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MEASURING THE TRENDS OF NATURAL RESOURCE COMMODITY PRICES: AN EMPIRICAL ANALYSIS*

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Abstract

It is believed that over time the price path of exhaustible recources would form a U-shape. Initially prices will show a downward trend due to technological progress in extraction, followed by a price rising trend due to increasing scarcity of resources. Using the optimality theorem, this study investigates the availability of nonrenewable natural resources and examines the possible shape of their price paths for the period of 1870 to 1987. The analysis, using the linear and quadratic trend model, supports the U-shaped hypothesis of increasing resource scarcity.

I. *Introduction*

It is now widely believed that over time the price path of an exhaustible natural resource would form a U-shape. This is due to the interaction between the price declining trend due to technical progress in mining, refining and so on, and the price rising trend due to increasing scarcity of high grade ore in the physical sense. This study, employing the optimality theorem, as pioneered by Hotelling (1931) investigates the availability of non-renewable natural resources and examines the possible shape of their price paths for the period of 1870 to 1987.

The idea that limited natural resources might limit the economic growth dates back to the late eighteenth century with the publication of *The Coal Question* by William S. Jevons (1865), which may have been the first economic analysis of possible exhaustion of an under ground recources. Similar concerns were echoed by later generation of economists such as Ricardo and Malthus who developed steady state models based on fixed supplies of agricultural resources, but the agricultural resources could be renewable should the land be properly managed.

Materials shortages related to World War II, the Korean War, and the sudden population boom in the 1950s and 1960s led to renewed interest in the subject of adequacy of natural

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resources. The formation of the U.S. President's Materials Policy Commission (known as the Paley Commission) during the Truman Administration and the publication of several theoretical and empirical studies (Potter and Christy, 1962; Barnett and Morse, 1963, for example) were evidence of concern at that time. In the 1970's several events, including the Arab oil embargo, the emergence of strong environmentalist lobby groups, and the publication of "The Limits to Growth" by Donella Meadows and others (1972) initiated an active debate on the availability of natural resources.

II. *Survey of Relevant Literatures*

In the theoretical literature of non-renewable resources, models have been developed that predict an increase in marginal extraction cost over time [Hotelling (1931), Solow (1974)]. In contrast, empirical studies have reached mixed conclusions. Following the seminal empirical work of Barnett and Morse (1963) several studies [Barnett (1979), Smith (1979), Johnson, Bell and Barnett (1980), Slade (1982)] have been undertaken using statistical analysis. However, there is still no consensus among economists as to whether non-renewable natural resource commodities are becoming scarce compared to other factors of production.

Using the Ordinary Least Square method, Barnett and Morse (1963) detected falling commodity prices. They used 13 minerals for the period of 1870 to 1957 and found that unit cost in fact decreased rapidly for all the minerals except lead and zinc, for which the decrease was small. Barnett (1979) in an updated study, defended this conclusion and the bulk of the cost reduction, according to him, was attributable to technological development in resource extraction. Smith (1979) argued that test statistics based on recursive regressions for the period 1900–1973 does not decisively support either the hypothesis of increasing scarcity or the reverse. Johnson and Bennett (1980) updated the original Barnett and Morse (1963) work to 1972 and reached a similar conclusion of decreasing scarcity. They observed that both gross and net output of the observed variables have increased steadily over the entire period, while the extraction cost, both in term of labour and labour plus capital has declined since the 1920s. Baumol and Oates (1979) examined price trends for fifteen minerals for the period of 1900 to 1975. They found that prices of seven out of fifteen minerals under investigation fell after correction for changes in the value of the dollar, and the prices of eight resources increased. According to them price decreases tend to predominate at the beginning of the preiod, while increases were more frequent toward its end.

A different conclusion was drawn by Slade (1982). Slade developed a model with exogenous technical change and endogenous change in the quality of resource deposits. On the theoretical level, the improved technical change is assumed to offset the exponential increase in marginal extraction costs for lower quality resources. However, Slade's model predicts a U-Shaped trend for mineral prices because it assumes that increasing marginal user cost and declining quality of mineral grade eventually overcome the cost decreasing trend of exogenous technological improvements. This was empirically tested by fitting linear and quadratic equations to price trends of 11 mineral commodities, and using the OLS method Slade detected falling relative resources price (declining scarcity) until the mid 70s followed by rising relative prices (increasing scarcity).

This U-Shaped hypothesis has been questioned by Hall and Hall (1984) and Mueller and Gorin (1985). Mueller and Gorin argued that Slade's model has an important bias and the equation is misspecified. They argued that Slades' model neglected many real world phenomena which may have influenced the price paths of the minerals. In reply Slade (1985) rejected Mueller and Gorin's claim that her model neglected real world phenomena of non-market influences. Slade argued that non-market factors might influence the price paths in the short run, but when assessing long-run price trends (100 years or more) they probably act as random noise in the system. Thus, neglect of variables that may influence prices does not bias the estimated results unless the excluded variables are correlated with the included variables.

It is clear from the existing work that the issue of the time-trend of natural resource commodity prices relative to other goods is unsettled issue and needs to be readdressed. The purpose of this paper is to re-examine and reconcile the theoretical predictions of an increase in resource prices over time with the empirical findings of falling real prices or the reverse. The second objective of this paper is concerned with the specification issue and the appropriate choice of scarcity index. There has been considerable debate about this [Smith (1978), Brown and Field (1979), Fisher (1979), Smith and Krutilla (1979)], and still there is no consensus with respect to the choice of appropriate scarcity indicator. Hence, in this paper, beside the wholesale price index (WPI), the GNP deflator has also been used as an index to test the scarcity hypotheses.

The paper is organised as follows. Section III develops a model of non-renewable natural resources in the spirit of scarcity hypothesis, where it has been hypothesised that over time the price paths would form a U-shape due to exogenous technological improvements and endogenous change in quality of resource deposits. Section IV discussed the methodology and reports the empirical results and concluding remarks appear in section V.

III. *The Long-Run Pricing Model*

Among theoretical models in the natural resources field, the theory of the optimal exhaustion of minerals is probably the best known, and was pioneered by Harold Hotelling (1931). Hotelling developed his model with the assumptions of a known and finite stock of resources, constant cost and homogeneous quality of resoyrces. Newer treatments allow for the possibility that depletion of minerals may be taking place without assuming that actual exhaustion is in the offing [Barnett and Morse (1963), Smith (1978), Baumol and Oates (1979), Slade (1982), Anderson (1985)]. The theoretical model of real-price movements for nonrenewable natural resource commodities developed here is due to Slade (1982) and Anderson (1985).

We start with the basic assumptions that marginal extraction cost increases as cumulative production takes place, resource stock is non-homogeneous in quality, and unknown (no finite limit). The problem is to choose a time path for extraction rates that will maximise the discounted stream of current and future benefits minus cost.

Consider two time periods, t and $t+\Delta t$, in the sequential use of a nonrenewable resource subject to rising marginal production cost with cumulative production. We also assume that above-ground storage or depreciation costs are zero, so that extraction can proceed sale. Marginal extraction cost at time t is $C(t)$ per unit while units extracted at $(t+\Delta t)$ have higher marginal production cost equal to $C(t+\Delta t)$, which exceeds $C(t)$ because the resource units extracted at t are higher quality units in the production sequence. Suppose resources are sold in a competitive markets where P is the product price, then the difference between the product price (P) and marginal production cost (C) is usually called the net price (π) though it can also be referred to as the *in situ* value of the resource, the royalty, the scarcity rent per unit of the resource, or the resource's marginal user cost. Thus, net price for two periods is denoted as:

$$P(t)-C(t)=\pi(t) \tag{1}$$

$$P(t+\Delta t)-C(t+\Delta t)=\pi(t+\Delta t) \tag{2}$$

Equilibrium between two periods requires that resource owners are not attempting to shift production between the two periods in their attempt to maximise wealth. In other words, equilibrium requires that the present value of the net price in $(t+\Delta t)$ equals the net price at (t) such tht:

$$P(t)-C(t)=[P(t+\Delta t)-C(t+\Delta t)]/(1+r\Delta t) \tag{3}$$

where r is one period discount rate. Suppose the resource owners sell the high quality (lower cost) resource at time t. If the net price received at time t is invested at the current interest rate then it will be worth $\{\pi(t)(1+r\Delta t)\}$ at the end of period $(t+\Delta t)$. If, instead of selling the high quality resource at time t, resource owners wait until the end of $(t+\Delta t)$, they will receive $\pi(t+\Delta t)+C(t+\Delta t)-C(t)$, which is the net price for the next period plus an amount equal to the difference in extraction cost, since the owner sell both the high quality and low quality resources at the same price. Thus, resource owners will try to sell later if,

$$\pi(t)(1+r\Delta t)<\pi(t+\Delta t)+C(t+\Delta t)-C(t) \tag{4}$$

since the return in the later period (taking discount rate into account) exceeds the return in the earlier periods. Next consider resource owners selling the lower quality (higher cost) units at time $(t+\Delta t)$. If they sell units at time t instead of at time $(t+\Delta t)$, they receive net price equal to $\pi(t)-[C(t+\Delta t)-C(t)]$. If this return is invested at the ruling rate of interest then at the end of period $(t+\Delta t)$ they could have obtained $[\pi(t)-\{C(t+\Delta t)-C(t)](1+r\Delta t)$. If this amount exceeds what they would have received by selling their low quality units at $(t+\Delta t)$, they will not be satisfied and will try to sell earlier. Thus, they will try to sell the low-quality resource earlier if:

$$[\pi(t)-\{C(t+\Delta t)-C(t)\}]\ (1+r\Delta t)>\pi(t+\Delta t) \tag{5}$$

Rearranging (4) and (5) we get (6) and (7):

$$r\pi(t)<[\{\pi(t+\Delta t)-\pi(t)\}/\Delta t]+[\{\pi C(t+\Delta t)-C(t)\}/\Delta t] \tag{6}$$

$$r\pi(t)>[\{\pi(t+\Delta t)-\pi(t)\}/\Delta t]+[\{C(t+\Delta t)-C(t)\}/\Delta t]+r[C(t+\Delta t)-C(t)] \tag{7}$$

Writing them more compactly:

$$r\pi(t) < \Delta\pi/\Delta t + \Delta C/\Delta t \tag{6.1}$$

$$r\pi(t) > \Delta\pi/\Delta t + \Delta C/\Delta t + r\Delta C \tag{7.1}$$

When $\Delta t \longrightarrow 0$, then $r\Delta C \longrightarrow 0$, and we get

$$r\pi < d\pi/dt + dC/dt \tag{8}$$

$$r\pi > d\pi/dt + dC/dt \tag{9}$$

Inequality (8) says that the owner of the higher quality resource will shift the extraction to later periods while inequality (9) says the owner of the low quality resource will shift the extraction to earlier periods. Equilibrium occurs when:

$$r\pi = d\pi/dt + dC/dt \tag{10}$$

where owners of high quality recources maximise their gain by extracting higher quality (lower cost) resources followed by lower quality (higher cost) resource owners. Referring to our basic assumption, we know that marginal extraction cost increases as the higher quality resources are exhausted and production moves to the lower quality resources. Say X is the production. As time elapses, the cumulative production, denoted as dx, increases, and the resource industry moves to higher cost deposits. Thus:

$$dC/dt = (dC/dx) \quad (dx/dt) = C_x{}^*q \tag{11}$$

where dx/dt (denoted as q) is current output and dc/dx measures the slope of cumulative cost curve. Substituting equation (11) into equation (10) we get:

$$r\pi = d\pi/dt + C_x{}^*q \tag{12}$$

This is the optimal condition that must be satisfied at every point in the extraction of non-renewable resources. If we make a simplifying assumption that marginal extraction cost $C(t)$ is constant for a given grade and state of technology and is influenced by time, the marginal cost function can be written as:

$$C = C(x,t) \tag{13}$$

where x measures cumulative production, and t is the time variable that incorporates exogenous technological change. Examining the separate marginal effects of depletion and technological change,

$$dC/dt = (\partial C/\partial x)^*(dx/dt) + \partial C/\partial t \tag{14}$$

where $(\partial C/\partial x)^*(dx/dt)$ measures the impact of depletion on cost during the time interval dt and $\partial C/\partial t$ measures the impact of technological change on cost (assumed to be negative). The presence of technological change does not alter the resource owner's basic decision-making framework. Equation (10) still describes the optimal path for the net price when production costs are constantly subject to the pressure of depletion. Due to technological progress marginal extraction cost over time is declining ($dC/dt<0$). We assume our model to be firm model, and resource owners still maximise net wealth over time, so that the net price must be growing parallel to the rate of interest. From the net price equation we have $\pi=P-C$, which gives:

$$dP/dt=d\pi/dt+dC/dt \tag{15}$$

In the early stage of extraction net price is high and extraction cost is low so that $(dP/dt)>0$, over time as the extraction cost increases the difference between net price and extraction cost falls. If rising extraction cost outweighs the falling net price then $(dP/dt)<0$. In order to interpret the impact of technological change, it is useful to rewrite equations (12), (14) and (15) as a system:

$$r\pi=d\pi/dt+C_x{}^*q \tag{12}$$

$$dC/dt=C_x{}^*q+\partial C/\partial t \tag{14}$$

$$dP/dt=d\pi/dt+dC/dt \tag{15}$$

In equation (14) $C_xq=(\partial C/\partial x)(dx/dt)$, and by means of substitution we can easily derive the following equation:[1]

$$dP/dt=r\pi+\partial C/\partial t \tag{16}$$

The equation (16) indicates that the rate of change of price, which includes marginal extraction cost and rent, is equal to the rate of change of marginal cost due to changes in technology plus the discount rate times net price. It also states that product price may be rising $dP/dt>0$ or falling $dP/dt<0$, depending upon the rate of technological change. Without technological change, prices increase with time because net price π is always positive. However, if the rate of technological change is sufficiently positive then, prices will fall. If $\Delta C/\Delta t$ falls with time, but at a decreasing rate, while π increases with time, then the price path will generally be U-Shaped. In the following sections we have examined the shape of the trend, as well as the choice of the appropriate index of price which are subject to some conntroversy.

Several authors [Smith (1978), Brown and Field (1979), Fisher (1979), Smith and Krutilla (1979)] have addressed the issue of the appropriate choice of scarcity index. The unit cost measure of Barnett and Morse (1963), the most commonly cited index of scarcity among economists, is an ambiguous indicator of scarcity for the following reasons. Firstly, it can be argued that this measure understates the true cost of providing current resource

[1] If we assume our model to be a firm model, then the results of equations 12, and 14–16 can be obtained with a simple control model as follows: Profit $(t)=P(t)^*q(t)-C(t,x)^*q(t)$ & $dx(dt)=q(t)$. If the firm maximises the present value of profit over $t=0$ to $t=\infty$ subject to $dx/dt=q$, the current value hamiltonian is: $H=P(t)^*q(t)-C(t,x)^*q(t)-\beta(t)^*q(t)$. The necessary conditions for intertemporal maxima are:

$P(t)-C(t,x)-\beta(t)=0,$

$d\beta/dt=Cx^*q(t)-r^*\beta(t).$

output, since the cost of natural resources *in situ* (the net price) is excluded from this measure. Furthermore, the unit costs are average costs, they may not measure the costs of inputs needed to provide resource products from the worst (marginal) resource in use. Secondly, under static conditions it can be shown that an increase in per unit extraction cost is associated with a decrease in aggregate per capita output, hence a decline in per capita consumption. But in a world enriched throughout by technical progress this could be an ambiguous scarcity indicator. Brown and Field (1979, p. 221) argued that the unit cost measure is a lagging, not a leading indicator. Expected future costs of extraction are not contained in this measure. In addition, as a measure of scarcity index, it has practical difficulties as well. It is a difficult index to measure precisely. There is the problem of measuring the inputs, particularly capital, and combining them into a meaningful aggregate.

Not everyone agrees that rents are useful measures of scarcity [Anderson (1985)]. Firstly, there is so little data that often the rental rate is not a practical measure in the short run, and very seldom are they observable as statistical series. Secondly, Bernett and Morse (1963, pp. 225–226) argued that rent is not a useful measure of scarcity in a world of depletion or of technological change. An increasing rent will reflect increasing scarcity, but increases in rent may also be due to changes in interest rates, relative demand, and expectations concerning future resource availability. Under these conditions, advances in rent on unhomogeneous resources are an ambiguous indicator of increases in scarcity.

Thirdly, the rental rate as a scarcity indicator assumes that nonrenewable resources are being utilised in accordance with the optimal exhaustion model [Hotelling (1931), Slade (1982), Anderson (1985)]. If instead, resources' are simply brought into production whenever their product prices cover marginal production costs, then the rental rate tends to approach zero, and in that case it will be an ambiguous indicator.

In what follows scarcity will be considered to be the result of demand and supply conditions for non-renewable resource commodities so that relative prices (prices adjusted for inflationary effects) would offer the best indexes of resource scarcity. The real price of resource goods is superior to other indices, as an indicator of scarcity for the following reasons. Firstly, it is forward looking in so far as it reflects the expected future cost of explorations, discovery, and extraction. Secondly, the real price of a resource can rise or fall, indicating increasing or decreasing scarcity.

Furthermore, this choice is similar to other studies [Smith (1978), Fisher (1979), Baumol and Oates (1979), Slade (1982)], and is also in consistent with comments of Barnett and Morse (1963, p. 211) who noted: "Comparison of prices of extravtive and non-extractive goods has important advantages over the relative cost measure. It is comprehensive as regards to cost coverage in its inclusion of all purchased inputs. Also, price quotations are more plentiful, and are frequently superior objectivity and statistical quality to measures of labour and capital inputs over the long term."

IV. *Methodology and Empirical Results*

Given the diversity of demand and supply characteristics of non-renewable resource commodities, a simple trend model [Slade (1982)] was selected as representative of the conventional hypothesis on natural resource availability. Thus the price index for the relevant commodity aggregate is hypothesised to be a linear or quadratic function of a time trend variable as shown by the following equations (17) and (18).

$$\ln(P_{it}/WPI)=\alpha_{0t}+\alpha_{1t}(T)+e_{it};\quad e_{it}{\sim}N(0,\sigma^2) \tag{17}$$

$$\ln(P_{it}/WPI)=\beta_{0t}+\beta_{1t}(T)+\beta_{2t}(T^2)+u_{it};\ u_{it}{\sim}N(0,\sigma^2) \tag{18}$$

where P_{it} is the deflated price of the ith commodity at time t, and $E(u_t^2)=\sigma^2$. T is time measured in years. If $\alpha_{t0}\leq 0$, $\beta_{1t}\leq 0$ and $\beta_{2t}\leq 0$ then we have declining scarcity, and if they are found to be positive then we say that the resources are becoming scarce (increasing scarcity). If β_1 is negative and β_2 positive then the time path of price would be U-Shaped.

The data consist of annual time series for the period 1870 (or the year of earliest available figures) to 1987 for all the major metals and fuels. Prices were deflated by the 1967 wholesale price index (1967=100) and are thus 1967-constant dollars. For some commodities, prices of both ore and metal are available (bauxite and aluminium, for example). However, for consistency, metal prices were always used.

Appendix one lists fourteen commodities, the units of measurements of their prices, and the data sources. Seven of fourteen series were taken from Manthy (1978). These series were updated to 1987 by using the sources listde in Manthy (1978, Tables MP-3 and MP-6, pp. 211–212), and also by using the Statistical Abstract, and Historical Statistics of the U.S.

The initial estimation was done by using the Ordinary Least Square method where many of the estimated coefficients were found to be insignificant. In addition, autocorrelation and ARCH effect [Engle (1982)] were detected. Using the OLS estimation from the linear trend model, seven of the fourteen mineral price series exhibited declining scarcity and the estimated coefficients of ten variables were significant at the 95 per cent confidence level. Since some of the estimated coefficients were found to be positive, so no generalisation can be made from the linear trend alone. On the other hand for the quadratic model, price series for all the minerals except lead, cadmium, mercury and magnesium showed a raising trend (increasing scarcity) and twelve out of fourteen variables were statistically significant at the 95 per cent confidence level.

The Cochrane-Orcutt (CORC) method is used for autocorrelation correction, where the estimated coefficients gave better results. The CORC estimated results of linear and quadratic models are reported in Tables I and II. For linear trend model we found that all but gas, coal, tin, and iron showed a declining scarcity, and the estimated coefficients of only three of the declining trend variables namely coper, aluminium, and magnesium were significant at 95 per cent confidence level. For the quadratic trend model we found that the estimated β_1 coefficients of ten variables showed declining scarcity ($\beta_1<0$) and the estimated β_2 coefficients of all but four variables namely lead, cadmium, mercury and magnesium showed raising scarcity ($\beta_2>0$) but only two of them, cadmium and mercury are statistically significant at the 95 per cent confidence level. Thus based on these results it would not be unrealistic to conclude that non-renewable resources are becoming scarce relative to their prices.

As mentioned earlier, the initial testing showed the presence of ARCH effects in the price series in both the linear and quadratic trend models. The ARCH corrected results are reported in Table III where α_1 reports the estimated coefficients of linear trend model.

TABLE I. REGRESSION RESULTS FOR THE LINEAR TREND MODEL FOR THE PERIOD OF 1870 TO 1987

ESTIMATED MODEL IS: $\ln(P_{it}/WPI)=\alpha_{0i}+\alpha_{1i}(T)+e_{it}$

Variables	a_{0i}	a_{1i}	R^2	D.W.	Rho
Copper	−0.75	−0.005 (−2.21)[a]	0.772	1.82	−0.83
Lead	−1.92	−0.0015 (−1.06)	0.58	1.62	0.17
Zinc	−1.83	−0.001 (−1.47)	0.35	2.06	−0.03
Silver	0.90	−0.44 (−0.83)	0.89	1.76	0.10
Aluminium	0.54	−0.02 (−5.96)[a]	0.93	1.60	0.20
Natural Gas	−2.03	0.006 (0.65)	0.73	2.18	−0.28
Petrol	−3.32	−0.001 (−0.65)	0.45	1.45	0.15
Nickel	−0.0053	−0.0026 (−0.58)	0.76	1.60	0.16
Coal	−3.34	0.0062 (4.23)[a]	0.91	1.67	0.11
Tin	−0.40	0.008 (2.64)[a]	0.82	1.52	0.22
Cadmium	1.30	−0.012 (−0.98)	0.80	2.01	−0.07
Mercury	0.70	−0.0022 (−0.32)	0.76	1.45	0.27
Iron	−0.017	0.005 (0.25)	0.66	1.74	0.09
Magnesium	0.35	−0.011 (−2.23)[a]	0.85	1.90	0.04

* CORC estimation has been used, | t | statistics are in parentheses.
[a] Significant at 95 per cent confidence level.

Although all the estimated coefficients are significant at 95 per cent level but only half of them showed declining scarcity ($\alpha_1<0$). Similarly, β_1 and β_2 reports the ARCH corrected results of quadratic model where we are mainly interested in the sign of β_2, and it shows that all but zinc, cadmium and mercury showed rising scarcity. The estimated β_2 coefficients of all the variables except nickel and magnesium are significant at 95 per cent confidence level. Table III also reports the goodness of fit test for the normality of residuals for the quadratic model, and it shows that residuals of twelve out of fourteen variables are normally distributed. This shows that most of the estimated results are unbiased, and this further reaffirms our finding that non-renewable resources are becoming scarce and the empirical results supports the U-shaped hypothesis.[2]

[2] As mentioned earlier, there exists considerable disagreement about the appropriate choice of scarcity index. To shed some light on this, using the GNP deflator as the scarcity index, a re-estimation was done on the linear and quadratic trends for the period of 1870 to 1987, and the obtained results were similar to those reported in Tables I and II except that cadmium and mercury were found to have negative trends (declining scarcity). Thus, we are in the opinion that our choice of relative prices of resource goods as the scarcity index is the appropriate one.

TABLE II. REGRESSION RESULTS FOR THE QUADRATIC TREND MODEL FOR THE PERIOD OF 1870 TO 1987

ESTIMATED MODEL IS: $\ln(P_{it}/WPI) = \beta_{0i} + \beta_{1i}(T) + \beta_{2i}(T^2) + u_{it}$.

Variables	β_{0i}	β_{1i}	β_{2i}	R^2	D.W.	Rho
Copper	−0.58	−0.014 (−1.90)[b]	0.007 (1.23)	0.774	1.82	0.08
Lead	−1.98	0.0012 (0.23)	−0.00023 (−0.52)	0.58	1.62	0.17
Zinc	−1.73	−0.0063 (−2.15)[a]	0.00042 (1.82)[b]	0.62	2.03	−0.02
Silver	1.61	−0.043 (−5.27)[a]	0.0031 (4.79)[a]	0.90	1.64	0.15
Alminium	1.60	−0.054 (−4.90)[a]	0.0024 (3.14)[a]	0.93	1.64	0.14
Natural Gas	6.43	−0.22 (−9.12)	0.0014 (9.74)	0.84	1.74	0.01
Petrol	−3.03	−0.017 (−2.36)[a]	0.0016 (2.42)[a]	0.50	1.52	0.15
Nickel	0.53	−0.017 (−0.51)	0.00086 (0.43)	0.77	1.60	0.17
Coal	−3.19	−0.0023 (−0.49)	0.00072 (1.92)$_1$	0.92	1.70	0.13
Tin	0.14	−0.0094 (−0.58)	0.0018 (1.10)	0.82	1.50	0.25
Cadmium	−9.30	0.24 (3.56)[a]	−0.014 (−3.76)[a]	0.83	1.97	−0.01
Mercury	−1.07	0.052 (1.67)[b]	−0.0036 (−1.74)[b]	0.77	1.43	0.77
Iron	0.31	−0.0194 (−5.17)[a]	0.002 (5.52)[a]	0.71	1.78	0.10
Magnesium	0.125	0.0014 (0.08)	−0.0001 (−0.73)	0.85	1.90	0.04

* CORC estimation; [a] Significant at 95 per cent level; [b] significant at 90 per cent level.

V. *Summary and Conclusions*

The analysis of long-run relative price movements of non-renewable mineral resources for the period of 1870 to 1987 supports the U-shaped hypothesis of increasing resource scarcity. In this study we have estimated fourteen price series where only three of the quadratic term variables gave negative coefficients (means declining scarcity), and twelve of them showed positive coefficients indicating increasing scarcity, and all the estimated variables are statistically significant.

The industrial revolution brought with it not only the growing demand for power but also the demand for raw materials in such an alarming rate that the world had never experienced before. The rate of resource utilisation has continued to grow throughout the twentieth century and obviously this rate has been different in different parts of the world. By and large this has been heavier in the western world and among the member countries of the OECD, and heaviest by far in the U.S. This heavy resource utilization rate and rapidly growing demand in the world market as a whole inspired a chorus of forecasts of imminent doom (such as Club of Rome study) and our investigation in this paper showed

TABLE III. ARCH CORRECTED RESULTS OF THE LINEAR AND QUADRATIC MODELS FOR THE PERIOD OF 1870–1987

Variables	α_{1t}	β_{1t}	β_{2t}	Normality Test* x^2	D.F.
Copper	−0.006	−0.029	0.003	10.68[b]	5
	(−14.90)	(−27.40)	(24.30)		
Lead	−0.0098	−0.0036	0.0027	26.57	5
	(−2.81)	(−2.74)	(2.35)		
Zinc	−0.0017	0.0034	−0.00047	25.24	5
	(−3.77)	(2.57)	(−4.32)		
Silver	−0.014	−0.054	0.0037	12.56[a]	5
	(−36.77)	(−35.78)	(30.60)		
Aluminium	−0.024	−0.06	0.0030	4.74[b]	1
	(−101.43)	(−43.08)	(30.57)		
Natural Gas	−0.029	−0.19	0.0012	2.94[a]	1
	(−8.67)	(−42.26)	(44.41)		
Petrol	0.051	−0.078	0.0008	14.52[b]	5
	(17.27)	(−3.09)	(3.62)		
Nickel	0.027	−0.017	0.0002	1.63[b]	1
	(5.01)	(−0.40)	(0.99)		
Coal	0.06	−0.033	0.0009	9.60[a]	5
	(24.98)	(−4.02)	(14.14)		
Tin	0.058	−0.023	0.002	6.11[b]	1
	(10.50)	(−5.18)	(7.37)		
Cadmium	0.009	0.15	−0.0089	2.05[a]	1
	(8.71)	(8.85)	(−9.26)		
Mercury	0.009	0.067	−0.0045	5.94[a]	1
	(9.55)	(10.18)	(−10.40)		
Iron	0.025	−0.021	0.002	11.88[b]	5
	(7.90)	(−11.98)	(12.66)		
Magnesium	−0.012	−0.078	0.00002	9.70[a]	5
	(−182.92)	(−13.64)	(0.40)		

$|t|$ ratios are in parenthesis; [a] significant at 95 per cent level; [b] significant at 99 per cent level. * Goodness of fit 8test for the normality of the residuals for the quadratic trend model variables, and α_{1t} is from the lineartrend model; β_{1t} and β_{2t} are from the quadratic trend model.

similar results. In most cases the price paths showed a rising trend since the beginning of seventies and it would be interesting to note that the world trade market has been very volatile since the seventies as well. Future research in this area should investigate whether the price paths of the minerals have been influenced by non market factors such as tariffs, monopoly powers and so on. It may also be possible to use some non parametric tests in determining the price trends.

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Appendix 1.

Data Sources, List of the variables, units of measurement and the sources

Variables	Units	Time period	Sources
Copper	¢/lb	1870–1973	Manthy
		1974–1987	Statistical Abstract
Lead	¢/lb	1870–1973	Manthy
		1974–1987	Statistical Abstract
Zinc	¢/lb	1870–1973	Manthy
		1974–1987	Statistical Abstract
Silver	¢/ounce	1970–1970	Historical Statistics
		1971–1979	Metal Statistics
		1980–1987	Statistical Abstract
Aluminium	¢/lb	1885–1970	Historical Statistics
		1971–1979	Metal Statistics
		1980–1987	Statistical Abstract
Natural Gas	m^3 ft	1919–1973	Manthy
		1974–1987	Statistical Abstract
Petroleum	$/bbl	1870–1973	Manthy
Nickel	¢/lb	1913–1941	Historical Statistics
		1942–1976	Metal Statistics
		1977–1987	Statistical Abstract
Bit. Coal	$/ton	1870–1973	Manthy
		1974–1987	Statistical Abstract
Tin	¢/lb	1900–1979	Metal Statistics
		1980–1987	Statistical Abstract
Cadmium	¢/lb	1931–1987	Metal Statistics
Mercury	$/flask	1900–1987	Metal Statistics
Iron	¢/lb	1870–1973	Manthy
Magnesium	¢/lb	1915–1979	Metal Statistics
		1980–1987	Statistical Abstract