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The Dynamic Properties of Natural Resource Prices

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Abstract:

Whether the trends in natural resource prices are stochastic or deterministic remains a contentious issue. A number of studies have employed unit root tests that determine the order of integration of the price series which in turn allows us to infer whether or not prices contain a stochastic trend. While earlier studies have delivered mixed results, the more recent studies have rejected that natural resource prices contain a stochastic trend and are therefore not persistent to shocks. However, a drawback with these studies is the assumption that the underlying model is linear, as integration is a linear concept. Since theoretical papers have argued that prices are likely to be nonlinear, the existing definitions of integrability do not apply. This paper employs a new concept, summability, which is a generalisation of integrability. A further contribution is made by updating the data. This is timely and topical given the upheavals that have occurred in natural resource prices in recent years. The conclusions show that the results are sensitive to the sample size and the underlying nonlinearity in prices. We conclude that the dynamic properties of individual natural resource prices differ and each price should be evaluated on an individual basis.

Acknowledegment:

JEL Codes: Q31, Q32

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JEL Codes: C18; C22; Q02; Q31

Keywords: Natural Resource Prices; Integration; Summability; Non-linearity.

The Dynamic Properties of Natural Resource Prices

I. Introduction

Over the years there has been a growing interest to determine whether non-renewable natural resource prices contain stochastic or deterministic trends (e.g. Presno et. al. 2014, Lee et. al. 2006, Ahrens and Sharma 1997, Berck and Roberts 1996). The finding of a stochastic trend in natural resource prices will lead one to believe that shocks to such prices would be highly persistent in nature, while the finding of a deterministic trend would lead one to conclude that shocks to the prices would be transitory. This issue of the nature of persistence in natural resource prices is of importance for several reasons as highlighted by Lee et. al. (2006). First, economic models lend support to the view that the path of natural resource prices tends to be systematic and hence trend stationary (Slade 1988). However, the demand, reserves and extraction costs for non-renewable resources can fluctuate considerably and unpredictably, thereby leaving the nature of persistence in the prices of natural resources an empirical question (Pindyck 1999). Secondly, it is important to know the time series properties of the trend in non-renewable resource prices so that well specified economic models and statistical regression analysis along with appropriate hypothesis testing can be carried out (Phillips 1986). Thirdly, knowledge of the nature of persistence in non-renewable resource prices are imperative for sound economic forecasting, which in turn helps policy makers (Diebold and Senhadji 1996, Diebold and Kilian 2000). The evidence so far on the persistence of natural resource prices has been mixed. We argue that the extant studies on this topic have overlooked a potential feature of natural resource prices and this paper addresses this issue when investigating whether shocks to non-renewable resource prices are persistent or transitory in nature.

The seminal study by Slade (1982) provides theoretical underpinnings to suggest that the dynamics of natural resource prices can be described as nonlinear. This possible nonlinearity in natural resource prices has been overlooked in recent empirical studies when considering the issue of the order of integration of such nonlinear time series processes. In a recent paper, Berenguer-Rico and Gonzalo (2014) have stated, that “integration is a linear concept” and therefore the existing definition of integrability do not apply to natural resource prices which have been described to contain nonlinear time paths based on economic theory. As pointed out by Granger (1995) this would not only affect econometricians, but also economic theorists who need to know the nature of the time paths of economic variables to construct their theoretical models. Natural resource prices is a case in point. Berenguer-Rico and Gonzalo (2014) show that summability is a generalisation of integrability in the sense that the order of summability is synonymous with the order of integration. This paper makes two distinct contributions to this area. First, we apply the concept of summability to establish whether shocks to natural resource prices are persistent or not, after testing and establishing that most of the prices considered are nonlinear. Secondly, we extend the popular database that has been used in several prominent studies. The popular data set comprises of eleven commodity prices that span a period from 1870 to 1990. In this study we extend the same set of commodity prices to 2014[1]. This extended data beyond 1990 is timely and called for, given the large upheavals that have dominated the time path of natural resource prices especially with respect to minerals (Livernois 2009).

The origins of non-renewable resource prices can be traced back to the classic paper by Hotelling (1931) where the principle result, coined as ‘Hotelling Rule’ is that the net price of non-renewable resources will rise with the rate of interest in a competitive market. Intuitively,

[1] The only exception is iron for which no data was available.

this rule is expected to hold as the present value of the net price that could be received from selling in some periods would be higher than in other periods. This rule continues to provide theoretical underpinnings for the economics of natural resources. However, the empirical evidence of this rule has been weak. This could be due to the fact that the basic rule is overly simplistic. For example, extraction costs can increase as the natural resource is extracted. This can occur within an individual deposit as the firm digs or drills deeper to extract the resource. Alternatively at an industry level, the deposits that are least costly to extract are extracted first before moving on to more expensive extraction. Under these circumstances of increasing extraction costs, one would expect the price to increase at a slower rate than the rate of interest in a competitive equilibrium. Even in imperfect competition the net price may still increase at a slower rate than the interest rate but less rapidly than under perfect competition (Livernois 2009). While the Hotelling Rule is deterministic, the real world is uncertain (Slade 1992). Unknown initial stocks of reserves, stochastic discoveries of new supplies are examples of uncertainty which can affect the dynamics of natural resource prices by causing these prices to be stochastic. Uncertainty may lead to the breakdown of the Hotelling Rule as expected prices may not increase at the rate of interest. Alternatively the efficient market hypothesis can explain the behaviour of many natural resource commodity prices. The Efficient Market hypothesis states that the market for a commodity is efficient when new information is incorporated in to the prices. If not, there would be opportunities for arbitrage. This new information cannot be forecast and is therefore uncorrelated with any past information.

The crux of these arguments is that the basic model of Hotelling leads to non-renewable prices being trend stationary given the deterministic nature of the model. Alternatively, when introducing uncertainty to the Hotelling model, Slade (1988) shows that the natural resource prices could contain stochastic trends. To this end Slade (1988) makes use of a stochastic differential equation (to be discussed later) to analyse the price dynamics of natural resources. The stochastic equation combines the simple model of Hotelling and an efficient market model. In the case of the efficient market model it is implied that the price of the natural resource is a martingale where price is composed of simple random increments. This would be the case if speculation were the principle factor determining the natural resource price (Slade 1988). As a result, the empirical analysis of natural resource prices throws up an important issue as to whether they exhibit stochastic or deterministic trends. To this end unit root tests have been applied to analyse natural resource prices. If a unit root is rejected then the prices are stationary around a trend, otherwise one cannot rule out that prices are integrated and contain a stochastic trend. As mentioned already, the evidence so far has been mixed and therefore a puzzle remains as to whether shocks to natural resource prices are transitory or persistent.

To this end we employ a novel concept that stems from the plausible fact that the time path of non-renewable resource prices are likely to be nonlinear and therefore the standard methods used in recent studies may not be effective. Further, we update the data set that has been used in extant studies and conduct the analysis chosen on the time period used in recent studies as well as the updated data set for robustness. The paper is structured as follows: Section II provides a literature review of the popular studies that have investigated the issue of response of natural resource prices to exogenous shocks. Section III outlines the setting for the econometric estimation with a brief description of the methods employed in this study. Section IV describes the data set used in this study along with the empirical results. Finally, Section V concludes.

II. Literature Review

A number of studies have contributed on the persistence of shocks to natural resource prices. While the extant literature on more novel and powerful methods of unit root tests are developed, the applications of these methods have contributed to the understanding of the possible presence of stochastic trends in natural resource prices. Some of the recent and most pertinent studies, analysing data stretching to about or over a century, are reviewed in this section.[2]

The first statistical analysis of long run trends in natural resource prices dates back to Barnett and Morse (1963) where they examined the hypothesis of scarcity in natural resources which was thought to lead to increasing prices. Analysing data from 1870 to 1957 for several natural resource prices, they found a negative trend contrary to the conjecture of an increasing trend. Using relatively more sophisticated procedures, Smith (1979) found no discernible trend, either positive or negative, in the price index of mineral commodities.

Slade (1988) was the first to empirically examine the time series properties of natural resource prices to determine whether they are characterised by deterministic or stochastic trends. The results find that seven chosen commodities, being copper, pig iron, lead, bauxite, silver, petroleum and coal could be characterised as a unit root process, thereby containing stochastic trends. However, the empirical analysis suffers from two limitations. First, the data generating process of natural resource prices is assumed to be a simple autoregressive process of order one, which is a restrictive assumption of natural resource prices given that these prices are known to be highly correlated (see Deaton 1999). Secondly, the unit root tests excludes a time trend from the regressions which can seriously bias the results of a unit root test (see Hamilton 1994).

[2] It is not possible to cover all studies in this review. However, we aim to provide a comprehensive review of studies that use annual data over a fairly long period of time. Many studies have analysed data of high frequency, that is, weekly or monthly, over a relatively much shorter time period.

In a similar study Agbeyegbe (1993) considers the behaviour of mineral commodity prices. He nests the U-shaped path of natural resource prices with a random walk and studies the temporal properties of four mineral prices. His findings are similar to Slade (1988) where strong support for a unit root process is found, with three out of the four prices exhibiting stochastic trends. However, recent studies have pointed out that his model does not allow for the possibility of structural breaks. It is well known that if structural breaks are present in the data and are ignored when conducting unit root tests, then the chances of non-rejection of the null hypothesis of a unit root increases.

Ahrens and Sharma (1997) extend the work of Agbeyegbe (1993) and Slade (1988) by allowing for unit root tests that incorporate a time trend that can be of an arbitrary *n*th order polynomial and also allow for the presence of structural breaks in the data. Using this framework, Ahrens and Sharma (1997) find that six out of eleven natural resource prices over the period 1870 to 1990 can be characterised as a trend stationary process. However, serious limitations may result from analysing the issue of deterministic as opposed to stochastic trends in this framework. First, the structural break test is conducted using the model of Perron (1989) where the break date is chosen exogenously. It is now well known that the exogenous choice of a structural break has serious limitations (see Christiano 1992). The *n*th order polynomial is introduced with the help of the procedure developed by Ouliaris et. al. (1989). However, Agiakloglou and Newbold (1992) show that such tests which allow for an *n*th order polynomial trend are likely to suffer from size distortions.

Berck and Roberts (1996) provide an alternative theoretical approach regarding the time path of natural resources. Slade (1982) argued that technical progress in extraction and processing of minerals along with a depleting grade of a mineral assumed to be continuous can lead to a U-shaped time path of natural resource prices; empirical analyses are conducted on annual data spanning from 1870 to the mid1970s. In contrast, Berck and Roberts (1996) employ a discrete model of many grades with technical progress and show that natural resource prices can be expected to remain stagnant or fall. They argue that abundance of natural resources can lead to stagnant prices. The empirical analysis consists of unit root tests to determine whether the natural resource prices are difference or trend stationary. They employ annual data spanning from 1870 to 1991. The analysis is conducted over short and long samples, where the short sample is simply a sub-sample of the data set to facilitate a comparison with Slade (1982). Their results show that there is overwhelming evidence of the prices being difference stationary based on Lagrange Multiplier tests complemented with Dickey Fuller tests. Berck and Roberts (1996) conclude that natural prices are difference stationary and that leads to only a weak supposition that natural resource prices would increase.

Pindyck (1999) examined whether the evolution of the real prices of oil, coal and natural gas measured on an annual basis over the period 1870 to 1996 is governed by stochastic trends by employing ADF tests. The results show that except for oil the null hypothesis of a unit root cannot be rejected, implying stochastic trends for natural gas and coal. However, Pindyck (1999) makes a remark concerning the failure of the ADF test to reject the null hypothesis of a stochastic trend due to the low power of the test. He also makes use of the variance ratio tests of the sort used by Cochrane (1986) and Campbell and Mankiw (1987) to address the *extent* to which price shocks are temporary or permanent, or equivalently, the relative importance of any random walk component in the price data. His results show that for coal and oil, the permanent component of price shocks is small, so that shocks are mostly transitory in nature. The broad conclusion is that these unit root tests are unlikely to provide much information about the stochastic processes that best represent the long-run energy price evolution.

Postali and Picchetti (2006) use the Lee and Strazicich (2004, 2003) test to find evidence of trend stationarity in crude oil prices in an attempt to assess the suitability of Geometric Brownian Motion as a proxy for oil prices. Using an annual series of U.S. average crude oil prices from 1861 to 1944 and extended using price data for Arabian Light and UK Brent up to 1999, they reject the null of a unit root for the full samples and a range of subsamples when allowing for trend and intercept breaks. In a concurrent study using the same methods, Lee et. al. (2006) contributes to the extant literature on the time path of natural resource prices by pointing out that the potential structural break in natural resource prices has been largely overlooked in previous studies. They emphasise that if a structural break is indeed present in the data, then ignoring the break in the data would falsely lead to non-rejection of the null hypothesis of a unit root (see Perron 1989). To this end, they test for unit roots that allow for endogenously determined structural breaks, due to Lee and Strazicich (2003) and also allow for a quadratic trend. The results of their study show that out of the eleven natural resource prices, all prices are found to be stationary. However, it would be intuitive to ascertain if breaks are at all present in natural resource prices, before proceeding to conduct unit root tests that allow for breaks to be present in the data. If structural breaks are not present in the data then these tests suffer from low power due to the inclusion of extraneous break dummies (see Ghoshray et. al. 2014).

Presno et. al. (2014) conducts structural break tests that allow one to be agnostic to the underlying order of integration of the natural resource prices. To this end they apply the procedure of a trend break due to Perron and Yabu (2009) and if a break is present then a sequential test to detect a further break is applied following the method of Kejriwal and Perron (2010). A further test to detect pure level shifts is applied using the method of Harvey et. al. (2010). Once the presence of breaks (or no breaks) are ascertained in the data, Presno et. al. (2014) compute stationarity tests under both the linear and the quadratic specifications and consider two types of models that incorporate breaks and smooth transitions. They argue that the latter specification is of particular interest, as it incorporates the possibility of gradual rather than instantaneous, changes and allows the nonlinear nature of the series to be more flexibly captured. Their paper makes use of a range of procedures based on Landago and Presno (2010) in order to investigate the stochastic properties and the change points in a database of 11 non-renewable resource real prices. Their results indicate that most of the series are stationary, but there are two clear exceptions: natural gas and silver.

However, as Presno et. al. (2014) note, the approach to determine the number of breaks requires trimming which always involves the risk that breaks on the extremes pass undetected; and the loss of power as a result of sample size reduction. Further, only two breaks are considered when analysing data that spans over a century. This again, is unduly restrictive during a period that has experienced a preponderance of events that would justify the occurrence of more than two breaks. However, choosing more than two breaks has, in a statistical sense, its pitfalls for the number of observations in the data sample (see Ghoshray et. al. 2014). For example, allowing for a large number of breaks is not an appropriate strategy if one wants to determine if a unit root is present. The reason is that a unit root process can be viewed as a limiting case of a stationary process with multiple breaks, one that has a break (permanent shock) every period. Further, as discussed in Kejriwal and Perron (2010), the maximum number of breaks should be decided with regard to the available sample size. Otherwise, sequential procedures for detecting trend breaks will be based on successively smaller data subsamples (as more breaks are allowed) thereby leading to low power and/or size distortions. It is therefore important to allow for a sufficient number of observations in each segment and choose the maximum number of permissible breaks accordingly (see Ghoshray et. al. 2014).

To sum up, the earlier studies that test for persistence of natural resource prices have employed econometric methods such as unit root tests which essentially test for the order of integration which is a linear concept. The economic model due to Slade (1982) outlines that natural resource price data may be nonlinear. While several studies have allowed for structural breaks in unit root tests, we test for nonlinearity that somewhat obviates the need to test for structural breaks, if we find evidence of nonlinearity. Given that the tests for nonlinearity are based on an underlying model that follows a function of an exponential smooth transition or logistic smooth transition process, such nonlinearity can approximate the presence of structural breaks. More importantly, the fact remains that integration is a linear concept and these variants of ADF tests and LM tests may not be appropriate. To this end, the objective of the paper is to employ a novel alternative procedure to determine whether natural resource prices are 'summable' thereby allowing one to determine the degree of persistence and the evolution of variance of natural resource prices.

III. Model and Econometric Methods

Slade (1988) puts forward a model describing the dynamic nature of the price of natural resources, generated by the stochastic differential equation of the following form:

$dP = \alpha P dt + \sigma dz$

or, $dP = \alpha P dt + \sigma \varepsilon \sqrt{dt}$ (1)

where P denotes the price of the natural resource, z is a Weiner process and $\varepsilon \sim N(0,1)$. If $\sigma = 0$, then prices grow at a deterministic rate α. This is in line with the model of Hotelling (1931) where α is the rate of interest. If $\alpha = 0$, then the price is the sum or in this case the integral of independent random increments of zero mean, or in other words, a martingale. This is the likely case if speculation was driving the price of the natural resource and the commodity is transacted in an efficient market. If both α and σ are nonzero, the rate of growth of price is a random variable with mean/drift equal to α.

A discrete time approximation to (1) can be given by the following equation:

$$\Delta P_t = \alpha P_t + \nu_t \qquad \text{where } \nu_t \sim N(0, \sigma^2) \qquad (2)$$

The model is linear and the test for whether the price contains a stochastic trend or not can be carried out using a unit root test. It is debatable however, to assume that unit root tests can give much information about the stochastic trend in natural resource prices. It has been shown in a seminal paper by Perron (1989) that a single structural break in the data can bias unit root tests. Pindyck (1999) shows that for non-renewable natural resources the trend is likely to fluctuate over time in response to fluctuations in demand, extraction costs and reserves of natural resources. Unpredictable, frequent and significant changes in these variables can affect the level and slope of natural resources. Also, it may be argued that if shocks to demand, extraction costs and reserves, all fluctuate continuously and unpredictably over time, then these variables could contain stochastic trends (Pindyck 1999). Hendry and Juselius (2000) state that, the nonstationary integrated variables could transmit to other variables which are dependent on these integrated variables. Following the reasoning of Hendry and Juselius (2000) we could argue that natural prices are likely to inherit a stochastic trend given that the prices are dependent on demand, extraction costs and reserves which may themselves contain stochastic trends. However, this is an empirical question that needs to be formally tested. What we can argue here is that the underlying demand function is nonlinear as well as the time path as derived by Pindyck (1999). Therefore the test for integration necessitates the adoption of an alternative approach to account for nonlinearity. The concept of summability neatly fits into this exercise.

In case where the data series is nonlinear, this necessitates the adoption of the concept of summability. The concept of summability has recently been formalised in a study by Berenguer-Rico and Gonzalo (2014). A stochastic process (say P) is said to be summable of order δ denoted $S(\delta)$ if there exist a deterministic sequence $\{\mu_t\}$ such that:

$$S_T = \frac{1}{T^{0.5+\delta}} L(T) \sum_{t=1}^{T} (P_t - \mu_t) = O_p(1) \text{ as } T \to \infty$$

where δ is the minimum real number such that S_T is bounded in probability and $L(T)$ is a slowly varying function. This procedure generalizes the concept of integration in the linear case and allows for establishing the order of summability for a number of nonlinear models. Indeed, if a linear time series P_t is $I(d)$ then it is also summable of order d, that is, $S(d)$.

Berenguer-Rico and Gonzalo (2014) make use of an assumption that $P(S_T = 0) = 0$ for $T = 1,2,3, \ldots.$ and allowing for $L(T) = 1$ we write:

$$U_T = log S_T^2 = log \left[T^{-(1+2\delta)} \left(\sum_{t=1}^{T} (P_t - \mu_t) \right)^2 \right]$$

The above expression can be written in regression form as:

$Y_k = \beta log k + U_k, \quad k = 1,2, \dots, T$

where $\beta = 1 + 2\delta$, $Y_k = log(\sum_{t=1}^{T}(P_t - \mu_t))^2$ and $U_k = O_p(1)$.

Berenguer-Rico and Gonzalo (2014) propose to estimate β by the following expression:

$$\hat{\beta} = \frac{\sum_{k=1}^{T} Y_k log k}{\sum_{k=1}^{T} log^2 k}$$

Given that $\beta = 1 + 2\delta$,, the OLS estimator of δ is:

$$\hat{\delta} = \frac{\hat{\beta} - 1}{2}$$

Subsampling methods can be undertaken to draw inferences on the order of summability independently of its true value. This is measured by taking 1000 replications of two sided nominal 95% symmetric intervals of δ and report the lower (I_{low}) and upper (I_{up}) bounds of the estimated confidence intervals. In this study two parametric forms of P_t is chosen. The linear form where $\mu_t = \mu_0 + \mu_1 t$ and the quadratic form where $\mu_t = \mu_0 + \mu_1 t + \mu_2 t^2$. In the constant only case, the proposed $\hat{\mu}_t$ is:

$$\hat{\mu}_t = \frac{1}{t}\sum_{j=1}^{t} P_j$$

In the linear case, the proposed $\hat{\mu}_t$ is:

$$\hat{\mu}_t = \frac{1}{t}\sum_{j=1}^{t} P_j - \frac{2}{t}\sum_{j=1}^{t}\left(P_j - \frac{1}{j}\sum_{i=1}^{j} P_i\right)$$

and in the quadratic case, the proposed $\hat{\mu}_t$ is:

$$\hat{\mu}_t = \frac{1}{t}\sum_{j=1}^{t} P_j - \frac{2}{t}\sum_{j=1}^{t}\left(P_j - \frac{1}{j}\sum_{i=1}^{j} P_i\right) - \frac{3}{t}\sum_{j=1}^{t}\left(P_j - \frac{1}{j}\sum_{i=1}^{j} P_j - \frac{2}{j}\sum_{i=1}^{j}\left(P_i - \frac{1}{i}\sum_{h=1}^{i} P_h\right)\right)$$

The choice of deterministic components does not alter the order of summability of the detrended process $(P_t - \hat{\mu}_t)$. The proposed procedure due to Berenguer-Rico and Gonzalo (2014) allows one to be agnostic about the data generating process. The method allows us to estimate the order of summability that works reasonably well.

IV. Data and Empirical Results

The data used in this study are annual real natural resource price series of 11 commodities comprising of eight metal prices, being aluminium, copper, iron, lead, nickel, silver, tin and zinc; and three mineral prices, being coal, petroleum and natural gas. The choice of variables are the same as employed in the popular studies that have investigated the degree of persistence of non-renewable resource prices, including those of Ahrens and Sharma (1997), Lee et. al. (2006) and Presno et. al. (2014). However, the data used in these studies are based on the time period 1870 to 1990. In this paper we make a contribution by updating the series to the most current period for which data is available. The data set is accordingly extended from 1990 to 2014 using the same sources were used by Ahrens and Sharma (1997). These include various issues of the *Minerals Yearbook* published by the 'U.S. Bureau of Mines' for selected metal prices and the *Annual Energy Review* published by the 'Energy Information Administration' for selected mineral prices. Following the method of Ahrens and Sharma (1997), the data has been converted to real prices by using the producer price index (1967 = 100) as a deflator. Most of the data series in the early years is originally sourced from Manthy (1978) and Schurr (1960). The time spans are not all the same. It was not possible to update the data for the price of iron. Copper, silver and zinc span the entire time period from 1870 to 2014. Lead and petroleum cover a time range of 1870 to 2013; aluminium from 1895 to 2014, copper from 1870 to 2011; gas from 1919 to 2012; and tin from 1885 to 2014.

Figure 1 below plots 10 out of the 11 natural price series chosen in this study. Given that the data for iron prices could not be updated we choose not to plot the prices as we cannot observe the path of natural resource prices post 1990.

[Figure 1 about here]

Each of the graphs display a vertical grid line demarcating the old data set used in several studies and the newly constructed updated data set. Krautkraemer (2005) points out that for most of the twentieth century natural resource prices have remained broadly flat or have trended downwards. For the old data set spanning up to 1990, this seems to be generally true for aluminium, copper, lead, petroleum, nickel, silver and zinc, albeit with the odd spike or two in silver, zinc and petroleum. The only exceptions are tin, coal and gas which show an upward trend in general, though it needs to be hastily added that the sudden increase in trend is close to the 1990 cut off point. This may not be surprising for coal and gas, given that these are non-renewable resources and are subject to increasing scarcity and as a result increasing prices.

However, what we find noticeable is that with the inclusion of new updated data to the original data set, the general trend seems to be somewhat reversed for a large chunk of the commodities chosen. For example, copper, coal, lead, petroleum, nickel, silver, gas and tin have experienced upward movements. In some of these prices the end of the sample records a relatively small decline, whereas for gas the decline has been very steep. For zinc and aluminium the price has been relatively flat over the extended sample. The upshot is that based on the conjectures discussed in the previous sections, one cannot really comment decisively about discernible linear or quadratic trends in the prices. This would be determined through formal tests for persistence of the prices. However, as described earlier in the literature review, prominent studies have allowed for both linear and quadratic trends when modelling the nature of persistence in natural resource prices. Accordingly, for completeness and comparison, we estimate the order of summability allowing for both a linear trend and a quadratic trend.

In the first instance we make use of this novel procedure on the smaller sample, that is 1870 to 1990, chosen in recent studies. To this end, we estimate the order of summability of the 8 natural resource prices over the period 1870 to 1990 with $\hat{\delta} = \hat{\beta} - 1/2$ and derive the subsampling confidence intervals denoted by (I_L, I_U). The results are shown in Table 1 below.

[Table 1 about here]

First, consider the case of a linear deterministic trend included in the data series. The lowest order of summability is found to be copper and the highest is found to be nickel. Also, for petroleum, silver and tin the degree of persistence is found to be high enough to indicate that the any shocks to these prices would have long lasting effects. The associated confidence intervals for nickel, petroleum, silver and tin show that although the degree of persistence is high, there is considerable variability in these natural resource prices. Copper, iron and zinc show relatively lower degree of persistence. Out of these three natural resources, the confidence intervals for iron and zinc incorporate both zero and unity thereby leading us to conclude that we cannot reject the null hypothesis that the prices are summable of order zero, that is S(0), or summable of order one, that is S(1). This suggests that while the degree of persistence is relatively lower than other prices such as silver and tin, there is enough variability in the data that prevents us from concluding that the summability of the price series is of a particular order. The confidence intervals are wide in general, but expected from commodity prices that are known to be highly volatile.

In the case where a quadratic trend is fitted to the prices of the natural resources, the commodity price with the lowest order of summability is iron, followed by zinc, copper and tin. The associated confidence intervals are very wide for iron, tin and zinc, which include both zero and unity thereby leading us to conclude that we cannot reject the null hypothesis that the prices are S(0) or S(1). The highest order of summability is found in petroleum, followed by nickel and silver. When comparing the results for different deterministic trends, we find that for both the linear and the quadratic trend, the degree of persistence and the associated level of variability of iron, nickel and zinc are roughly the same. Conversely, the results of copper and gas changes. For example, in the case of copper, we find that including a linear trend, the order of summability is low with a subsample confidence interval that incorporates zero. However, with a quadratic trend, the degree of summability is higher, suggesting a higher level of persistence and the subsample confidence interval excludes zero and includes unity instead.

Our results depart from the recent studies, where we find considerable evidence that natural resource prices are highly persistent to shocks given the high order of summability and the associated confidence intervals. At least half of the prices with a linear or quadratic trend, incorporate the possibility that the summability is of order unity. This contrasts with Presno et. al. 2014 and Lee et. al. (2006) where they find that most of the natural resource prices are trend stationary and therefore any shocks to the prices are transitory in nature. Conversely the results also depart from those studies that have concluded most or all natural resource prices to be highly persistent such as Slade (1982) and Berck and Roberts (1996). Our results also depart from those of Ahrens and Sharma (1997) where the evidence of high persistence in the prices is mixed. While Ahrens and Sharma (1997) find 5 out of 11 prices appearing to be difference stationary, and therefore high persistence to shocks; only 1 of those prices (being silver) matches with our study. While tin and natural gas prices are found to be highly persistent to shocks in the study by Ahrens and Sharma (1997), our results show some similarity when considering the inclusion of the linear trend in the case of tin prices, and a quadratic trend fitted to natural gas prices.

The same analysis is repeated for the extended data, that is, 1870–2014. In a similar fashion, the results are tabulated based on a linear trend fitted to the data and again separately for a quadratic trend. The results are shown in Table 2 below.

[Table 2 about here]

First, considering the linear trend, we find that the order of summability is lowest for zinc followed by natural gas. For natural gas, the confidence interval contains only zero, indicating that the degree of persistence is low. Zinc shows a very wide variability including both zero and unity in the confidence interval, and therefore we cannot conclude whether the series is S(0) or S(1). Nickel shows the highest order of summability, followed by tin, silver, lead and petroleum. While the confidence interval is large indicating a high evolution of variance, the intervals only include unity suggesting that the persistence is high for these commodities. Including a quadratic trend changes to some extent, the results for some of the natural resource prices. For example, the price of zinc indicates approximately the same degree of persistence and the about the same level of variability, though the lower bound is positive and the confidence interval no longer includes zero. When considering the degree of persistence, there is not much change for nickel and silver when compared to petroleum and lead. However, the change is relatively more prominent when considering the case of tin for example, where we note that there is a marked change in the degree of persistence. However, in general, the overall conclusion is that most of the prices considered show high persistence whether fitted to a linear or a quadratic trend.

Our empirical results offer some insight in to the nature of persistence in natural resource prices. The finding of mixed results in past studies based on the concept of integration, which is a linear concept, can be partly explained by the fact that the method is inappropriate when applied to data that is found to be largely nonlinear. Based on our empirical results, we cannot rule out the possibility that there is considerable evidence that natural resource prices are found to be highly persistent to shocks, and the evidence is greater when we incorporate recent data. However, we find that the degree of persistence can vary widely and in some cases we cannot be sure about the order of summability. But this is not entirely surprising, given that natural resource prices are known to be highly volatile.

V. Conclusion

We contribute to the literature on whether natural resource prices are highly persistent in two ways. First, all of the empirical studies since the seminal work of Ahrens and Sharma (1997) in recent years have relied on the same data over the time period 1870 to 1990. Given the recent upswings and downswings in commodity prices over the last 20 years, we update the data set to check whether the new addition of recent time series data has an impact on the results. It is well known that the empirical results can be sensitive to the sample chosen and so the analysis is conducted on both the smaller sample used in previous studies and the longer sample that includes more recent data. Secondly, this paper makes a contribution to the literature by employing a new kind of procedure for determining whether natural resource prices are highly persistent using the novel concept of summability due to Berenguer-Rico and Gonzalo (2014). This procedure is more pertinent given that most of the natural resource prices are found to be nonlinear. Using this method, we present a comparison of a linear and quadratic trend term fitted to the natural resource prices. The findings produce results which are starkly different from those of recent studies that in general, favour trend stationarity of natural resource prices. The finding highlights that there is no broad conclusion as to whether natural resource prices are trend stationary of difference stationary.

The findings lead us back to make inferences from the stochastic differential equation that is postulated for assessing the time path of natural resource prices. Two models are nested in the equation; one is the deterministic model due to Hotelling (1931) and the other is a stochastic model, based on speculation driving the price of the natural resource which is transacted in an efficient market. The price in the latter model is formulated by the sum of independent random increments. We may conclude that the natural resource prices used in this study show more support for the latter model, that is where prices of natural resources contain a stochastic trend. The underlying uncertainty and volatility due to changes in demand, extraction costs, reserves as well as political uncertainty overshadow the deterministic trends. However, this may be not be true for all prices and the price of each natural resource merits individual attention.

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Tables and Figures

Table 1. Estimation of the order of summability on natural resource prices 1870 – 1990.

	Linear Trend		Quadratic Trend	
	δ	I_L, I_U	δ	I_L, I_U
Aluminium	0.90	0.22, 1.57	1.12	0.49, 1.74
Coal	0.91	0.16, 1.64	0.72	0.10, 1.33
Copper	0.36	-0.16, 0.89	0.64	0.18, 1.09
Iron	0.52	-0.04, 1.08	0.50	-0.09, 1.08
Lead	0.82	0.12, 1.53	1.32	0.25, 2.39
Natural Gas	0.46	0.11, 0.81	0.79	0.47, 1.11
Nickel	1.21	0.33, 2.09	1.20	0.39, 2.00
Petroleum	0.81	0.35, 1.27	1.22	0.44, 2.00
Silver	0.88	0.24, 1.52	1.08	0.57, 1.60
Tin	0.99	0.29, 1.69	0.67	-0.03, 1.37
Zinc	0.49	-0.08, 1.07	0.58	-0.01, 1.17

Table 2. Estimation of the order of summability on natural resource prices 1870 – 2014.

	Linear Trend		Quadratic Trend	
	δ	I_L, I_U	δ	I_L, I_U
Aluminium	0.91	0.28, 1.53	1.11	0.54, 1.68
Coal	0.91	0.22, 1.60	0.76	0.14, 1.38
Copper	0.39	-0.10, 0.89	0.63	0.11, 1.15
Lead	0.86	0.16, 1.56	1.28	0.33, 2.23
Natural Gas	0.55	0.21, 0.89	0.79	0.23, 1.36
Nickel	1.18	0.32, 2.04	1.19	0.41, 1.98
Petroleum	0.81	0.39, 1.24	1.23	0.51, 1.95
Silver	0.91	0.37, 1.45	1.12	0.58, 1.66
Tin	1.02	0.34, 1.70	0.68	0.04, 1.32
Zinc	0.53	-0.02, 1.07	0.59	0.01, 1.18

Figure

Figure 1 Natural Resource Prices