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Trend and Cycles in Coal and Oil Prices in the Long Run: A Schumpeterian Approach*

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1. Introduction

Are we running out of energy resources? An economist's response to this question is to pose another question, namely are prices of energy commodities rising or falling? Rising prices are generally a sign of resource scarcity, while falling prices are a sign of abundance. The answer is complicated by prices that change day by day, week by week and year by year, reflecting fluctuations in short-run demand and supply forces, including political upheavals, ups and downs in the world economy and the sentiments of speculators. A more satisfying answer is possible if it is possible to separate out the impact of long-run forces on the ability to continue to supply the commodities, including depletion of reserves, new discoveries and technical change. These forces are expected to be revealed in the trend movement in price. Thus, a key task for energy economists is to identify the trend, if any, in the price of each energy commodity. In this paper we contribute to this task by examining very long series of prices for coal and oil, going back to 1650 in the case of coal and 1859 in the case of oil.

Classical and neoclassical economic approaches to the analysis of prices of non-renewable resource products, including coal and oil, start with the assumption of a finite and known natural resource as well assuming a given technology. This leads to the prediction of Hotelling's (1931) rule that the price of such products should rise at the rate of interest when extraction cost is zero or that the net price of the products should rise at the rate of interest when there are positive marginal extraction costs. Thus, the analysis clearly points to a rising trend in energy commodity prices when there are fixed natural resources and given technology. More recent analyses, such as those by Slade (1982a, 1982b) and Brown and Wolk (2000), recognize discovery of new reserves and technical progress as potential downward influences on prices of these products, working through driving down the marginal cost of extraction. However, discovery and technical change are exogenous to these analyses, so there is no basis for appraising the likely impact of these factors relative to the impact of finite and known natural resources.

We utilize an approach based on the work of Joseph Schumpeter (1934) in which technical change is treated as endogenous, with the pursuit of opportunities for profit providing a catalyst for innovation. For natural resource commodities, such as coal and oil, this approach has powerful implications on both the supply and demand side of the market. In particular, rising prices stimulate the search for alternative sources of supply and the search for technology that leads to substitution away from use of the commodity. Low prices stimulate finding new uses for the commodity. We point to examples of both phenomena in discussing the pattern of historical price movements for coal and oil. Even without price changes, the opportunity for profit through innovation that lowers cost or raises price remains. There is no guarantee that technology will come to the rescue to stabilize prices and ensure the security of supply, but it is important to understand the forces at work in assessing historical

price movements and the prospects for future price movements.[1] Certainly, the alternative of assuming no new discovery or technical change is implausible.

Importantly, Schumpeter (1939) argues that technical change imparts a cyclical pattern to the movement of prices. In particular he identifies long cycles in prices lasting more than half a century. Applying this method to coal and oil price series allows us to separate out long cycles in each price series, and then examine the intra-cyclical trends for indications of increasing or decreasing scarcity of coal and oil based on the movement in real price. We then appraise recent movements in coal and oil prices against previous cycles and suggest implications for the prediction of future price movements.

2. Endogenous Technical Change and the Business Cycle

In *The Theory of Economic Development*, Schumpeter (1934) contrasts economic development, which occurs through endogenous technical change, to the equilibrium of a stationary state. The endogeneity of technical change is derived from the capitalist organization of the economy, which allows entrepreneurs to profit through introducing innovations in the form of new production methods, new products, new forms of organization and the opening of new markets. This analysis suggests technical change is assured under capitalism, but it is discontinuous, with its nature, location and extent unknowable.

Much discussion of technical change focuses on developments in manufacturing, especially following the Industrial Revolution. However, Schumpeter's approach applies across all products and production processes. In his historical analysis in *Business Cycles*, Schumpeter (1939) gives plentiful examples of innovations in production techniques in mining and agriculture as well as manufacturing. Bartos (2007) goes even further to suggest mining is a high-tech industry. Further, Simpson (1999) provides extensive discussion of technical advances contributing to increased productivity in natural resource commodity production in the mid to late 20th Century, including chapters on coal and oil. In the discussion below, we point to a number of important innovations in the production, distribution and use of energy commodities that have had immense influence on the supply and demand of energy commodities, thereby influencing the pattern of price movements.

A further complication in examining the impact of natural resource scarcity and innovation on primary commodity prices is that there is feedback between scarcity and innovation. While nature may constrain expansion of capacity in primary production, impediments to growth are also opportunities for profitable innovation. Under capitalism the dictum "necessity is the mother of invention", becomes "profitability is the mother of innovation". However, there are no guarantees that innovative effort in exploration, introduction of new production techniques or development of substitute materials will be

[1] It is worth noting the impressive forces that stand in the way of innovation. Schumpeter emphasizes the general resistance to change, which means that special effort is required to successfully introduce innovations into the economy (providing a key role for entrepreneurs, who are capable of overcoming this resistance). More specifically, there are lock-in effects of previous technologies, vested interests that prefer the established structure, government rules and regulations, and very long lead times for associated with the development of new production areas in coal and oil.

effective in expanding resource supply or reducing resource demand. This imparts an inherent unevenness to the movement of prices.

In *Business Cycles* Schumpeter argues that the bunching of economic innovations is not completely chaotic, rather that it imparts a rhythm to the pattern of economic activity. In addition to long cycles lasting more than 50 years, noted as Kondratieff cycles (in recognition of earlier research by Kondratieff, 1935), Schumpeter also recognizes the existence of shorter Juglar cycles that last between 9 and 10 years and Kitchin cycles that last a bit more than three years. Schumpeter (1939, p.213) provides a stylized chart showing how the various cycle lengths overlap, leading to a Kondratieff cycle of 55½ years. The basic structure of each cycle has four phases, prosperity, recession, depression and recovery, although for some cycles, especially the shorter ones, there is no clear distinction between recession and depression.

Schumpeter's treatment of the business cycle has been subject to sharp criticism (see, for example, Kuznets, 1940). However, the argument that major innovations lead to alternating long periods of expansion and decline in prices and other aspects of economic activity is supported by Kuznets (1930) and has been adopted in a number of works dealing with the history of capitalism, for example, Mensch (1979), Tylecote (1992) and Freeman and Louçã (2001). In the later works, Schumpeter's rigid characterization of cycles is discarded in favor of cycles without the regular amplitude and duration. The terminology of a long wave is generally used in place of the Kondratieff cycle, with the long wave having a variable duration that averages something like a half century.

In spite of the criticisms and arguments for deviations from the regularity of the Kondratieff, we impose Schumpeter's strict interpretation of the Kondratieff cycle as covering a period of 55 or 56 years, with 55 years for the two cycles dated by Schumpeter and 56 years for all other cycles. This sets a regular pattern for analyzing sub-period movements of prices, albeit subject to the limitations attached to of any attempt to impose strict regularity on the historical record. Alternative approaches to the dating of business cycles are also subject to limitations.[2] From our perspective, the critical issue is whether the division of history into these cyclical episodes is fruitful in understanding the economic processes at work. Our dating of business cycles includes the two complete cycles identified by Schumpeter: 1787 to 1842 and 1842 to 1897. We then extend his method to add two more recent cycles: 1897 to 1953 and 1953 to 2009, and two earlier cycles: 1731 to 1787 and 1675 to 1731.[3]

[2] For an alternative procedure based on the realized cycles in primary commodity prices see Bloch and Sapsford (2010). The alternative procedure generates cycles lasting between 25 and 61 years in length.

[3] Some of the cycles are 55 years in length, while others are 56 years. Because our data are annual, we can't exactly match the 55½ years that Schumpeter specifies for the idealized Kondratieff cycle. It should be noted that Schumpeter did not apply his method to the period before 1787, presumably because this marks the start of the cycle he associates with the Industrial Revolution. However, as our concern is with primary commodities and coal in particular, earlier technological developments that affected the use of coal for and heating, particularly urbanization, are relevant.

3. Data and Interpretation

The key variable in Schumpeter's characterization of the cycle is the price level rather than the level of output or employment that feature in most discussions of the business cycle. This reflects Schumpeter's emphasis on innovation as leading to structural change and uneven development. The price level rises during the upswing of a cycle because enterprises that introduce innovations compete for productive resources with established producers. The innovators can absorb the higher input prices as their innovative products or processes involve higher value to buyers or lower production costs. As the high profits earned by innovators attract imitators, a downswing in prices occurs in the aggressive competition associated with Schumpeter's famous "gales of creative destruction".

We examine long historical series of price indexes for energy commodities relative to a corresponding price index of manufactured goods. The series have been constructed by Jakob Madsen as part of a database on the prices of internationally traded primary commodities and manufactures starting from 1650. The data come from a variety of sources, which are described in the Appendix to Harvey, et al (2010). These data series have been updated to 2010 by the authors.[4]

Our full constructed series of real coal prices covers the period from 1650 to 2010. The course of movements in prices over this period is depicted in Figure 1, in which the vertical axis gives the natural logarithm of the real price index with a base value of 1.0 in the starting year of 1650. The logarithmic scale is used so that a given vertical distance on the graph represents the same percentage change regardless of the initial value. For example, a rise of 0.1.0 represents a ten percent increase whether the rise starts from an index value of 0.5, 1.0 or 2.0.[5] Table 1 gives the annual percentage rate of change of real prices for both coal and oil prices for each of the Kondratieff cycles and also an average annual rate of change for the full period for which each data series is available. The course of movements of real oil prices over the period of 1859 to 2010 is shown in Figure 2 further below.

[4] Our thanks go to Jakob Madsen for supplying the basic data. We extend his series for coal and oil prices from 2005 to 2010 using data from the US Energy Information Administration and use data from the World Bank to make the corresponding update to manufacturing prices.

[5] Because of the peculiarities of percentage calculations, a decrease of .1 represents a percentage decrease of 100/1.1 or 9.09 percent. However, it is still the case that the amount of the percentage decrease is the same regardless of the starting value.

FIGURE 1 - LOG OF REAL COAL PRICE 1650 TO 2010 (1650 = 1.0)

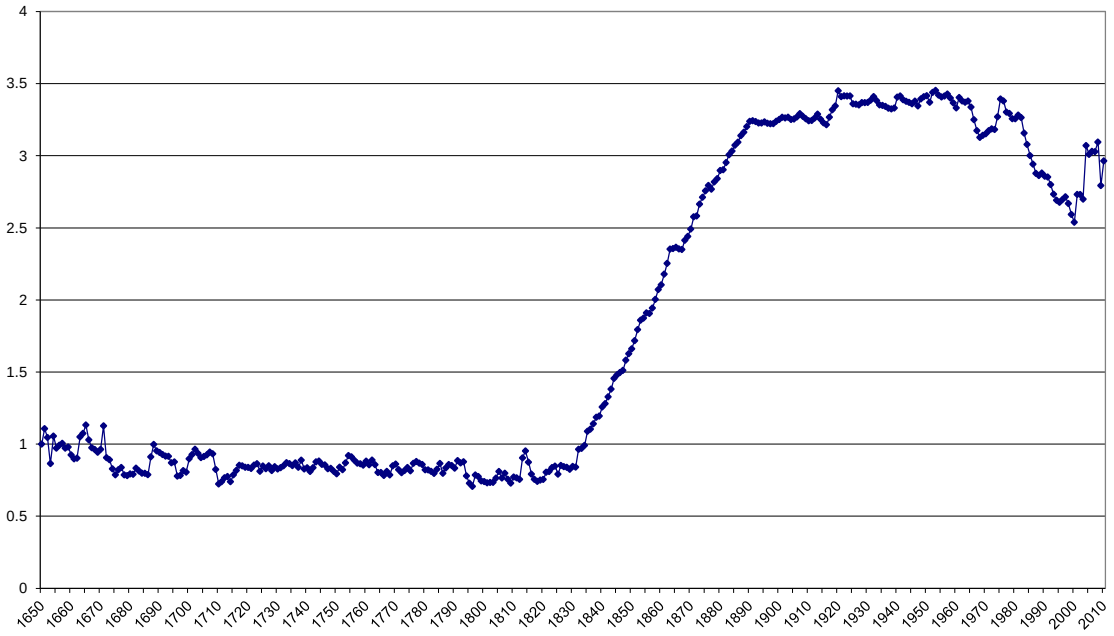


Table 1 – Annual rate of change of real coal and oil prices for various cycles and full period

Period	Annual % change in real coal price	Annual % change in real oil price
1675-1731	0.088	
1731-1787	-0.003	
1787-1842	0.897	
1842-1897	3.443	
1897-1953	0.413	2.716
1953-2009	-1.178	2.463
Full period	0.823	1.840

a. Technical change and trends in energy prices

Schumpeter associates each of the three Kondratieff cycles that he analyzes with a fundamental change in technology. These technological shifts each have had major implications for the use of energy commodities. The cycle from 1787 to 1842 is associated with the Industrial Revolution, that from 1842 to 1897 with railroadization and the cycle beginning in 1897 with electrification. Water and wind power as well as human energy are identified as the key drivers of the early Industrial Revolution, but the associated urbanization is seen as leading to coal supplanting wood as the prime heating fuel. The development of the steam engine for stationary power and then motive power can be held responsible for an enormously expanded demand for coal in the cycle associated with railroadization. Finally, in the era of electrification both oil and coal are major fuels for generating electricity, with the choice between them depending on availability and price in the local area.

Continuing with the Schumpeterian approach to identifying each Kondratieff cycle with a fundamental shift in technology, the latest Kondratieff cycle from 1953 and 2009 has been widely associated with the spread of information and communication technology (ICT) (see, for example, Freeman and Louçã, 2001 and Lipsey, et al, 2005). The spread of ICT has had positive and negative impact on the aggregate demand for energy commodities, expanding the level of economic activity but lowering its energy intensity. However, associated increases in travel and transport, particularly increased dependence on automobiles, planes and ocean shipping, have driven total demand for energy commodities upward and encouraged a shift from coal to oil.

In addition to the broader influence of technological shifts on the demand for energy commodities there have been changes in technology of that have substantially affected the supply of energy commodities. The mechanization of coal mining has been ongoing over the centuries of our data sample, beginning from simple winches, rails and pumps and continuing to modern draglines. Advances in geology, seismology and drilling technology have similarly transformed oil production. Without these advances in technique and the associated efforts in exploration and development, matching production to the enormous expansion in demand for energy commodities would have been impossible.[6]

To at least some extent the advances in technology for producing energy commodities can be seen as an endogenous response to the opportunities presented by high prices. Certainly, there are ups and downs in exploration for new coal and oil deposits that follow on rises and falls in their respective prices. However, the drive to reduce costs or expand production remains a driver of technology development in the energy business as elsewhere in the economy even without an immediate price signal. This is the key insight of Schumpeter's analysis of economic development under capitalism. The drive to change is continuous and it is this process of change that shapes the course of price movements.

Periods of sustained increases in real price are evident for both coal and oil in each figure and in Table 1. Over the period 1650 to 2010 the real price of coal rises on average by somewhat almost one percent per annum, while over the period from 1859 to 2010 the real price of oil rises by almost two percent per annum. In the context of the classical approach to natural limits to resource availability, these rises suggest increasing scarcity of energy commodities. However, these full-period averages mask variation in intra-cycle trends that suggest a more complex story of the interplay of resource depletion and technical change.

Taking the start and end date of the cycles as approximating long-period normal prices on average across the economy, any net movement in the relative price of an individual good from the

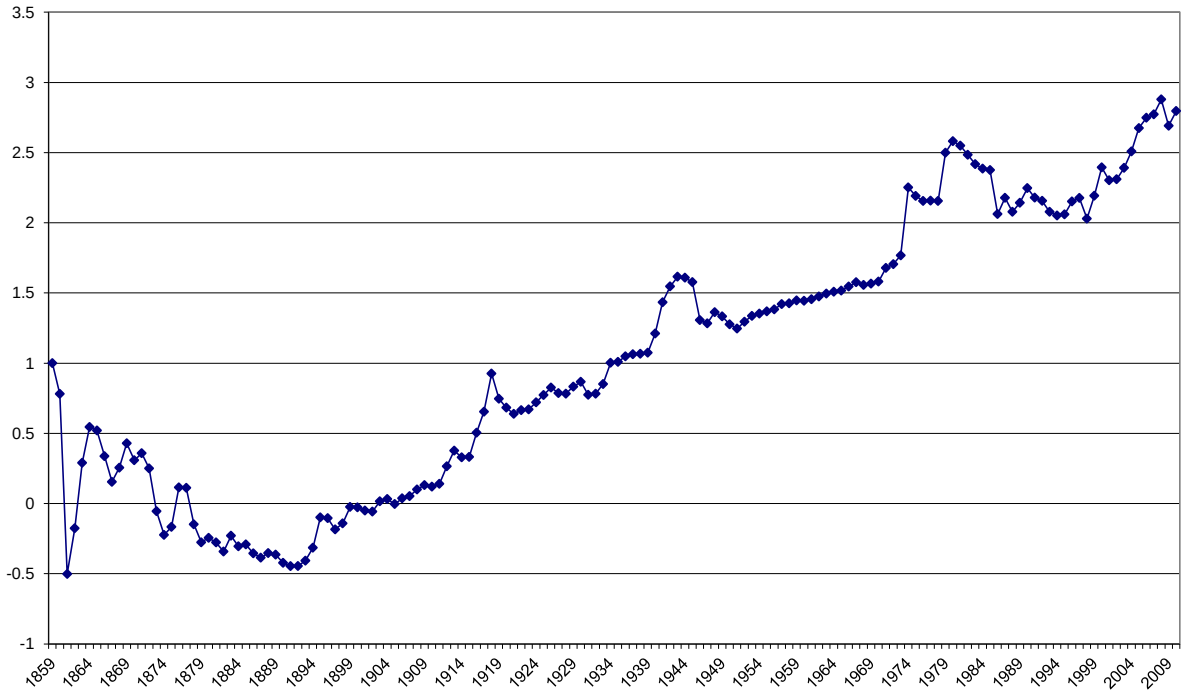
[6] Kuznets (1930, pp. 85-95) discusses the enormous expansion in coal and oil output in the US over the period from 1825 to 1925 for anthracite coal (see Chart 5, p.86), from 1840 to 1925 for bituminous coal (see Chart 6 p.90) and from 1860 to 1925 for crude petroleum (see Chart 7, p. 92). The increase in each case is in the many hundredfold. Large, but not quite as huge, increases for coal output are also shown for the UK (Chart 23, p. 124), Belgium (Chart 29, p.138), Germany (Chart 34, p.151) and France (Chart 41, p. 167).

beginning of the cycle to the end indicates the influence of factors specific to that good. Thus, the trend movements of real coal and oil prices over the course of a cycle provide an indication of the impact of long-run influences, namely the product-specific influences of technical change in production and consumption as well as the influences of resource depletion and new discoveries for that commodity.

As shown in Figure 1, real coal prices barely change over the first two full Kondratieff cycles (1675 to 1731 and 1731 to 1787). They then follow an S-shaped upward trajectory over the next three Kondratieff cycles, rising slowly in the first cycle, accelerating in the second cycle and then decelerating in the third cycle. In the most recent cycle, 1953 to 2009, the real coal price declines noticeably, especially in the recession and depression phases of the cycle, between 1972 and 2000.

The substantial rise in real coal prices of more than two hundred percent is localized to a period stretching a bit longer than the Kondratieff cycle from 1842 to 1897. Otherwise, real coal prices have been stable or falling for the remainder of the three and a half centuries covered by the data. Thus, there is evidence of increasing scarcity of coal, in terms of a rising relative price, but clearly the forces of technical change, including exploration and development of new deposits, have been sufficient to offset depletion through most of the period examined. This is in spite of an enormous increase in the quantity of coal consumed annually across the world.

FIGURE 2 - LOG OF REAL OIL PRICE 1859 - 2010 (1859 = 1)



Our series of real oil prices as shown in Figure 2 only goes back to 1859, which includes only the last two Kondratieff cycles. The early years of data show a sharp fall of the real oil price, leading up the beginning of the Kondratieff cycle in 1897. A fall in relative price is a common phenomenon

for the early years of development of new product, with diffusion of innovations and scale economies in production outstripping growth in demand.[7] However, from 1897 onward the trend of real oil prices has been upward, albeit in a far from smooth fashion. Clearly, there is evidence over these cycles of an increasing scarcity of oil in terms of a rising relative price.

The role that technological shifts can take in explaining movements in real coal and oil prices is clearly illustrated by comparing movements in real coal and oil prices over the last two Kondratieff cycles (1897 to 1953 and 1953 to 2009). In the first of the cycles, real prices for both coal and oil are shown as increasing, although the oil price increases relative to the coal price. In the second cycle the difference in price movements increases, with the coal price falling and the oil price continuing to rise. Interestingly, coal started the first of these cycles as the dominant fuel for motive power with steam railroads and ships reaching their peak. Over time coal has been displaced by oil as the primary motive fuel with the shift to automobiles, trucks, planes and oil-powered trains and ships. Against this, both coal and oil remain as fuels for stationary power, including the generation of electricity, but the change in relative price has seen oil's use fall in favor of coal and other fuels. There has also been a greater incentive for technological development and exploration for oil than for coal.

Considering all of the technological factors enumerated above, the demand shift associated with technical change in transportation stands out as a factor contributing to the increase in the price of oil relative to that of coal over the last two Kondratieff cycles. The other factors mentioned generally attenuate any divergence of relative prices. Constraints posed by the extent and location of natural resource deposits clearly play a role in explaining the increasing real price of both coal and oil and, perhaps, to the divergence of price changes. However, the enormous increases in both coal and oil production over the two cycles, suggest that these constraints are far from the fixed limits assumed in classical economics. Technological changes on both the demand and supply side have been essential in determining the path of real prices of both coal and oil.

b. Cycles in energy prices

Cyclical swings in prices obscure the working of innovation on the trend in particular goods or groups of goods. This is particularly true for primary commodities, which dominate listings of goods with "sensitive prices" that Schumpeter (1939, p.525) recognizes 'will display cycles in prices both relatively promptly and relatively strongly'. Thus, we expect that during the first 19 years covering the upswing phase of the 55 or 56 years of a Kondratieff cycle, the secondary effects of innovations elsewhere in the economy put upward pressure on the demand for primary commodities as raw materials, including energy commodities, leading to rising prices relative to prices of manufactured goods. During the following 28 years of the recession/depression phase, the opposite pressure occurs

[7] Compare to Kuznets (1930, pp. 91-95) who finds an inverted parabolic shape to the time path of oil prices in the US from 1862 to 1916 and explains the downswing as being typical of the price movement of a new commodity. The bottom of Kuznets' inverted parabola occurs in 1892, which corresponds to the recovery phas of the Kondratieff cycle that dates from 1842 to 1897.

with real commodity prices falling. Finally, in the final 9 year recovery phase there is a tendency for real raw material prices to move upward to the level dictated by long-run influences.[8] In each case, the predicted change in real price for the primary commodity is relative to the trend movement for that commodity in the particular Kondratieff cycle. In Table 2, we show the average annual change in real coal and oil prices over each phase of all the Kondratieff cycles for which data are available.

The average rate of price change in upswings exceeds that for downswings for both coal and oil, while the rate of price in recovery exceeds that in the downswing for coal but not for oil. However, most of the differences in the average rates of change are small and there is much variation over the Kondratieff cycles, which suggests that the differences are not statistically significant. Thus, it seems that support for the Schumpeterian hypothesis regarding the cyclical pattern of price movements is weak at best.[9] This is not too surprising given the multitude of other factors, such as wars, that impact on energy prices in the short run.

Table 2 – Annual rate of change of real coal and oil prices over cycle phases

		Annual % change in real coal price	Annual % change in real oil price
1675-1694	upswing	0.4385626	
1694-1722	downswing	-0.057815	
1722-1731	recovery	-0.197419	
1731-1750	upswing	-0.223103	
1750-1778	downswing	0.2637891	
1778-1787	recovery	-0.197419	
1787-1805	upswing	-0.137085	
1805-1833	downswing	0.5725378	
1833-1842	recovery	3.9718463	
1842-1860	upswing	4.3137918	
1860-1888	downswing	3.7800298	-4.05049
1888-1897	recovery	0.6539248	1.87471
1897-1916	upswing	-0.035066	3.6254677
1916-1944	downswing	0.5538928	3.9440507
1944-1953	recovery	0.9197834	-3.026653
1953-1972	upswing	-1.403553	1.9397948
1972-2000	downswing	-2.312946	2.4626343
2000-2009	recovery	2.8274075	3.2930345
Average	upswings	0.4922578	2.7826312
Average	downswings	0.4665813	0.7853984
Average	recovery	1.3296872	0.7136972

[8] For a more extensive discussion of the cyclical behaviour of basic commodity prices see Bloch and Sapsford (2010). See also the treatment of primary commodities as basic materials in Rostow's (1978, 1980) extension of Schumpeter's analysis of the business cycle.

[9] Slade (1982b) also finds no support for the existence of cycles in coal and oil prices over a much shorter sample period.

4. Conclusions and Prospects

We adapt Joseph Schumpeter's approach to business cycles in identifying six Kondratieff cycles covering, 1675 to 1731, 1731 to 1787, 1787 to 1842, 1842 to 1897, 1897 to 1953 and 1953 to 2009. We then calculate intra-cycle trends in the real price of coal for each of the six cycles and for oil for the last two cycles (the only cycles for which data are available). Annual rates of increase in real price of greater than two percent are found for coal in one cycle, 1842 to 1897 and for oil in two cycles, 1897 to 1953 and 1953 to 2009. These substantial rises in real price suggest increasing scarcity for the respective commodity in those periods. However, there is no noticeable change in coal prices for the earliest cycles, from 1675 to 1731 and 1731 to 1787, as well as a notable decline in the latest cycle, from 1953 to 2009.

What does this experience imply about future prospects? Clearly, there is no unitary trend across coal and oil that would suggest a general failure of supply due to universal depletion of fossil fuels. Instead, the suggestion is that developments in technology are of critical importance in determining the path followed by the real price of each energy commodity. In particular, the shift in motive power from coal to oil over the past two Kondratieff cycles is associated with a rise in the price of oil relative to coal and, in the most recent cycle, a trend decrease in the real coal price.

The Schumpeterian approach to economic development emphasizes the endogenous character of technical change under capitalism. The opportunity for profit from innovation ensures that innovations are continually introduced into the economy. However, the exact nature of the innovations and how they might affect the supply and demand for energy commodities is unpredictable. High prices are certainly a spur to innovative effort, but they don't guarantee success. Thus, the future course of prices of energy commodities can't be known. This is a disappointing conclusion for those in search of certainty, but arguably a more useful guide to thinking about future developments than calculations based on the application of Hotelling's rule with its underlying assumptions of fixed resource stocks and given technology.[10]

With regard to the cyclical movement of prices, Schumpeter's analysis suggests that real prices of raw materials in general tend to be rise during the upswing of the Kondratieff cycle, decline in the downswing and then rise again in the upswing. We date the current Kondratieff cycle as starting in 2009, so that the expectation based on the Schumpeterian model is that there will be a cyclical upward movement in real prices of energy commodities for around a decade and a half, followed by downward cyclical movement for close to three decades and, finally, an upward movement in the last almost decade of the cycle. However, the evidence for the existence of such cyclical movements in

[10] In the context of predictions of rising real prices for both renewable and non-renewable natural resource products, it is useful to note that Harvey, et al (2010) find no statistically significant evidence of an increasing real price trend for any of twenty-five primary commodities examined using long time series of annual prices that cover from as early as 1650 to 2005. Instead, they find robust evidence of a negative trend for eleven of the commodities. For coal and oil their finding is that there is no statistically significant evidence of either a positive or negative trend.

previous Kondratieff cycles is weak at best. Also, the dating of Kondratieff cycles is subject to much debate and very difficult to evaluate without the benefit of hindsight. Thus, these predictions based on cyclical movements should be treated with great caution.

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