DEBATE

Fossil fuels will not run out

by Marian Radetzki

The concern that mankind will run out of exhaustible resources is as old as the large scale exploitation of these resources. In this article the author analyses fossil fuels and his conclusion is decisive: We will not run out of oil, gas and coal. Instead he argues that fossil fuels will contine to have a very important role to play in the world's energy supply and that the most probable development is that the world's supply of energy can be secured at stable or falling costs until alternative forms of energy become established.

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The concern that we will run out of exhaustible resources is as old as the large scale exploitation of these resources. From the early years of industrial society onwards, the Cassandras have compared an exponential increase in resource utilisation with a declining resource base and have prophesied the impending troubles that will confront material civilisation once the exploitation of natural resources slows down, prices rise dramatically and hair shirts become the order of the day:

During the late nineteenth century, Stanley Jevons, a leading economist of the day wrote The *Coal Question* (Jevons,1866), a well-argued, influential study which raised a number of difficult issues for his contemporaries. At that time, England was still the leading industrial nation and coal was the engine that drove the country's economic development. A combination of painstaking research and considerable bravery led Jevons to the conclusion that although England's coal resources were very large, they would at the present rate of expansion be soon exhausted. This would lead to rising costs, a reduction in competitiveness and present a threat to the country's prosperity. Jevons reached the gloomy conclusion that the country had to choose between a sustainable but sluggish rate of industrial development and a spectacular expansion that ended in complete failure. All of this was on account of the finite nature of coal resources.

The 1960s will no doubt be seen by historians as the decade during which the world economy expanded most rapidly. The exploitation of metals and fossil fuels grew at an even faster rate than the world economy and many were appalled by the realisation that these prevailing trends would not be tenable in the long term. The danger of exhausting the supply of fossil fuels was one of the leading arguments underlying the heavy public investment in nuclear power. At a more general level, these concerns were forcefully expressed in the writings of the Rome Club in the early 1970s. (Meadows et al 1972). The authors placed substantial emphasis on the limited world reserves of metals and fuels. For example, since copper reserves represented only 30 years current production, the world would be bumping against the resource ceiling long before the end of the century, notwithstanding the addition of substantial new reserves. Under no circumstances would the resource base be able to provide every Chinese household with a telephone. We would run out of copper long before that would prove to be possible.

The early 1980s saw the triumph of the so-called Hotelling rule. Subject to certain assumptions, this rule stated that the real price of finite resources must always rise at the same rate as the real rate of interest. This argument was supported by sophisticated scientific models which demonstrated why this must be the case. Among academic economists, oil analysts and political decision-makers, the view became widely held that the increase in oil prices during the 1970s wasthe beginning of a continuous rising trend. The price forecasts made by experts during this period convey a clear message. They all point steeply upwards. Neither scientists, economists nor politicians were able to see any way around the scarcity of resources. Oil and the other increasingly scarce raw materials could only become more expensive. A gloomy prospect indeed.

How we escaped from the clutches of doom

The three days of doom did not occur as had been prophesied. Human flexibility and ingenuity removed the growing spectre of resource scarcity and we quite simply forgot for a while our previous concerns:

The production of coal in United Kingdom tripled from 75 Mt in 1860 to 220 Mt in 1900 and remained at this high level until the 1960s. Subsequently, it declined dramatically to a level of 50 Mt in 1994. This fall in coal production was however not due to the exhaustion of coal supplies. In the1970s, the country's coal resources were actually three times as large as they had been one hundred years earlier, notwithstanding the massive exploitation that had taken place during the intervening period. The principal explanation was that during the 1960s it had become increasingly economic to replace domestic coal by imports or by oil and gas, resources that were largely unknown when Jevons was writing. During the past thirty years, the British economy would undoubtedly have performed much better if it had not had to bear the burden of a deeply traditional, strike-prone, unprofitable coal industry. It is ironic that valuable coal resources whose assumed scarcity worried those responsible for energy policy in the 1860s have been transformed into worthless assets that have been exploited more recently at a high cost to both customer and taxpayer.

Between 1970 when the Rome Club was busy polishing its gloomy predictions and 1994, the global production of copper has almost doubled without any reduction in reserves. In global terms, reserves have doubled which suggests that the thirty year multiple still applies. However this multiple no longer sets any limitation on Chinese telephone ownership. A technical innovation during the 1980s replaced the expensive copper wires in telephone communications with the more efficient and in practice inexhaustible glass fibre. The physical resource requirements of the telecommunications industry were further reduced during the 1990s as a result of the technical innovations associated with the mobile telephone.

The high oil prices of the 1980s were a result of the operations of an efficient cartel that controlled the world's largest and most profitable oil resources, and not a consequence of a growing depletion of these resources. The price forecasts of this period based on the erroneous Hotelling rule proved to be monumental mistakes. Later in the decade, the price of oil collapsed as a result of a change in marketing strategy by the members of the cartel. The forecasts of the 1990s predict stagnating or falling prices for the forseeable future.

Neither God-given nor determined by nature

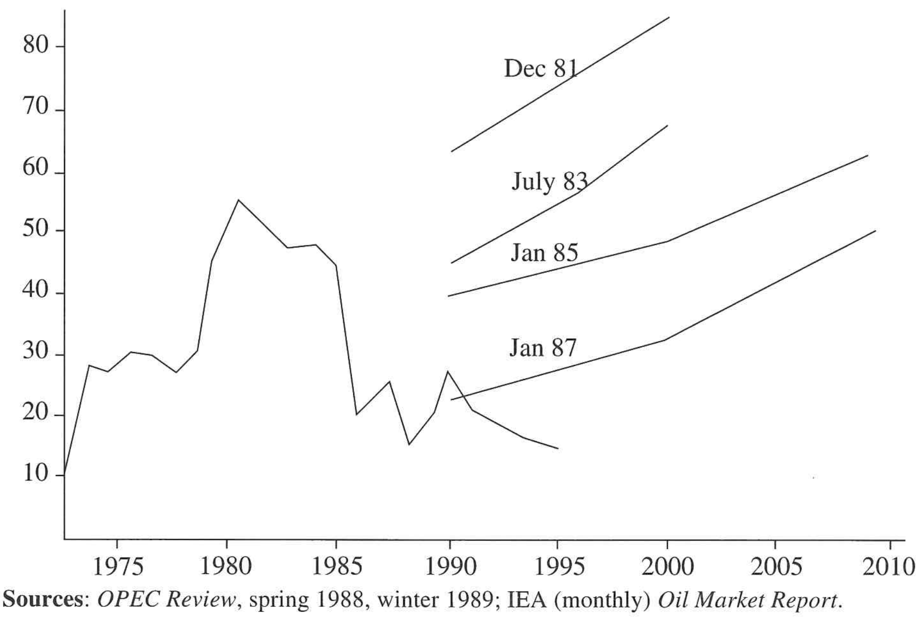
In 1970, world production of copper was 6.4 Mt while reserves were thirty times that amount. By 1994, world production of copper had reached 12 Mt. However reserves have kept pace with the increase in output and are still thirty times as great. Indeed if we go back to 1925 when copper production was only 1.4Mt, we find that the reserve multiple is the same. Similar constant relationships also apply to all of the other exhaustible resources.

The global production of copper increased more than eightfold between 1925 and 1994. In the case of iron ore, there was a fourfold increase while aluminium production grew more than one hundred times during this period. Oil and gas production rose by a factor of 20 and 50 respectively. On the other hand, there was only a slightly less than threefold increase in the production of coal. The reserves of each and every one of these raw materials increased at approximately the same rate as the growth of production.

If we view these reserves of raw materials as gifts of nature, it may appear paradoxical that available coal reserves increased only threefold during this seventy year period while oil reserves grew more than twenty times. It will be easier to explain this development if we treat these reserves as capital equipment. which has resulted from a deliberate investment programme aimed at finding new sources of supply that will secure the long term growth of mining and energy production.

These reserves act as a buffer for the companies that will guarantee stability in relation to the exploitation of resources and the expansion of production at a rate that corresponds to the growth of de-

Figure 1. Oil prices 1973–1995 and the median price of authoritative forecasts made at different points in time in the 1980s. Constant USD (1995) per barrel.



Sources: *OPEC Review*, spring 1988, winter 1989; IEA (monthly) *Oil Market Report*.

mand. Depleted reserves are replaced by new sources of supply. Accordingly the buffer remains constant. Exploration for new reserves will give rise to costs. Consequently it is not economical to explore for new reserves in excess of the level required for production planning in exactly the same manner that it would not be economical to purchase machines that will only be used in the future. In this perspective, it is not difficult to explain the thirty year multiple against a background of normal production growth and the long planning horisons of mining and energy companies.

Technical progress reduces the costs of natural resources

Resource depletion is an economic rather than a physical concept. A reserve stock that grows as a result of exploration is not therefore in itself an indication that depletion is not a problem. The worry remains that the new reserves may be of poorer quality and more expensive to exploit.

Empirical evidence provides a very mixed picture regarding changes in the quality of world reserves of various minerals and fossil fuels:

Reserves of copper have undoubtedly declined in quality over time. At the turn of this century, reserves that had a metal content of under 5 per cent were not worked. Nowadays, the majority of copper ores that are exploited have a metal content of 1 per cent and many mines are working copper deposits that have only a 0.5 per cent metal content. At the same time, the average size of the ore bodies in the reserve stocks has increased quite markedly during the period.

As regards iron ore and coal, the size of individual ore bodies have increased substantially and the proportion of open cast deposits has tended to rise. At the same time, both the average metal content and the energy content of the reserve stocks have tended to improve. While these undoubted improvements have taken place, there has been a geographical shift that has distanced the reserves from the final users. Earlier this century, most of the ore and coal was located close to the production site. Nowadays, huge volumes cross the oceans of the world and transport costs represent a substantial part of the final price.

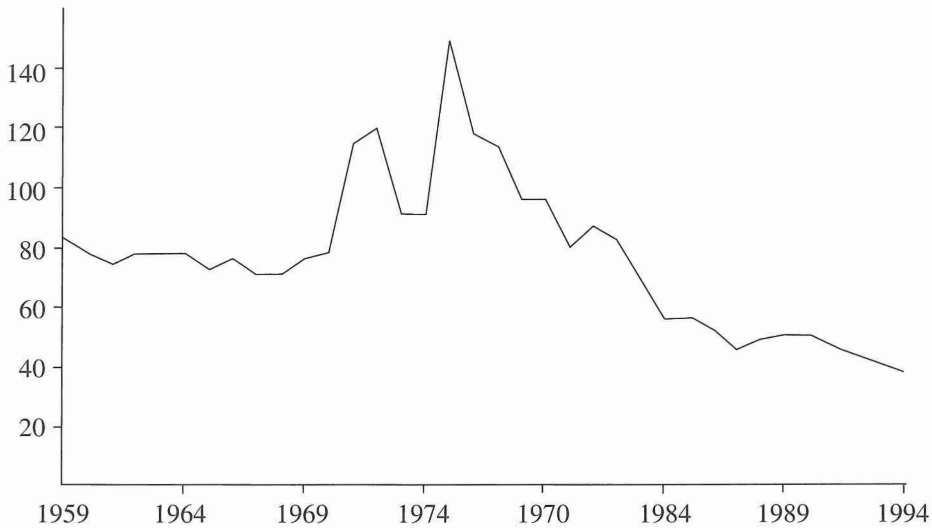
Europe's supply of natural gas has become increasingly dependent on the huge low cost fields of Russia and Algeria that have tended to replace the smaller higher cost fields in France, Italy and Germany that previously provided the bulk of European gas supply. As was the case with coal and iron ore, the proportion of transport costs in relation to the total costs of delivery has tended to rise as more distant reserves have been brought on stream.

During the 1950s, as the enormous potential of Middle Eastern oil was gradually understood, there was a radical improvement in the quality of world oil reserves. However after 1973, quality declined as a result of the supply limitations of leading OPEC members. This had the effect of stopping exploration where the potential was greatest. Less accessible deposits of smaller size, e.g. Alaska and the North Sea have provided the bulk of the new additional oil reserves. The result has been a reduction in the average quality of the oil reserves.

This brief overview indicates that there is no clear-cut long term trend towards a lower quality of reserves, despite the large scale increase in production volumes. On the other hand the costs and prices of practically all of the world's exhaustible resources, irrespective whether the quality of the reserves has improved, have clearly fallen over the long term.

During the period 1900–1972, prior to OPEC's control of the oil market, the real delivery price of oil has been falling. The same trend has also applied to metals and minerals (Radetzki 1990). As a result of the market interventions of the OPEC cartel, the price of oil has subsequently risen. At the same time, the fall in the prices of metals and minerals has tended to accelerate. Between the early 1970s and the early 1990s, the real price of these categories of raw materials have fallen by almost 50 per cent (World Bank

Figure 2. Import price of steam coal at European ports. Constant USD (1995) per ton coal equivalent.



Source: 1959–1979, Statistics Sweden, *Utrikeshandel Månadstatistik*: (Foreign Trade; Monthly Statistics) 1980–1994, IEA (annual) *Coal Information Paris.*

1994). Similar price trends can also be found in the world market for coal.

Over periods of time that are as long as those discussed here, price trends on competitive markets will not be able to diverge significantly from the cost of supply. On the basis of the price data presented, the costs of delivery of metals, minerals and fossil fuels have been falling over the long term. Hence the predictions of economic theory in relation to the depletion of exhaustible raw materials have not been borne out in practice. The costs of delivery include the costs of transport to the user. As a result of the growing geographical distance between production and consumption, the latter have tended to rise in relation to total costs. Hence the fall in actual mining costs has exceeded the fall in delivery prices.

Falling costs as a result of technical innovations in prospecting, mining and transport is the principal explanation of these favourable trends. A continuous reduction of costs may even be noted in those cases where the quality of reserve stocks has clearly deteriorated. The costs of producing copper in the 1990s from reserves with a metal content of 0.5 per cent is substantially lower than the equivalent costs in the 1910s when the ore content of copper was ten times higher. The negotiating position of the OPEC cartel has been steadily undermined by the dramatic reduction in the costs of oil exploitation which has enabled low quality oil fields in the North Sea and Alaska to be increasingly competitive.

Human ingenuity has so far had an upper hand over resource shortages. Falling costs and prices bear witness to the fact that scarcity has been held at a growing distance.

A permanent upward movement of costs and prices would represent an early warning of approaching depletion. A still earlier warning would be provided by a rise in the costs of prospecting for new reserves. No such signals have so far been received.

Satisfying needs

The price of copper or oil is actually of little significance for our material civilisation. It is the costs of satisfying human needs that is of fundamental importance. This statement points to yet another degree of freedom in the resource depletion dilemma. Even if costs were to turn upwards and oil and copper were to become increasingly expensive, the costs of satisfying human needs could nevertheless be held constant or indeed fall as a result of the substitution of cheaper alternative materials or by a more efficient use of existing scarce materials.

The substitution of glass fibre for copper in the tele- communications industry is an example of how a cheap and almost infinite resource (silicon) was substituted for a much dearer and potentially scarce resource. The substantial increase in productivity that resulted from this substitution may be seen as a benificial side effect. Glass fibre of a given weight and volume is able to carry a vastly increased number of telecommunication signals than would have been possible with the same volume of copper. This substitution took place in the face of a long run fall in the price of copper. The incentive to substitute would naturally have been greater if copper prices had been rising.

The explosive growth of the nuclear energy industry during the 1960s and 1970s provides us with another important example of substitution. In this instance, it is a question of replacing fossil fuels in the energy sector. Here the degree of success is not quite as evident as in the substitution of glass fibre for copper since there was a need for substantial financial support from the public sector during the initial stages of developing nuclear power. At the same time, during recent years, there have also been considerable political and economic obstacles to the continued expansion of the nuclear energy industry.

The succesful substitution of solar power or some other futuristic source of energy for oil is presumably still some way off. This process would be accelerated by a major increase in fossil prices as a result of clear signs of resource depletion (improbable) or due to high taxes introduced in order to reduce oil consumption.

Access to an advanced broadly-based technology will facilitate the processes of substitution. The opportunities to satisfy human needs by the use of various types of substitution of both methods and materials are much more numerous in rich diversified economies than in poor underdeveloped societies. The post-industrial era has been justifiably termed "the age of substitutability" (Goeller and Weinberger 1976). Our increased capacity for substitution reduces our dependence on each individual exhaustible resource.

It is nevertheless quite remarkable that the prices of exhaustible resources have tended to fall in relation to those of finished goods (falling real prices of exhaustible resources) and there is perhaps good reason to examine the question more closely. There is a lot of sound reasoning in Mill's argument (Mill 1848) that the fall in the costs and prices of natural resources and finished goods respectively brought about by technical progress should be of the same magnitude whereas the pressure of growing scarcity, albeit weak, should lead to a rise in the prices of resources but not in those of finished goods. It is this argument that provides the basis for the classical view that the real or relative prices of exhaustible resources will always rise.

Why then does all the empirical evidence point in the opposite direction i.e. that the prices of exhaustible resources have fallen over time ? Generations of economists have debated this question. One conclusion that is gaining ground is that price comparisons do not take sufficient account of improvements in the quality of finished goods. Oil and copper in 1995 is more or less identical with oil and copper from 1925. A tractor or a light bulb produced in 1995 performs much better in terms of durability, energy consumption, loading or lighting capacity respectively, than the equivalent product produced seventy years ago. However price statistics fail to take complete account of these positive changes. Tractors and light bulbs tend to remain just as tractors and light bulbs. If a tractor could be purchased for the equivalent of ten tons of oil in 1925 whereas twenty tons were required for the same purchase in 1995, the statistics would indicate a substantial fall in the price of oil in relative terms. It is possible, indeed probable, that the statistics should in fact indicate the opposite when full account is taken of the change in quality and the resultant rise in the utility value of the tractor over time.

Statistical adjustments of this type may possibly verify the classical view that the relative price of exhaustible resources ought to rise. However the satisfaction of human needs is not particularly dependent on the relative price movements of exhaustible resources and finished goods. The central issue concerns the costs of satisfying human needs. Here we have to take account of the costs of both natural resources and finished goods. A fascinating study of the real costs of light over the past hundred years (Nordhaus 1994) argues that conventional cost and price series provide an irrelevant measure of the cost of satisfying human wants. On the basis of real price indicies for the United States (1883 =100), the price indicies for kerosene and electricity in 1993 were 75 and 3 respectively i.e. a fall in the real prices of these commodities of 25 and 97 per cent respectively over this period. Similar real price indicies for kerosene lamps and electrical bulbs of various types do not indicate any significant fall in real prices for these goods over this period. However the index for the real cost of a lumen, a unit measurement of light, was only 0.1 per cent in 1993 i.e. a given quantity of lighting in that year cost only one thousandth of what the same quantity of lighting would have cost one hundred years ago.

The figures clearly indicate the power of technical progress to generate light with ever-decreasing inputs of finished goods and to economise with kerosene and electricity. The real cost of light would not have been notably affected if the prices of fossil fuels had doubled or trebled during the period owing to growing resource depletion. Human ingenuity rather than the price of exhaustible resources has been the decisive factor underlying our ability to satisfy human needs and thereby contribute to human welfare.

Fossil fuels will remain in the ground

We will not run out of oil, gas and coal. Fossil fuels have a very important role to play in the world's energy supply. Existing trends indicate that the world's supply of energy can be secured at stable or falling costs until alternative forms of energy become established. It is possible although somewhat improbable that current trends will change and a growing shortage of resources will lead to higher supply costs. This would lead in turn to increased efforts to accelerate the process of substitution and reduce the dependence on fossil fuels.

A good guess is that by the year 2097, fossil fuels will play a marginal role in world energy supply although in quantative terms their importance will be significant. The fossil resource base will still be very large although a growing proportion of these resources will have become increasingly uneconomical as was the case with British coal reserves in the mid twentieth century. New technologies and new types of fuel, most of them still unknown, have taken over the predominant role that fossil burning will play in meeting our need for energy.

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