the mean reversion price. Section 4 provides examples of how our price model can be applied in price projections, using certain specific assumptions. Section 5 offers a discussion, and Section 6 formulates brief conclusions.

2. Analysis of historic oil prices

We analyze past realizations of crude oil prices in the commodity market, applying regressions, probability density functions, kernel smoothing, and volatility to quantify the dynamics of oil prices for various periods. Price volatility was modest in the 1980s and 1990s, but increased in later decades. Past price volatility helps to construct models for possible future price scenarios to aid decision-making, but any such prediction involves assumptions about constraints on future market dynamics (see Section 6).

Our price data sources are as follows. For historic world oil prices (1861–present) we use annual production data (BP, 2015; OPEC, 2015). From 1986 onward daily time-series of WTI and Brent spot prices are readily available. WTI remains the benchmark price for North American operators, and we analyze in detail daily WTI spot prices (1986–present) and monthly domestic production data (1986–present; EIA data sets; WTI, 2015). The prices of WTI futures (trading on NYMEX since 1983; see WTI Futures, 2015) and