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# Stationarity changes in long-run energy commodity prices☆

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ABSTRACT

Situated at the intersection of the literatures on speculative storage and non-renewable commodity scarcity, this paper considers whether changes in persistence have occurred in long-run U.S. prices of the energy commodities crude oil, natural gas and bituminous coal. We allow for a structural break when testing for a break in persistence to avoid a change in the stochastic properties of prices being confounded by an unaccounted-for deterministic shift in the price series. We find that coal prices are trend stationary throughout their evolution and that oil prices change from stationarity to non-stationarity in the decade between the late 1960s to late 1970s. The result on gas prices is ambiguous. Our results demonstrate the importance of accounting for a possible structural shift when testing for breaks in persistence, while being robust to the exact date of the structural break. Based on our analysis we caution against viewing long-run energy commodity prices as being non-stationary and conclude in favor of modeling commodity market fundamentals as stationary, meaning that speculative storage will tend to have a dampening effect on prices. We also cannot reject that long-run prices of coal and, with some hesitation, gas follow a Hotelling-type rule. In contrast, we reject the Hotelling rule for oil prices since the late 1960s/early 1970s.



## 1. Introduction

One of the key features of long-run commodity prices is strong autocorrelation, meaning that the effects of shocks to prices persist into the future. There has been substantial debate in the literature over the extent of this memory: If it is less than perfect, prices will be stationary around a deterministic trend, whereas with perfect memory they are non-stationary, i.e. they contain a stochastic trend. Determining the extent of memory in commodity prices is relevant for understanding the fundamentals of the underlying commodity markets. Stationarity properties of prices are of importance to the theory on speculative storage, as they inform the modeling of the underlying supply and demand processes. An integrated price process may be the consequence of rigidities in the underlying fundamentals of each commodity market, e.g. due to the existence of market power on the supply side in the context of strong demand growth, and the strategic decision by suppliers of commodities to not satisfy demand at every level (Dvir and Rogoff, 2009, 2014). Such behavior is sometimes ascribed to the OPEC in the case of crude oil market. Since circumstances in which such rigidities exist are typically temporary, it may be that prices move from stationarity to non-stationarity and vice versa. Understanding stationarity is also relevant for the empirical examination of non-renewable resource scarcity, which seeks to test whether long-run prices follow a deterministic trend to evaluate if prices are consistent with the predictions of a Hotelling (1931) type model.

The theoretical literature linking highly auto-correlated commodity prices to the underlying market structure is well-established. Deaton and Laroque (1992) combine independently and identically distributed (i.i.d) demand and supply processes with a risk-neutral commodity speculator so that speculative storage introduces autocorrelation in commodity prices even with i.i.d. underlying market fundamentals. However, the high degree of autocorrelation observed in actual price data can only be matched by modeling demand

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and supply as long-memory AR(1) processes (Deaton and Laroque, 1996).[1] Dvir and Rogoff (2009) extend the model by allowing for the possibility of non-stationary commodity demand. They find that storage may exacerbate price volatility, whereas in the standard storage model it dampens price variability. Whether prices are stationary or not is relevant to this literature, as it may necessitate the introduction of non-stationarity when modeling market fundamentals.

A substantial empirical literature in the area of resource scarcity is devoted to determining whether long-run prices follow a Hotelling (1931) type rule. If prices are determined as predicted by a Hotelling-type model, prices should increase at the respective discount rate. Thus, the literature tests whether long-run commodity prices are stationary around a deterministic trend (Slade, 1982). The evidence on the stationarity of long-run commodity prices based on this literature is inconclusive. Pindyck (1999) analyzes the price paths of bituminous coal, crude oil and natural gas and finds shifting quadratic trends in the data, while Kaufmann et al. (2004) focus on oil prices and find them to be non-stationary. Slade (1988) and Berck and Roberts (1996) evaluate a number of commodity price series and find that they are mostly non-stationary, while Ahrens and Sharma (1997) conclude that the evidence on stationarity is mixed. Using the same data and applying the unit root test by Lee and Strazicich (2003), Lee et al. (2006) find evidence in favor of trend stationarity. However, the tests used in this literature assume that each price series is stable with respect to its stationarity properties over the entire sample period, i.e. that it is either stationary or non-stationary throughout.

This assumption can be relaxed by using recent developments in the methodology literature on stationarity testing, based on the work by Kwiatkowski et al. (1992). Stationarity testing has evolved to allow for a test of the null hypothesis of (trend) stationarity over the entire sample period against the alternative that a change has occurred from stationarity to non-stationarity, as well as to determine the period in which the change has occurred (Kim, 2000; Kim et al., 2002; Busetti and Taylor, 2004).

This paper contributes to both the storage and scarcity literatures by providing empirical evidence on the stationarity of long-run energy commodity prices. We apply recent advances in stationarity testing to annual U.S. price data for crude oil, bituminous coal and natural gas from the 19th to the early 21st century. Based on an initial descriptive analysis we hypothesize that long-run prices of all three commodities may have shifted from stationarity to non-stationarity during the 20th century. Such a shift from a stationary to an integrated process would indicate a change in the underlying fundamentals of the commodity market in question, e.g. towards a highly autocorrelated supply process (Deaton and Laroque, 1996; Dvir and Rogoff, 2009, 2014). We then proceed in two steps: First, we test whether each price series has moved from stationarity to non-stationarity at some point during its evolution assuming that no structural breaks have occurred in prices. However, as shown by Perron (1989) the presence of a neglected structural break can bias any such test towards finding a unit root. Thus, in a second step, we eliminate this source of bias by allowing for an exogenous structural break while testing for a break in stationarity, i.e. we allow for changes in the deterministic components of the underlying model. In order to specify the time period for the structural break we test for the presence of a structural break in both constant and trend using the tests developed by Perron and Zhu (2005), Perron and Yabu (2009a) and Perron and Yabu (2009b).[2] We find strong evidence for structural breaks in 1973 for bituminous coal prices and in 1997 for crude oil prices, while there is weaker evidence for a structural break in 1976 for natural gas prices. For robustness we also consider a range of further potential structural break years from the existing literature (Perron, 1989; Kaufmann, 1995; Ahrens and Sharma, 1997; Lee et al., 2006). Comparing results from the two steps enables us to evaluate the importance of introducing this robustification.

The test without a structural break yields that all three series exhibit a change from trend stationarity to non-stationarity. However, once we allow for a structural break our results diverge, confirming that introducing the second-step robustification is important. We can no longer reject that bituminous coal prices are trend stationary throughout their sample period. We still find that crude oil prices change from trend stationarity to non-stationarity, confirming the result by Dvir and Rogoff (2009). The changes in persistence for the case of crude oil are all estimated to have occurred around the 1970s, a period in which OPEC rose to prominence, depending on the structural break year chosen. In the context of the storage literature this finding suggests that rigidities on the supply side of the oil market introduced by OPEC are reflected in an integrated price series. In contrast, we find no evidence of such rigidities in the case of bituminous coal. The coal price series is trend stationary, consistent with predictions from the scarcity literature. The result for natural gas prices is ambiguous, also due to fewer observations in the gas price series, as the case for specifying a structural break is weaker than for coal and oil. Once we do include a structural break the evidence in the case of natural gas prices is also in favor of trend-stationarity. Overall, our results are robust to the choice of the specific structural break period, i.e. they do not depend exclusively on choosing the structural break points based on our estimation of the structural break point, but also hold for the structural break years suggested by the literature (Perron, 1989; Kaufmann, 1995; Ahrens and Sharma, 1997; Lee et al., 2006).

Our overall results caution against abandoning the approach by Deaton and Laroque (1996) of modeling supply and demand as stationary AR(1) processes in favor of concluding that far-reaching regime changes have occurred in the nature of market fundamentals during the latter part of the 20th century, e.g. towards non-stationary demand in combination with market power on the supply side. Including just one structural break is sufficient to clearly conclude against non-stationarity of prices for two out of the three commodity price series considered, although some evidence for a break in stationarity in the case of crude oil prices remains. Thus, we cannot reject that speculation, at least as specified in the competitive storage literature, continues to play a secondary role in price formation compared to market fundamentals.

With respect to the scarcity literature we find diverging evidence for the three commodities. The results for coal prices and, with somewhat less confidence, on gas prices suggest that prices of these energy commodities follow a deterministic trend in the long run, consistent with the findings of Slade (1982) and Pindyck (1999), although this trend may be subject to rare deterministic shifts. This result establishes that the long-run trajectory of gas and coal prices may be consistent with a Hotelling (1931) type rule, although the evidence is far from conclusive. For crude oil prices we clearly reject a deterministic trend, in line with Kaufmann et al. (2004) and the evidence cited in Watkins (1992). We therefore do not find evidence of the Hotelling principle at work in oil prices.

Finally, the results from this paper are related to an important stream of empirical literature testing for energy commodity market integration based on cointegration methods. The overall evidence in this literature is in favor of significant integration between oil and gas markets (Serletis and Rangel-Ruiz, 2004; Villar and Joutz, 2006; Panagiotidis and Rutledge, 2007; Kaufmann et al., 2009), while there is limited evidence of integration of coal markets with the other two energy commodity markets (Bachmeier and Griffin, 2006;

[1] Deaton and Laroque (1996) argue that demand may be more prominent as a driving force of price formation than supply. This view is consistent with empirical evidence provided by Kilian (2009) on the prominent role of demand shocks in determining oil prices in recent decades.

[2] We thank two anonymous referees for this valuable suggestion.