NATURAL NONRENEWABLE RESOURCE DEVELOPMENT INFORMATION AND KNOWLEDGE

Giancarlo Barbiroli and Antonio Focacci
Faculty of Economics—Business and Management Department: Technology and Resources Valorization Area, University of Bologna, Italy

Keywords: Natural resources, technological change, sustainable development, non-renewable resources, resource depletion.

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Summary

Given the importance of natural resources for all aspects of human activity, an account is provided of the current level of knowledge and information analysis with regard to their availability and adequacy, with particular reference to ore resources. Traditional models of the exploitation of natural resources need to be revised, particularly in the light of the concept of sustainable development, which demands greater qualitative development rather than mere quantitative growth.

The information currently available concerning technology, costs and prices should take these points into account, with the result that what is needed is a profound transformation of society in order to achieve such goals. Besides the classical (and well-established) position, new paradigms are emerging, placing a greater emphasis on environmental concerns compared with that afforded in the past.

1. Introduction

Concern about the adequacy and evaluation of raw materials (and thus about the available relevant information) can certainly be considered of significant importance within the field of sustainable development studies.

The industrialized world saw the economic growth of the 1960s as countering the fear of imminent shortages of natural resources, and as a result the question of availability inevitably became less important. Nevertheless, the 1973 energy crisis produced alarming increases in the price of oil and other raw materials, leading to a radical change in this view. Previously, the Club of Rome's famous report (*The Limits to Growth*) had already lent further support to the thesis of the long-term inadequacy of exhaustible resources.

During the 1980s, falling commodity prices led to renewed optimism over resource availability. Yet at the beginning of the new decade, the concept of "sustainable development" was already coming to the fore, both in academic and government circles. However, the following three fundamental premises are of particular interest:

(i) the availability of resources is quantitatively limited, given the size of the Earth;
(ii) this limited availability has been countered, in both quantitative and qualitative terms, by the recent discovery of unknown resources, by the use of new resources in place of previously employed ones, and by the lower level of use of each resource per unit of finished product; and
(iii) real availability also depends on technology, since technological change is used to counter the lack of available resources, although the required technological knowledge is not always at hand when it is most needed, and it is not always possible to utilize such knowledge in practical applications.

This article addresses various aspects of natural resource development and information, with particular reference to nonrenewable resources, as exemplified by ore/mineral resources.

2. Theories of Depletion

The current economic theory of nonrenewable resources derives from Hotelling's well-known rule (1931), which considers user cost to be tied to the rate of interest. Intuitively speaking, as has already been pointed out, a resource is comparable to a capital asset where, *coeteris paribus*, the user cost will be positive (and increasing) if the resource is becoming scarcer as a consequence of use. This rule takes the behavior of the entrepreneur to be linked to the change in user cost over time, so that if:

(a) The interest rate were lower than the variation in the user cost, then the resource would not be extracted in order to gain future benefit from its increase in value, and thus from increased earnings resulting from the ensuing appreciation.
(b) The interest rate were higher than the variation in the user cost, then it would be better to extract the resource more quickly so as to benefit from more advantageous investment alternatives through the reinvestment of the value obtained from its subsequent market sale. There would also be a strictly

financial aspect to take into consideration, e.g., in a situation characterized by increasing rates of interest, it would be an advantage to sell a nonrenewable resource such as ore so as to pay off accrued debts which could become particularly burdensome in such a situation.

(c) The rate of interest were equal to the variation in the user cost, then it would make no difference to the entrepreneur whether the nonrenewable resource was extracted or left where it was.

In fact, as can be seen from the above propositions, the economic agent has to compare the market interest rate of the alternative investment opportunities, with the profitability index of (in the case discussed here) mineral extraction (given by the variation in user cost, over time, of extraction of the nonrenewable resource). By doing so, a decision can be made on the level of economic activity, and thus, by implication, the speed at which the resource is to be "exploited" and therefore, the time-scale of its complete depletion. This original model was defined on the basis of a series of simplified assumptions, i.e., a situation of perfect competition, with firms (companies) maximizing net present value, a fixed stock of a homogeneous resource, constant extraction costs, and no technological change. Subsequent authors have tried to relax such constraints by proposing increasingly complex forms of analysis which took into account certain aspects which had previously been ignored.

The principal current theories of depletion of exhaustible resources can be divided into two different schools of thought, the one egalitarian, and the other individualist. The egalitarian perspective adheres to the so-called fixed-stock paradigm, whereas the individualist perspective supports the opportunity-cost paradigm.

2.1 The Fixed-Cost Paradigm

The fixed-cost paradigm position is held by those who are particularly concerned about the possible scarcity of resources in the near future. Depletable resources (oil and copper, for example) are considered to be nonrenewable; the fear being that at the current rate of consumption, humankind will inevitably reduce the overall supply of natural resources available to future generations, since the total quantity of such resources cannot be modified.

Despite the fact that new discoveries and technological improvements have partly countered the depletion process, the proponents of this view are still worried by two specific issues:

(i) Future growth in demand could reach exceptional levels and thus seriously challenge the capacity to satisfy requirements.

(ii) Concern over the environmental impact of human activities, whether they involve the extraction of resources or not. Take the example of copper extraction: current extraction of copper from minerals with a copper content of 0.3% produces a quantity of waste material ten times greater (per ton of metal obtained) than what was previously produced using minerals with a copper content of 3%. The available resource is smaller and the waste by-product is greater, which has a negative impact on the natural environmental balance. In addition to these concerns, proponents of this view also argue that the advent of new technology often produces such vast and rapid changes that existing political and economic institutions are incapable of effectively coping with them. They maintain that failure to consider the social and environmental costs of such activities can easily lead to the harmful and excessive exploitation of resources.

2.2 The Opportunity-Cost Paradigm

Those who support this opportunity-cost paradigm are less worried about the scarcity of resources than those who support the fixed-cost position, as they do not consider the limited nature of the overall supply of natural resources to be a decisive factor, since the utilization of a mineral for its conversion into a metal does not, in fact, mean that the resource has been eliminated. The central argument is one of supply and demand: if the cost of resource production rises to a particularly high level as a result of the difficulty of extraction, then demand for such resources will be reduced or eliminated. Two possible scenarios are as follows:

(i) Should there be a scarcity of a given resource, then the economic system would be forced to turn to the exploitation of deeper, more expensive deposits of that resource, which in turn would lead to a significant increase in production costs (and thus in prices), and subsequently to curtailed demand.

(ii) If the price of a resource rises to a particularly high level, then demand may cease altogether, and the remaining deposits of that resource will remain underground without having been completely exhausted.

One important aspect of both these positions is that technological change (in terms of both the discovery of new deposits, and of the costs of production and transformation) may have a counterbalancing effect on the utilization of mineral resources that are increasingly costly to extract. Consequently, increasing levels of exploitation would not automatically lead to the scarcity of resources. Furthermore, the opportunity cost of extraction and transformation in such a case would consist of the "full" cost; that is, it would have to include all external environmental factors. Contemporary economic opinion tends to favor the opportunity-cost paradigm as a theoretical model, although it enjoys less support from ecologists and other scientists.

2.3 The "Business-as-Usual" Hierarchists

A summary of the positions held by scholars would not be complete without a mention of the intermediate position held by those adherents to the hierarchical school of thought. The latter are not so sure that technological change is going to be faster than it has been in the past, and they adopt an intermediate management style and world view.

The general characteristics of the three different perspectives described in the sections above are summarized in Table 1.

General characteristics	Egalitarian	Individualist	Hierarchist
View of nature	Ephemeral	Benign	Perverse, tolerant

Concept of human nature	Born good, malleable	Self-seeking	Sinful
Management style	Preventive	Laissez-faire, adaptive	Control, regulatory
Desired system properties	Sustainability	Exploitability	Controllability
Ideal scale	Small	Appropriate	Large
Economic growth	Not a primary goal	Unconditionally desirable	Desirable with conditions
Salient risks	Catastrophes	Threats to free market	Loss of control
Risk-handling style	Reduction	Risk-seeking	Institutionalization
Attitude to needs/resources	Needs-reducing strategies	Rational allocation of resources	Expanding resource base

Source: Vuuren et al. 1999

Table 1. General characteristics of the three different "schools of thought" on theories of nonrenewable resource depletion

3. Availability, Costs and Prices

The importance of natural resources for all forms of human activity is a well-known fact. All economic sectors are ultimately based on resources found in nature. Natural resources can be classified according to two different perspectives: the one based on the physical properties of the resource, and the other on the time scale of the respective adjustment processes.

As far as the first criterion is concerned, natural resources can be classified as either biological (e.g., most agricultural products, forestry products, fish and mammals), or non-energy mineral (iron ore and most minerals), or energy (fuels such as oil and coal), or environmental resources (e.g. air, forests, groundwater, uncontaminated wilds, and so on).

Given the time scale of the respective adjustment processes, the most widely accepted definition of natural resources sees them divided into two main categories: renewable resources (e.g., fisheries, forests and woodland) and nonrenewable resources (otherwise known as exhaustible or depletable resources, such as oil, iron ore and coal).

The finiteness of a commodity is one of the major concerns in the field of natural resources study, and even though, in simple economic terms, it should be reflected in its costs and price, it should be pointed out that other factors should also influence price, such as the environmental aspects of natural resources, amenity provision, waste assimilation and life support. A distinction should be made here between physical and economic indicators of scarcity.

Physical indicators of scarcity. Physical indicators are mainly based on geological estimates of reserves, and are related to the level of demand. The fundamental distinction in mineral resource information is between reserves and resources. The first term, most commonly used by mining and geological engineers, is the size of the current known working inventory of the material that can be produced economically, given present costs and prices; changes in prices or costs invariably alter this stock base.

All estimates of the life expectancies of resources (both fuels and ores) are based on such reserves. This life expectancy is usually calculated using the current production/reserve ratio. As an illustration of this, Table 2 shows estimates made by the World Resources Institute with regard to the year 1992.

Metals	World reserves base life index (years)
Aluminum	270
Copper	64
Lead	38
Mercury	80
Nickel	119
Tin	56
Zinc	46
Iron ore	247

Source: The World Resources Institute 1994

Table 2. World reserves base life index of some metals (years)

The second concept, that of resources, refers to the quantity of the material that cannot be produced economically at present, but that could be produced at a higher price which met production costs. Thus reserves are one part of overall resources. It is clear that both these concepts are linked to a number of factors (for example, the state of technology, market conditions, political relationships, uses and so on) if a dynamic position is adopted with regard to economic evaluation. An excellent theoretical explanation of this can be found in the model proposed by Govett and Govett, where all these different aspects are assembled within a triangle (representing the finiteness of the resource) divided into different areas according to the classification of the resources at the various stages of economic utilization and according to the state of technology (Figure 1).

Estimates of different kinds of resources constitute the most important information requirement when calculating future adequacy, and consequently the most important reason for wanting to formulate such estimates is the identification of those particular minerals whose production costs and prices could rise over the next few decades. Sharp increases in costs are likely if production costs rise in a discontinuous manner and at an increasing rate, while the opposite is true if production costs rise in a continuous manner and at a declining rate. The identification of such situations would be much easier if both sound methods and appropriate data were available with regard to the estimation of potential mineral stocks.

Economic indicators of scarcity. Many studies have attempted to formulate a definition of economic indicators of scarcity, and all of them have been addressed to the definition of indicators that take in all the sacrifices made in order to obtain a unit of the resource itself. The most generally used measure is the unit cost of production (calculated from the real costs paid at the production stage) and the true user cost (unobservable in practice, this reflects the present value of the benefit of postponing the production of a unit of the resource to a future date).

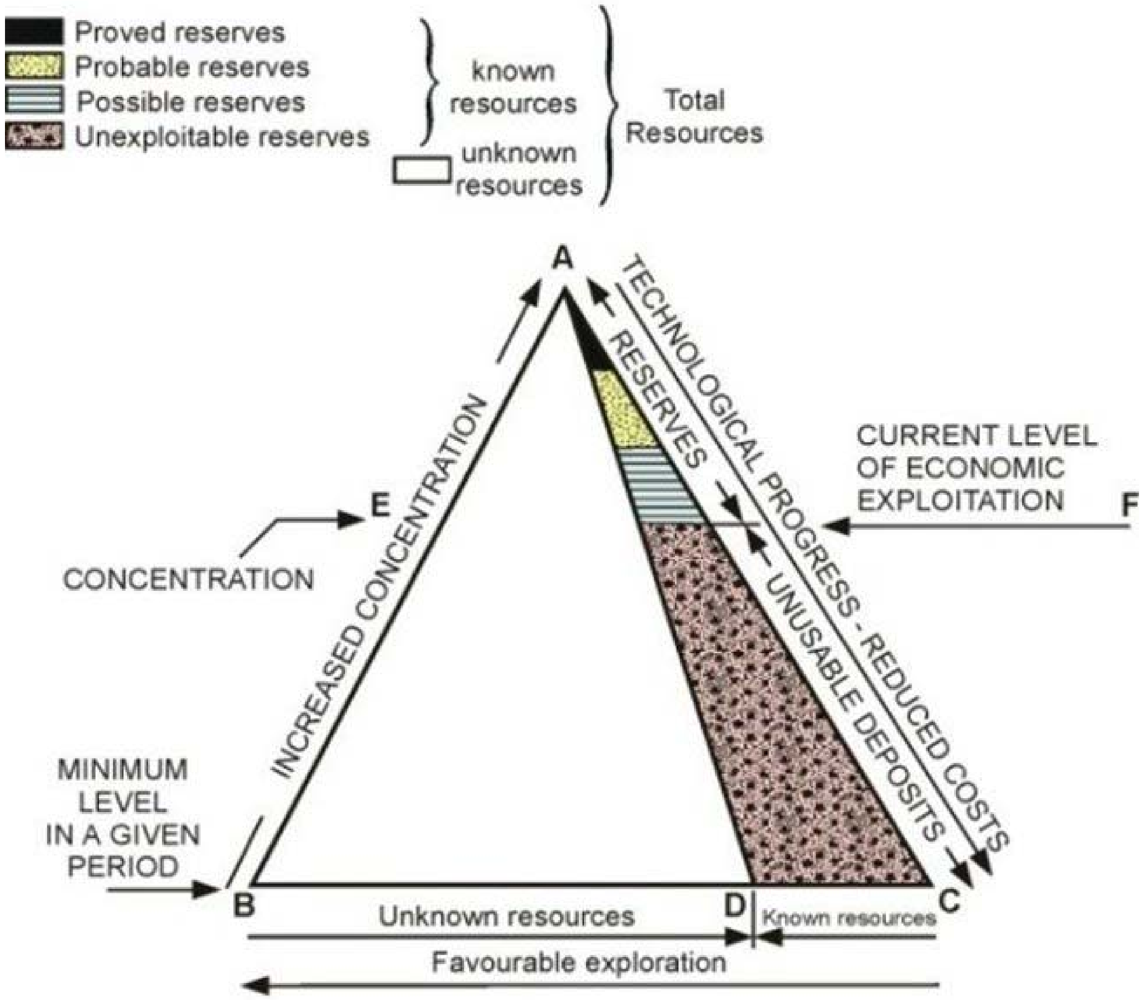

Figure 1. The Govett and Govett model (1974) representing resources and reserves in relationship with technological and economic conditions

The glossary also gives definitions of the various categories of reserves (reserves—used as a term on its own, and indicated, inferred and measured reserves) and resources

(resources—used as a term on its own, and known, nonrenewable, renewable, total, and unknown resources), mostly with specific reference to ore/minerals.

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Biographical Sketches

Giancarlo Barbiroli has been a Full Professor of Technology of Production Cycles at the Faculty of Economics, University of Bologna, since 1975. His fields of research are techno-economic analyses carried out on production activities, in order to evaluate their main features, with regard to the technologies adopted and their global performance, the efficient use of energy sources and materials, the impacts on ecosystems, and quality. He has set up and implemented special indicators and models, able to measure the aspects of global performance of production activities, at company and economic system levels; these can be useful for making efficient and appropriate choices, as well as in improving methodological procedures. The branches of production he has systematically investigated, as important case studies to draw general assumptions, have been durable goods (automobiles, appliances), metals and materials (steel, aluminum, cement, paper, etc.), and foodstuffs. Publications (180 articles and 14 books) have appeared in international journals such as: *Technovation, Energy Economics, Journal of Environmental Management, Energy Sources, Applied Energy, Structural Change and Economic Dynamics, Journal of Mathematical Economics, International Journal of Systems Science, International Journal of Sustainable Development and Industrial Ecology, Journal of Scientific and Industrial Research, Energy Policy, Resources Policy, Rassegna Economica,* and *Note Economiche*, and in the proceedings of international symposia. He has participated in the Italian National Research Council project with the theme Alternative Technologies for a Dynamic Dependence (1984–87), and as coordinator of Theme 1. He has taught in two European Master Degree courses on Environmental Management (Sofia and Ankara) organized by the International Centre for Technical Research in London, and funded by the EU (1994–1997). He is a member of the Italian Society of Economists. He has been Dean of the Faculty of Economics, University of Bologna (1984–1993), during the celebrations of the Ninth Centenary of the University of Bologna.

Antonio Focacci graduated in Economics from the Faculty of Economics of the University of Bologna in 1993. He is a researcher in Commodity Science at the Department of Business and Management—Technology and Resources Valorization Area, and has been in the same Faculty since October 1996. He is involved in research projects concerning economic and technological aspects of production processes, and the rational use of resources by using techno-economic analyses and an interdisciplinary approach. His publications have been included in all the different kinds of typical academic productions: journals, monographs and proceedings of congresses. He has also had working experience in management control and financial management within private companies.