

**B48 2002-3**

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**LECTURES NOVEMBER 12, 14: PART 1 OF 2**

**IS THE WORLD RUNNING OUT OF RESOURCES?**

**Physical measures of scarcity**

In the 1970s it was very popular to argue that the world would run out of natural resources because of the exponential nature of economic and population growth. The most famous document presenting this view was *The Limits to Growth*, produced by the 'Club of Rome'. This view still exists, although today it tends to go under other names such as 'ecological footprints' or 'environmental space'. The argument is simple. Exhaustible resources are fixed in quantity and cannot be renewed. Any positive rate of use will therefore deplete the resource stock and one day we will run out of the stock altogether. The faster we use up the resources, the sooner the 'limit' is reached. Moreover, there is room for surprises. Suppose the use of a fixed stock of natural resource doubles each year and arbitrarily set the stock equal to 1 unit in year 1. Suppose there are 100 units of the stock. Then the sequence is:

1, 2, 4, 8, 16, 32, 64

The vertical line is there to indicate that at some point in year 7 we run out of the resource. Yet in year 6 we have only used one-third of the resource!

One way of looking at the physical scarcity of an exhaustible resource is via the 'exponential index' of stocks. This measures the number of years before stocks are exhausted given an estimate of stocks and an estimate of the rate at which consumption grows. The formula for estimating this index,  $T$ , which is in years, is obtained as follows:

The stock  $Q$  at any time  $t$  is given by

$$Q_t = Q_0 - q_0 \int e^{gt} \quad \dots\dots[1]$$

where  $g$  is the growth rate of consumption of the resource,  $t=0$  is the initial period, and  $q_0$  is the annual rate of use in the initial period.

At the terminal date,  $T$ , then,  $Q_T = 0$  and the definite integral is evaluated over  $t=0, T$ , so

$$Q_T = Q_0 - q_0 \int_0^T e^{gt} = 0 \quad \dots\dots[2]$$

hence  $Q_0/q_0 = [(e^{gT} - 1)/g] \quad \dots\dots[3]$

But  $Q_0/q_0 = s$ , is the *static reserve lifetime* (the length of time stocks will last if the initial consumption rate stays constant over time), so that

$$s = [(e^{gT} - 1)/g]$$

and

$$sg = e^{gT} - 1 \quad \dots\dots[4]$$

Taking logs

$$\ln.(sg + 1) = gT$$

and T, the time to exhaustion is given by

$$T = \ln.(sg + 1)/g \quad \dots\dots[5]$$

The effects of resource discoveries at some rate  $\delta$  means that the initial stock  $Q_0$  would, if no extraction occurred, increase to  $Q_0 \cdot e^{\delta T}$ . Building this into the above equation for T gives

$$T^*_{\delta} = \ln.[s(g-\delta) + 1]/(g-\delta) \quad \dots\dots[6]$$

Consider the example of natural gas. Let the two periods be 0 and T. Let stocks be  $Q_0$  and  $Q_T$  respectively. Let the actual rate of using up resources in any period t be  $q_t$  and the actual rate of discovery be  $d_t$ . Then

$$Q_0 - \sum q_t + \sum d_t = Q_T$$

so that  $\sum d_t = Q_T - Q_0 + \sum q_t \quad \dots\dots[7]$

In 1975 world reserves of natural gas were 63.2 trillion cubic metres (tcm). In 1995 they were 139.7 tcm, more than a factor of two higher. Converting these to tonnes of oil equivalent to make them compatible with data on production, this gives 56.9 billion tonnes of oil equivalent rising to 125.7 billion toe. Between 1975 and 1995 the world consumed natural gas at around 1500 million toe each year (the average of a rising trend), i.e. around 30 billion toe over the whole period. So, between 1975 and 1995 there must have been discoveries equal to some 99 billion toe, or around 5 billion toe each year (125.7 - 56.9 + 30.0). Put another way, discoveries exceeded consumption by 3.3 times (5 billion toe/1.5 billion toe). A similar analysis for oil shows a discovery/consumption ratio of about 1.9.

Table 1 computes some values for the exponential index, T, for various fuels and minerals. The general picture is one in which reserves rise faster than consumption increases, with the result that T actually increases through time. There are several ways of viewing this same phenomenon. For example, the consumption of oil rises steadily year by year for the world as a whole. In 1990 annual consumption was 66 million barrels per day. In 2001 it was 76 million barrels per day. Yet the level of reserves stayed virtually constant in that period at some 1 billion barrels of oil. Reserves expanded so as to offset the increase in consumption. Of course, for any single oil field, or set of oil fields (such as the North Sea), the time profile of production is likely to have an upside down 'U' shape: production must peak and then decline. What is happening is that better use is made of existing reserves and that new reserves are discovered.

**Table 1      Changing values of 'resource life' 1970 to 1994**

Resource	T <sub>1970</sub> years	T <sub>1994</sub> years	Rate of change in T % p.a.
Aluminium	31	104	5.2
Copper	21	25	0.7
Iron	93	115	0.8
Lead	21	11	- 2.3
Mercury	13	20*	1.8
Silver	13	na	na
Coal	111	139	0.9
Gas	22	42	2.7
Oil	20	35	2.3

**Economic measures of scarcity**

Probably the most celebrated argument for supposing that the world is not running out of natural resources is that associated with the evidence that economic indicators of scarcity have generally fallen over time. Hall and Hall (1984) discuss various economic measures of scarcity. They offer the following classification:

- Malthusian stock scarcity (MSS): the resource is fixed in absolute size and extraction costs are constant
- Malthusian flow scarcity (MFS): the resource is fixed in absolute size but extraction costs rise with the rate of extraction
- Ricardian stock scarcity (RSS): no absolute limit on the stock but extraction costs rise with the rate of extraction and with the past quantity extracted
- Ricardian flow scarcity (RFS): no absolute limit exists but extraction costs rise with the rate of extraction

The corresponding relationships between price (P) and costs (C) is:

MSS	MFS	RSS	RFS
Price = average cost + user cost	Price = average cost + (PV(FC) + user cost	Price = average cost + PV(FC)	Price = average cost

'User cost' is the cost, in terms of lost future consumption, of consuming a resource today. User cost is also known as the *rental* or *rent* on the resource. The notation PV(FC)

refers to the *present value*<sup>1</sup> of increases in future average costs of extraction (FC). In this case, extraction now makes extraction in the future more costly. Hence the true (financial) cost of extraction must account for these future cost increases. Note that the indicators vary and hence adopting any one indicator may be misleading if the resource in question exhibits features relevant to another indicator. For example, we might choose the RFS concept which is very simple: price = average extraction cost. But if the resource has costs that rise with past levels of extraction, the relevant concept would be RSS, which means adding in an estimate of PV(FC).

The obvious short-cut to finding the 'right' indicator is to use resource price since in all cases this is the correct indicator. Focusing solely on price assumes, of course, that the relevant markets work well enough for prices to reflect the associated cost concepts. The most famous study of economic scarcity is that by Barnett and Morse (1963). This was a study of unit costs of extraction and hence captures only Ricardian flow scarcity. Barnett and Morse (1963) found that *average costs* (in real terms) of the extractive, agricultural, minerals and fishing industries in the USA 1870-1957 fell. Only in the forestry sector did average costs rise then fall again. Barnett (1979) updated the analysis and found no reason to change the original conclusions. Slade (1982) analysed *prices* for 1870 to 1978 for the USA and found some evidence of a 'U' shaped curve, prices falling for a long time and then beginning to turn up, suggesting near-term scarcity. But the final years of the data were distorted by OPEC activities on the oil price. The scarcity induced by OPEC was 'cartel-induced scarcity' and not therefore a reflection of underlying physical scarcity.

Hall and Hall (1984) fitted an equation of the form:

$$S = a_1 + a_2.D_1 + a_3.D_2 + b_1.t + b_2.D_{1t} \quad \dots\dots[8]$$

to time series of US resources for the period 1860 to 1980. S is the measure of scarcity (prices, unit costs); t = time (1960-1980); D is a dummy variable such that D<sub>1</sub>=0 for t<1969 and 1 for 1969-1980, and D<sub>2</sub> = 0 for <1974 and 1 for >1974. The focus on the period 1960-80 for the dummy variables is to ensure that the effects of the OPEC-induced price rises are separated out. The equation can be interpreted as follows: b<sub>1</sub> provides an indicator of scarcity in the 1960s and b<sub>1</sub>+b<sub>2</sub> provides an indicator of scarcity in the 1970s. Again, the interest is in the recent period since there is no dispute about the longer run historical trend of costs and prices, which was downwards.

The unit cost data are suited to the measure of RFS, and, of course, are part of all the indicators of scarcity. The price data reflect all the indicators<sup>2</sup>. In nearly all cases for the cost data, the sign of b<sub>1</sub> was significantly negative (the 1960s situation). The sign of b<sub>1</sub>+b<sub>2</sub> (1970s scarcity) was significantly negative for agriculture and non-ferrous metals, indeterminate for electricity and ferro-alloys, and was positive for coal and oil/gas. The suggestion is that unit costs began to rise for coal, oil and gas and electricity before the impact of OPEC was felt. The price data revealed a similar picture but coal failed to

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<sup>1</sup> A present value is the value now of a stream of benefits, revenues or costs over time. The present value of \$1 next year is \$1/(1+r) where r is the 'discount rate' which, for current purposes, can be thought as the interest rate. This is easy to see since investing \$1/(1+r) now would produce \$1(1+r)/(1+r) = \$1 next year. The present value of \$1 two years hence is then \$1/(1+r)<sup>2</sup> and so on.

<sup>2</sup> However, the RFS case has price equal to average cost so that the implicit assumption is that there is a perfectly competitive state of the world.

show a rising trend in price in the 1970s. The OPEC-induced price rises were on top of these underlying changes.

In general, the evidence appears to suggest that real resource prices and costs decline through time, with perhaps some evidence of an upturn in the 1970s which combined with OPEC-induced scarcity to produce some rising real price levels.

How useful are such exercises? There are two major problems with drawing conclusions from the studies. First, the externalities associated with the use of the resources in question are ignored. Yet these are a central part of the 'true price' of resource use. What matters is the social cost of minerals and energy, not their market prices. Second, and a related issue, the analysis has, by definition, to be limited to *marketed* resources, whereas the focus of modern attention is not on those resources but on *non-marketed* resources such as the global atmosphere, the oceans, land-based ecosystems and so on. This has been termed 'the new scarcity' and the market price analysis tells us little or nothing about these scarce resources. Perhaps the most that can be said is that if non-marketed assets were subject to market forces they would also benefit from the features of marketed goods, i.e. efforts would be made to conserve them.