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MINERALS SCARCITY AND ECONOMIC CHANGE; DESIGN AND DISCUSSION

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CONTENTS

MINERALS SCARCITY AND ECONOMIC CHANGE : DESIGN AND DISCUSSION

I. INTRODUCTION

Concern for natural resource scarcity, initially agricultural land, goes back centuries in time. Many publications on public policies embodying economic analysis date from Adam Smith, Thomas Malthus, David Ricardo and John Stuart Mill in the latter 18th and early 19th Centuries. Further modernization of concepts of natural resource scarcity occurred later in the 19th Century. Among important writing were W.S. Jevons on coal, George Perkins March on ecology, Henry George on land rent, and the founders of the European and American conservation movements on forests, water and agricultural land.

In the first half of the 20th Century, natural resource scarcity doctrine, including minerals, was extended in the Western world. The leaders were conservationists and government officials. Policies to cope with scarcity were embodied in major laws and policies concerning public lands, taxes and government investment. Minerals scarcity concepts became significant. In some countries, they were the basis for preferential tax laws, governmental reserves, and public assistance in geology, exploration and development. Foreign investments by companies from developed countries occurred or expanded.

Minerals availability/scarcity concerns have been even more emphasized following World War II. The reasons are increased industrialization and dependence of economic growth and national security on minerals use, depletion, and foreign supplies. Foreign investments by multi-national companies in the developing countries have expanded enormously. Governments and public corporations have become heavily involved in minerals activities.

Natural resource events became even more prominent in contemporary public affairs during the 1970's. There have been explosions of new interests, with major policy implications. Because of new developments, simple extensions of former economic trends are no longer appropriate. One event is the initial promise and then growing disillusion and distrust over widespread use of nuclear electric power to overcome possible scarcity of fossil fuels. A second is the Organization of Petroleum Exporting Countries (OPEC) and other cartels. More generally, the quest for a New International Economic Order (NIEO) has changed the relations between developing and developed countries, particularly in the field of exploitation and supply of minerals. A fourth event is potential availability of vast mineral resources from the oceans at economical costs. A fifth is the phenomenally successful environmental-ecology movements in the U.S. and - perhaps to a lesser extent - in other countries. In profound and sweeping legislation, they have eliminated vast mineral resources from economic availability and have increased costs from present reserves; these have fostered scarcity in mineral supplies. Some of these and related events have been novel and all have been potent.

The recent developments call for not merely extending scarcity doctrine along conventional lines but for re-thinking what we have learned earlier about economic aspects of physical scarcities and substantially enlarging the scope of our analysis.

IIASA, in its System and Decision Sciences Area (SDS), has undertaken a modest research effort, focused on Europe during the past 2 or 3 decades, The present working paper is an exploration and discussion.

II. RESEARCH OBJECTIVES

The specific objectives of the research effort are as follows:

Task 1: To formulate minerals scarcity concepts and measures appropriate for the long term for Europe and individual European countries.

Task 2: To measure trends in minerals supply scarcity in the world and Europe, as these affect European countries.

Task 3: To account for and explain the contemporary minerals scarcity trends in terms of basic forces.

Task 4: To make economic projections of European economic change for the next decades, and to reach conclusions concerning future costs and other conditions of minerals supply for European countries.

III. STATIC ECONOMIC THEORY OF INCREASING ECONOMIC SCARCITY OF MINERALS

Our concern is the increasing economic scarcity of minerals and their products -- ores, fuels, metals, bulk fertilizers, etc. The basic notion is that these are essential for economic welfare and growth; their economic scarcity could impair welfare and development.

To help define this notion of increasing economic scarcity of minerals in terms of effects on basic economic variables, we begin with an illustration of two economies, which differ *only* in minerals endowment.

Parable of Two Economies

Vizualize two equal size areas, identical in every respect except mineral resource endowments. Area "A" has almost unlimited mineral resources of highest grade, and "S" has very large but relatively fewer mineral resources of highest grade. Both have virtually unlimited minerals of lower grade. We now put identical people in both areas -- half of each twin pair in each area. They become Economy A and Economy S, isolated from each other, without international trade.

For 1000 years, the two economies grow identically. Marginal cost of mineral product supplies relative to demands are the same in both economies. Both enjoy plentitude of mineral resources of highest grade, relative to demands. The more limited ultimate mineral resources endowment of highest grade in Economy S have not yet become economically relevent. The two economies, we observe, are identical in year 1000: in GNP and GNP per person, capital in place, industry composition, labor force, prices (including wage rates, interest rates, land rents), marginal productivities of factors, etc., etc. Knowledge is complete in both economies, there are no uncertainties, there is perfect competition, societies and cultures are identical. Economic rents for mineral resources in place in this condition of economic plentitude of mineral resources are zero, assuming no transport cost.

After 1000 years, it becomes apparent in Economy S that highest grade mineral resources would, at then rate of use, be exhausted in another 100 years or so. Recourse must be to resources of a lesser economic grade, which are available in enormous quantities. In the latter part of the 100 year period the highest grade resources in S will command a Ricardian economic rent, equal to the difference between marginal cost of a standard unit of minerals supply from highest grade resources and the lesser grade. A standard unit is one which has equal economic efficiency in use, no matter what its source. In Economy A, on the other hand, highest grade mineral resources exist sufficient for thousands of years of production at then rates of use, and there are no economic rents to mineral resources.

In summary: for the first 1000 years, resource plentitude was constant in both economies. There was *no* economic scarcity of mineral resources. In the next 100 years, increasing scarcity entered in Economy S, but not in Economy A.

We compare the two economies in the year 1100: *cet.paribus:*

-- Real GNP, total and per capita, are lower in S.

-- Growth rate of real GNP is lower in S than A.

-- Prices of minerals products in standard units (such as tons of crude steel, barrels of gasoline, etc.) relative to all prices are higher in S, assuming no trade.

-- Capital formation is lower in S.

-- Real wage rates and interest rates are lower in S.

-- Marginal and average productivities of labor and capital are lower in S, if the propensity to save is positive.

-- Minerals utilization in standard units is lower in S, as noted above.

-- Better mineral resources command economic rents in S, as noted above.

Cet.paribus, the effects of increasing economic scarcity in S are that minerals supplies in standard units have become more costly and their real prices have risen. Because of this, fewer standard units are used. This has reduced productivity of other factors of production and has lowered their real prices. The GNP is lower and growing less rapidly. *Cet.paribus*, all of this is directly due to a single, significant economic limitation in supply, in this case decline in physical *quality* of marginal mineral resources.

In our simplified case to this point we have permitted no divergent influences other than increasing minerals scarcity from declining physical grades. There were no divergent uncertainties, technological changes, monopolies, different evolutions of people, international trade, etc., nor repercussions from these. For example, monopoly over the declining volume of best resources did not occur nor aggravate (increase) the scarcity effects in Economy S. Also, we have confined ourselves to "first order" effects. For example, we excluded the possibility that the decline in mineral resource quality might trigger favorable technological change and international trade which might overcome first order scarcity effects.

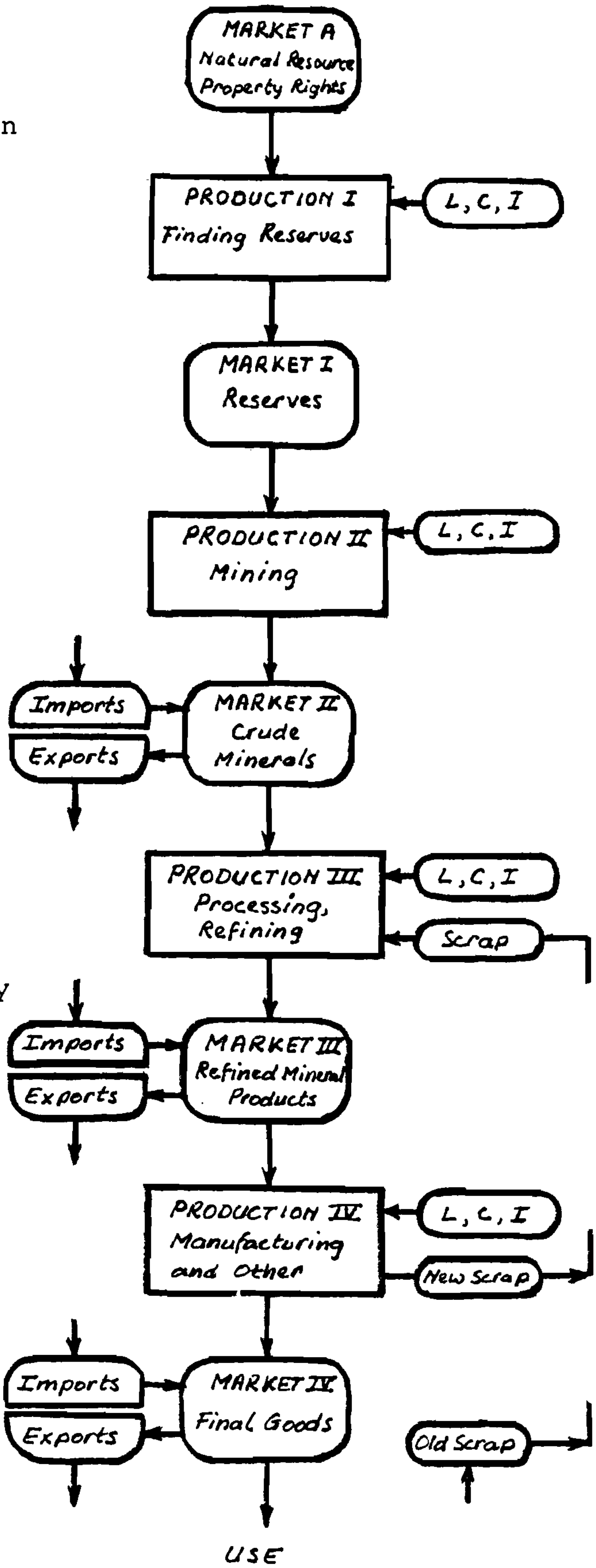
The parable represents a classical Ricardian-type economic view of mineral scarcity. It reflects only physical limits converted into economic scarcity. The only societal melioration is substitution away from a now more expensive input in static (parametrically invariant) production or utility functions. In the economic theory of real dynamic societies, neither of these limitations are present. First, single or multiple conditions other than physical limits could create or intensify economic scarcities of mineral resources. Second, changes in social and technical parameters could mitigate scarcities from physical or other causes.

IV. MINERALS FLOW CHART

It is useful for our concepts and measurement discussion to construct and discuss a minerals flow chart. We have set up four stages. In each, the production activity and product markets are identified. Production activity is in rectangles, markets (including relevant transportation) are in circular or oblong figures. Each productive activity and market is a significant, recognizable minerals activity.

"Production I, Finding Reserves" involves mapping, exploration, drilling, identifying and estimating of mineral reserves. It buys and employs property rights from Market A (for example, bonus and royalty payments for oil leases) and also employs labor (L), capital (K) and purchases materials and electrical energy (I). In our chart, the reserves which are identified are sold to companies in Market I; this occurs extensively in mineral fuels and for some metal reserves. Frequently, the company which finds the reserves avoids Market I and utilizes them itself, in Production II Mining.

"Production II: Mining" is developing, drilling, extracting, milling, concentrating activity of the traditional mining company. The output--crude oil, washed coal, ores and concentrates--goes to Market II as crude minerals. Market II, unlike Market I, is worldwide and augmented by imports and reduced by exports and involves transportation.



"Production III: Refining" transforms crude minerals into refined ones--petroleum products, coke, steel, copper, aluminium, etc. Sometimes, of course, this stage is by-passed, when the crude mineral from the preceding stage is ready for final use--e.g. coal, sand and gravel. More frequently Production III is a major economic activity, which is often carried out in or near industrialized regions after imports of the crude minerals. It produces recognizable products for Market III which, again, is subject to transportation and foreign trade.

Market III is the terminus of the mineral supply activities.

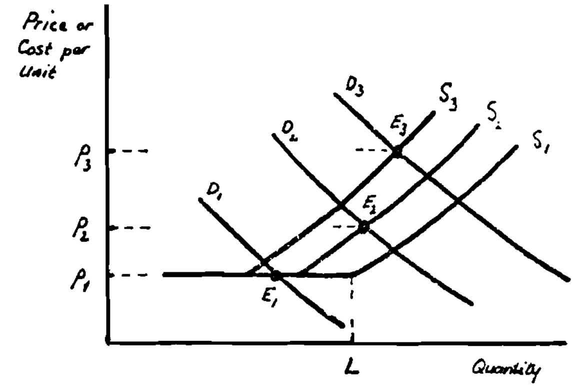
Finally, Production IV is a variety of non-minerals supply activities. One is manufacture of petrochemicals, metal products, glass, finished fertilizers. Other activities are construction, domestic trade, etc. Production IV and Market IV are shown only to complete the description of the minerals flow chain; they are the ultimate demanders of mineral products from Market III (and, for some minerals from Market II). The output from Production IV goes to a residual market of "final goods".

Our discussion has omissions. New scrap is recovered in Production IV and old scrap in the form of discarded consumer and investment goods from Market IV; the figures for some metals are large. These go back into Production III for reprocessing and refining. Very substantial transportation occurs in all numbered markets expect I. In some countries, domestic mineral flows do not exist or are small, needs are satisfied by imports to Markets II, III, and IV. Stock changes sometimes act very powerfully. Japan drew down its copper stocks by 270,000 tons in 1974, thereby reducing net imports from 370,000 tons in 1973 to 13,000 in 1974. Prices on the London Metals Exchange collapsed by 40% in 1975.

Comments Relative to the Flow Chart and the Parable of Two Economies.

From the flow chart, we now see how simple and abstract were the classical conceptions of economic scarcity from physical limits. For Malthus, it was limit in the total amount of reserves-- a fixed supply in Market I. For Ricardo, it was a decline in the economic grade of reserves, the best used first in Market I. Ricardian-type scarcity is more interesting, and is the one employed in the parable of two economies.

Ricardian-type scarcity introduces as an assumed fact that Market I is characterized in long-term by an upward sloping supply curve, after point L. Growth of the economy moves quantity demanded to the right. Depletion shifts the entire supply curve leftward. The result is increasing economic scarcity of resources relative



to economic growth, reflected in costs and prices per unit; of P_1,P_2 and P_3 for successive time periods 1,2, and 3 respectively.

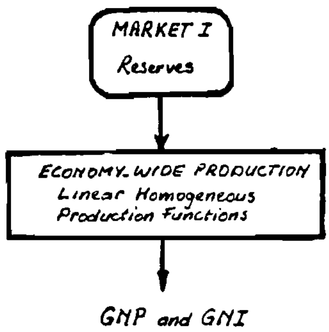
Compare the Ricardian scarcity of the parable with the chart. Let us accept the Ricardian premise concerning Market I for a moment. Then we are denied the opportunity to avoid scarcity in Market I and in the previous stages. Thus in Market I, we are simply given a stock and not permitted to learn that we may have been using less economical reserves earlier than the better reserves. Our knowledge is complete and perfect concerning not only locations, but also the economic efficiency of producing from all resources over the nation. Nor may we learn anything about improving the efficiency of markets. Nor does growth and spread of society create significant economies of social scale.

Production I activity (Finding Reserves) does not exist in this premise. If it did, we might find reserves of which we had no knowledge. Also, of course, improved economic efficiency in finding reserves cannot occur from accumulation of knowledge or technical change, since there is no reserve finding activity.

The prior "Market A: Property Rights" cannot, in an economic sense, operate or improve on the Ricardian model premise. If it did, then good resources previously blocked from recovery or use by Crown reservations or monopoly grants could become available. Or the reverse could occur and aggrevate scarcity. Government could abridge exploration and reserve finding of minerals on domestic public lands; they could limit the access to ocean resources; and could impose environmental impact conditions relative to existing property rights of use.

Finally, improvement in social arrangements and institutions or in quality or decline in cost of the factors of production L, K, and I exert no influence. Since there is no Production I sector, more or better scientists, computers, satellites, radioactive tracers, ocean technologies, etc. are irrelevant.

Turn now to the production and market stages subsequent to Market I. In the Ricardian model, this seems to simplify to the chart:



There are no intervening stages. All of the intervening economy, between minerals reserve endowments and GNP are subsumed in constant returns to scale to labor, capital, and minerals of constant quality. But, since the economic quality of the minerals factor of production declines by assumption, then the economy experiences *declining* returns to scale. Production stages 2,3 and 4, and Markets 2,3, and 4 disappear into insignificance. They are all within the rectangle of economy wide constant returns production functions, which become diminishing returns in the presence of economic scarcity of minerals.

In economies of the parable, there is *no* opportunity to overcome the premise of Market I of increasing cost of minerals. Nothing avails, there are no gains in or from knowledge, social arrangements, technology in thousands of industrial sectors, scale, reclamation of scrap, changes in GNP composition, capital accumulation, nor education.

V. SOCIO-TECHNICAL CHANGES

We identify some of these major categories of influences--parametric changes--which are in fact present in *real* economies to aggravate or overcome incipient economic scarcities of minerals in today's world.

(i) Creating or intensifying scarcities:

- Cartels and other market control, such as OPEC or its progenitors, Texas Railroad Commission and Interstate Oil Compact Commission.
- Certain doctrines of the New International Economic Order which may restrict development and production of minerals in developing countries and from oceans, or tend to change supply conditions.
- Governmental and inter-governmental obstructions or restrictions on minerals product developments, such as ocean minerals and nuclear materials facilities.
- Environmental pollution regulations, and land withdrawals for preservation.
- Economic growth and other socio-technical parametric changes.

(ii) Meliorating scarcities:

- Accumulation of knowledge, particularly scientific, technical and economic.
- Innovation, minerals discovery, recycling, substitutions, other technological change.
- Economic growth and economies of social scale.

- o International trade.
- o Capital accumulation.
- o Other social parametric changes--materials savings, culture, tastes, organizations.

The lists and flow chart show that it is too simple to view economic scarcity of minerals as only a question of declines in physical grades of mineral resources. Other phenomena in the real world both create and overcome mineral scarcities. Moreover, these influences may be present in all industrial stages and markets.

We are satisfied from previous work, especially publications of Resources for the Future over the past twenty years, that the classical Ricardian (and Malthusian) doctrines of increasing scarcity of minerals from physical limits are not valid in the 20th centry societies. Of course, they are right that the world is limited in physical extent and properties. But in our time, economic and social dynamics beyond their conceptions are of much greater force on long term minerals supply for economic welfare and growth. They viewed the economic system of nations as a neutral and relatively static (and static-wise efficient) mechanism for converting existing, known physical conditions into economic welfare and growth. It is not sensible that we today should see our economies as neutral or static (or always efficient) relative to physical world changes. Nor should we assume that social change forces are less influential than physical ones for increasing scarcity of minerals. It is significant that same or similar categories appear in both lists, above. The multiple forces which operate to increase or mitigate scarcity interact in complex ways -- simultaneously, with lags, and as individual phenomena rather than as economic aggregates.

<u>Environmental Externalities</u>

Environmental restrictions and limits are perhaps the major long-term minerals scarcity phenomena of our generation. Recently they have greatly restricted minerals supply. For example, the U.S. Bureau of Mines and Minerals industry complain that more than two thirds of the U.S. public domain (which is one-third of the U.S. land area) are no longer open to minerals exploration and development. In the flow chart, this is a restriction on property rights in Market A. As another example, in Market I and in Production I and II, billions of tons of U.S. coal reserves are proscribed from production and use because of high sulfur content, steep ground gradients, or restrictions on removal of overburden. Substantial U.S. restrictions have been laid on outer continental shelf and Artic oil and gas, iron ore, shale and other mining. These are restrictions in the supply from Market I or the parameters of Production II: Mining, in the flow chart; they increase costs of production. Similar phenomena have occured in European Nations, although of a somewhat different nature. First, in most of the European countries and Japan, only a limited part of the final mineral supply is extracted domestically. To a large degree, their needs are covered by imports of crude minerals, thereby often 'exporting' the environmental problems connected with the first production stages to countries with less stringent environmental rules. Second, the processing and refining of minerals in Europe mainly takes place in densely populated industrial regions (for instance the German Ruhr area). Here, environmental considerations have played an important role since the beginning of these activities, and have led to a gradually increasing legislation with respect to pollution.

Nevertheless, many of the policies were introduced in a crusade of environmental reform during the past decade, without explicit consideration of the effects upon minerals availability, scarcity, and costs. It is necessary to take account of the environmental protection influence in order to interpret the scarcity/availability record since the 1960's. Understanding this phenomena is important: in the next decade or so, societies will inevitably try to integrate the recent profound changes in attitudes into revised and stable public policies.

Now that we have 'discovered' externalities as being very important, there is need to improve the concepts of minerals scarcity and externalities with respect to each other. First, there is a large array of external environmental costs--polluted air and water and land disfigurement--which were generally neglected in earlier economics work. Obviously, these costs should be included in society's benefit-cost accounting. Second, it is particular environmental and other 'goods and services' which have been alleged to be especially subject to adverse impacts from minerals supply expansion: pure water supply, nature preservation amenities, privacy, genetic capital stock, and others. These are of special concern in our minerals analysis. Third, the widely-held ecological views of 'health' of the biosphere of Dubos and other biologists, as affected by modern industrialization, should be considered, but only insofar as related to minerals supply. Fourth, we must consider *favorable* externalities from minerals development and use, as well.*

It is not a simple task to bring externalities into cost and benefit functions related to the increasing mineral scarcity hypotheses. Many adverse externalities do relate to energy or minerals production and supply and thereby scarcity--e.g. oil spills and steel mill stack discharges. But many others related to energy or minerals product *uses* do not--e.g. automobile tail pipe discharges or abandonment. In the flow chart, minerals supply terminates in Market III (Refined Minerals) or earlier. If we define our problem as increasing scarcity of mineral supply, then we should include all externality costs up to Market III as chargeable to the provision of minerals. Costs in Production IV and Market IV would not seem to be a cost of mineral supply.

Consider nuclear devices, materials, and installations. One set of these is nuclear electric power plants. Another set is the tens of thousands of nuclear weapons, thousands of tons of

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* See Dorfman, Gordon, Kneese, Krutilla, Smith, Fisher, Mishan, Peterson, Ridker, Schultze and many others.

hot waste from weapons and research, thousands of military and research installations, ships, satellites, etc. The uranium production for electric power plants, their fuel and wastes, and their externalities should figure in appraisals of minerals (fuels) scarcity. The weapons related items should not. Further it is not certain whether externalities of providing uranium for weapon production should be charged as a cost of mineral supply.

There has been a tendency of view the world's nuclear danger -- the Faustian dilemna -- as if it were a singular phenomenon due to pressure of growth on mineral fuel resources, mineral scarcity, and thereby the need for nuclear power. This is not so. The nuclear hazards would not disappear if we took all our electric power from the sun or fossil fuels. They are primarily rooted in weapons, international relations and declines in social control over violence. It could be argued that only the *increment* of nuclear hazard due to production of uranium and nuclear power is an externality of mineral supply. The question is complex.

Similarly, today there is great interest in so-called 'technology assessment'. Not all external costs from technological changes result from efforts to overcome minerals scarcity, however. Some do, such as in strip mining and super tankers. Many of them in transportation, chemicals, pharmaceuticals, processed food, etc., do not. We noted that favorable as well as negative externalities should be appropriately included in mineral scarcity concepts and measures. Our benefit-cost measures should include, not only the damages from strip mining of coal, but also the lives saved which would otherwise be lost in underground mines; not only the transfer of mineral wealth from the developing to the developed countries, but also the transfer of capital and knowledge to the developing countries for mining activity. But not all favorable technology spillovers should be credited to minerals. Nuclear production may save lives in hospitals, but this should not be credited to minerals supply.

The externalities term is open-end and ranging, particularly in long-term analysis. For example, it embraces the concept of intergenerational equity (see the quotations from Mitchell and Pigou in *Scarcity and Growth*), nature preservation (Krutilla, Fisher, Smith), theory of justice (Rawls, steady-state and entropy economics (Page, Boulding, Georgescu-Roegen, Daly), very long term (Meadows, futurists), quality of life (Mishan, Olsen, Barnett and Morse), and welfare economics generally. It is necessary to explore and clarify the externality concepts, for our purposes. The externalities concept has been overextended and overused, in general. Further, most externalities are not significantly related to the concept of increasing economic scarcity of minerals.

Cartels and the New International Economic Order (NIEO)

Cartels and the thrust toward a NIEO is the second main social change of our generation relative to minerals.

In *Scarcity and Growth* (Barnett and Morse), the geographic area was the United States proper. The increasing scarcity hypothesis related to domestic availability. Foreign trade was relevant only in moderating or intensifying demand pressures on domestic resource supply. This was and still is a relevant concept. Countries are societal units. In the flow chart, there is an increase in economic scarcity of domestic minerals if production costs in mining or refining become more expensive (Production II and III).

As imports as well as the demands of foreign countries grow, however, the availability and scarcity of foreign supplies to meet world demands become important. A major escape for all nations has historically been access to the world's trading community. For our European analysis, we are thrust into world supply and, to a degree, world demands. Thus, if the cost terms of imports into Market II or III become more favorable, then the effect may be increased *plenitude*, whether or not domestic mineral resource costs were increasing.

Conventionally in the past, restrictions by international minerals cartels were not viewed as significant elements in inincreasing mineral scarcity. They were not the scarcity of nature, and (except for diamonds) were never highly successful for a long period, anyway. But this has recently changed for oil and it may yet for other major significant minerals. In the 1970's government cartels and associations have attempted to make minerals increasingly scarce. Account must be taken of this influence on the statistical record. In the flow chart, this means explicit concern for the imports and exports to the left of Markets II and III.*

The abruptness of the increase in petroleum scarcity has its own peculiar history. For more than half a century, into the 1970s, European and American companies discovered and developed petroleum resources at *declining* real costs in foreign places. The decline was very great; despite monopoly profits for the companies and host governments, prices fell by half or more. The situation was increasing plenitude; the cost to explore, find, develop and produce Middle East oil was less than a dollar a barrel, sometimes as low as ten cents. America and other countries permitted themselves to become highly dependent on these cheap resources, rather than on their own less cheap but very plentiful energy resources. When the situation was well developed (the term is 'hooked' in the case of drugs), the OPEC cartel struck, being assisted by a favorable political climate.

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* See Adleman, Amuzegar, Barnett, Bergstem Fried, Moran, Vernon, Vogely and others.

In addition to specific cartels, the New International Economic Order doctrines are changing access to foreign supplies. These complex developments and their eventual outcomes must be taken into account in modernized mineral scarcity analysis. Ownership, rates of development and terms of trade are all subject to radical change. Stable U.S. and European policies have yet to be developed. (See, for example, Gordon, Kaplan, Perlman, Tilton, Vernon, Stanley and others.)

Two recent and interrelated developments are noteworthy: the relatively low propensity to invest in certain mining sectors and the shift of foreign investment from developing to developed countries. Due to the considerable time-lag between exploration and actual production, insufficient investment in the present may cause serious supply problems in the medium and long-term.

The reluctance of the mining companies to invest might be caused partly by the uncertainties about expected growth rates in industrialized countries, which play an important role in determining future demand for and prices of minerals. This uncertainty, the low profit margins, and the often rising taxes force the mining firms to seek efficient production with huge plants and large-scale equipment. This has caused a sharp rise in investment costs of new capacity in mining industries. The financial requirements often exceed the capabilities of the mining firms, and external funding by commercial banks is, under these circumstances, difficult to obtain.

Industrialized countries that depend mainly on foreign investment of domestic firms for their supply, have also to consider structural changes in their relations with developing countries. Many of these countries have successfully increased the control over exploitation of their national resources. Measures they have taken to increase participation of domestic firms have aggrevated the conditions under which foreign firms may operate.

This, together with the risks of expropriation and political instability, make foreign investors more inclined to move to developed countries, where expansion costs are higher due to the remoteness and lower grade of deposits. Of course, this is increase in economic scarcity of minerals, but should not be seen as increased *physical* scarcity.

Further, the numerous nations of the Third and Fourth Worlds have extended their concepts of New International Economic Order to ocean resources.

The General Assembly of the United Nations accepted in 1970 (only Eastern Europe abstained) that the ocean resources are the "common heritage of mankind" and should be exploited under an international regime. The actual legislation, however, still has to be agreed upon within the framework of the U.N. Law of the Sea Conference. The developing countries agree that the economic benefits of the exploitation of manganese nodules should be shared by all states, but also demand that special consideration should be given to the particular needs of developing countries. An International Authority would ensure this, but would also limit seabed-production in order to protect the interests of land-based producers of the minerals concerned. These are mostly developing countries. The Western Nations, especially those which have the sophisticated technology needed for seabed-mining, are resisting such policies. They do not agree with cartel-like powers of the Authority and fear that production and profits of their commerical firms would be too severely limited.

In summary, imports and the conditions under which they are obtained, are increasingly important in minerals supply. This is due to cartels, the NIEO, ocean resources, international interdependence, and (in some cases) depletions. For all nations, especially for Europe and Japan, mineral scarcity relates mainly to international mineral markets.

VI. CONCEPTS FOR MEASUREMENT OF INCREASING ECONOMIC SCARCITY OF MINERALS.

There is considerable literature on the measurement of scarcity. An early discussion appears in *Scarcity and Growth*, Part III (Barnett and Morse). More recently, there have been published discussions by Moroney, Nordhaus, Brown and Field, Smith, Fisher, Devarajan, Krutilla, Heal, Dasgupta, Randall, and others; see especially the articles and references in *Scarcity and Growth (S+G) Reconsidered*, 1979, ed. V.K. Smith, and the forthcoming Smith article in *Journal of Agricultural Economics*. Also see an RFF Conference volume and an NSF report by V.K. Smith and J. Krutilla, also forthcoming. Further discussions have been presented in other papers.

At a later time in our effort, we shall examine the literature in detail and present our own survey, synopsis, and conclusions with respect to the topic and literature. For the present, we refer the reader to the work cited above.

Here we have a very modest purpose. We try to state the economic concepts relevant for measurement of the hypotheses of increasing economic scarcity of minerals. The context is a very practical, applied one. We hope to compile the data for particular minerals for European countries within the next year or so. The discussion here indicates guide-lines, difficulties, and uncertainties.

Cost and prices per unit of minerals.

During a particular period, one economic concept specifies whether mineral supply has become economically more or less scarce than before. This is the economic cost to supply the society with minerals or products thereof.

To measure economic cost, we need a meaningful economic numeraire or yardstick. The appropriate numeraire, or value measure of economic cost, is the opportunity cost of mineral production. Below, we will consider these opportunity costs both: (1) in terms of labor (or labor plus capital) inputs needed to produce one unit of output; and (2) in terms of other goods, which might have been produced instead of minerals. We refer to these, respectively, as hypothesis and numeraire (1), and hypothesis and numeraire (2), and discuss each in turn.

The first possibility is the physical amounts of labor and capital which are required to produce a unit of net output* of minerals. Labor and capital are society's ultimate productive resources which, if applied to producing minerals in a period, are not available to produce other goods. The cost measures are labor cost per unit of minerals, or labor plus capital cost per unit of minerals. Symbolically, L/O or L+C/O. If we desire to add together units of labor and capital to get a single index of labor plus capital cost per unit of net minerals output, we weight the labor and capital input factors by relative importance. A former study (S and G, 1963, Barnett and Morse) showed that the average L+C costs per unit of minerals output [(L+C)÷O] declined as follows in the U.S.A:

	Index
1870-1900	210
1919	114
1929	100
1951	60

This time series of labor plus capital cost per unit of output was brought up to 1970 by M. Johnson and F.W. Bell, and shows continued decline. (See *S+G Revisited*, 1974, Barnett). In the century period in the U.S.A., the amounts of labor and capital to produce a net unit of minerals output declined persistently.

We can suggest a variant of this numeraire, still employing the concept of labor and capital cost as a yardstick of economic value. It is the comparison of changes in the prices per unit of each minerals, labour and capital. The concept here is that physical inputs of units of minerals, labor, and capital (putting aside other purchased materials) assembled appropriately, constitute the production functions whereby useful goods are produced for society. Raw materials, labor, and capital goods are the "scarce inputs" from which all goods flow, and each is paid a price equal to its marginal revenue productivity. When a factor of production becomes relatively scarce, its marginal productivity and price increase relatively. Thus, if minerals become increasingly scare relative to units of labor and capital, the price of minerals per unit will increase relative to the price of labor (wage rate) and price of capital goods (interest and depreciation rates related to cost of capital items). W. Nordhaus, G. Brown and B. Field have used this measure. Prices of major metals have fallen relative to wage rates in the U.S.A. over the long term; this would deny the scarcity hypothesis.

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* We say 'net output' in order to allow for (remove) the productivity of other factors of production, such as energy and other purchased materials.

It is possible to criticize both variants of the foregoing labor and capital cost numeraire or yardstick for ascertaining whether there has been increase in minerals scarcity. The criticism is that opportunity cost of minerals production should be measured in terms of alternative economic goods foregone, for the following reasons. The productivity of labor and of capital are increasing in the economy generally, from favorable parametric changes -- that is, favorable developments in technology, knowledge, social arrangements, etc. Therefore, it may be argued that cost of minerals, as measured by labor days or labor plus capital, does not truly measure opportunity cost, certainly not in terms of alternative economic goods foregone. The measuring unit, man-day of labor, is itself increasing in value due to socio-technical improvements in society, and the same holds for physical units of capital. It is true that it required only half as much L+C to get a unit of net mineral product in 1919 as in 1870-1900, but the 1919 L+C were worth a good deal more in terms of productivity of other goods than earlier. Similarly, when we compare price of minerals with wage rates or costs of capital goods inputs, we are again overlooking that parametric changes have increased the productivities of both labor and capital units. They have become generally more valuable in the economy, in terms of capacity to produce intermediate and final goods, over time.

This leads us to the second numeraire for measuring increasing (or decreasing) resource scarcity. It is that we use as a numeraire the opportunity cost of the minerals expressed directly in terms of manufactured and service goods foregone in order to produce the minerals. One way of doing this is to measure over time L or L+C cost to produce a unit of mineral goods *relative* to the L or L+C cost to produce a unit of non-extractive goods. Production of mineral goods differs from production of manufactured and service goods. The former relies on identified, depletable deposits, manufacturing and service rely less or not at all. Thus we measure

$$L_M \div O_M / L_N \div O_N \text{ or } (L_M + C_M) \div O_M / (L_N + C_N) \div O_N$$

where L, C, and O represent Labor, Capital, and net Output in the Mineral and Non-mineral sectors of the economy. If this ratio increases, then cost per unit of minerals has increased *relatively*, and this represents increasing economic scarcity of minerals in terms of opportunity cost in other goods. And vice versa.

A variant of this second measure is to simply observe price per unit of minerals relative to price of other goods. Price is a summation of the current market values of *all* the inputs re-required to obtain a unit of minerals products. Similarly, price measures the current market value of *all* the inputs to get a unit of non-mineral products. If the price of mineral product rises *relative* to other prices, then it must be because the current values of the inputs rose relatively. We emphasize that this price measure of relative mineral cost per unit over time embraces not only the *quantities* (Q) of labor, capital, and other inputs but also the effect of their unit prices (P) and of profits. That is, at any time,

$$\text{Price} = \Sigma[(Q_L \times P_L) + (Q_C \times P_C) + (Q_I \times P_I) + \pi] \div 0 \quad .$$

The assumption which is made in use of the relative price measure is that *price* changes of factors of production (i.e. per unit of labor, capital and other inputs) operate equally in minerals relative to other sectors. In such a case the ratios to other prices at successive times reflect changes in quantities of inputs.

In summary, these then are the two major indexes, and the variants in each, for our testing the hypotheses of increasing scarcity of minerals, over time:

1. <u>For the strong hypothesis of increasing scarcity (see below) the value numeraire is assumed to be the opportunity cost in terms of labor units or labor plus capital units consumed in physical terms.</u>

   (a) Labor cost per unit of minerals output, or labor plus capital cost per unit of minerals output

   $$L_M \div O_M$$

   $$(L_M + C_M) \div O_M$$

   (b) Unit cost of minerals relative to unit cost of labor or of labor plus capital

   $$P_M \div P_L$$

   $$P_M \div (P_L + P_C)$$

2. <u>For the weak hypothesis of increasing scarcity the measure of value (numeraire) is assumed to be the opportunity cost in terms of the quantity of other goods foregone:</u>

   (a) Relative labor or labor plus capital cost per unit of minerals output

   $$(L_M \div O_M) \div (L_N \div O_N)$$

   $$[(L_M + C_M) \div O_M] \div [(L_N + C_N \div O_N)]$$

   (b) Price of minerals relative to prices of other goods

   $$P_M \div P_N \quad .$$

The data problems -- units of measurement, index number construction, availability -- are discussed later. Numeraire 1 and numeraire 2 are each appropriate to a particular hypothesis of mineral scarcity. Hypothesis and numeraire 1 refer to the classical economic doctrine of Malthus and Ricardo. Increase of population to the limits of subsistence, the iron law of wages and the niggardliness of Nature contrived to present much progress. Economics was the 'dismal science'. A labor theory of value dominated markets. Agricultural activities and by implication minerals were characterized by diminishing returns to social scale. In this situation, it would be sufficient to measure opportunity cost of minerals in labor man-days (or a similar index of labor plus capital). These are also the hypothesis and appropriate measure of resource scarcity of many contemporary reformers -- Ehrlich, Harden, Forrester, Meadows, Georgescu-Roegen, Daly, Dubos, Schumacher, etc. They have rediscovered or asserted certain elements of Malthus, Ricardo and Mill, more than a century ago. If, indeed, what J.S. Mill termed 'progress of civilization' (increasing productivity of factors of production due to favorable socio-technical change) were to cease, this form of the increasing resource scarcity hypothesis would be very relevant. The measures of numeraire 1 would be the proper test.

The *second* hypothesis and measures are more meaningful of modern economies. The opportunity cost of a unit of minerals is the volume of alternative goods which are given up, in the view of most present-day economists. 'Progress of civilization' is a built-in characteristic of modern economics, with persistent increase in productivities of the labor and capital factors of production, due to socio-technical progress. In this case, the appropriate concept of increasing resource scarcity and measures for testing it are found under hypothesis number 2. These measures would reveal whether natural resource scarcity exerts a retardation by comparing trends of improvements in productivity in natural resource sectors (in this case minerals) with trends in economic sectors which are less or not dependent on natural resources. The assumption is that socio-technical progress operates in both sectors. On this hypothesis of increasing scarcity of natural resources, there would be manifestations of increasing minerals scarcity only if minerals costs per unit rise *relative* to other sectors of the economy.

The measures 1 and 2 apply to different concepts. Numeraire 1 and 2 apply to different concepts. Numeraire 1 is for a strong hypothesis of minerals scarcity where minerals exhibit diminishing returns to labor and capital, irrespective of economy-wide advances in productivity. Numeraire 2 is for a weak hypothesis of minerals scarcity, where productivity in fact advances in all sectors of the economy, but slower in minerals. If true, the strong hypothesis might call for strong policies -- like the birth and consumer controls of Ehrlich, Harden, Daly, etc. -- since the diminishing returns in natural resources would otherwise bring economic growth to a halt, and then to a decline. This hypothesis was a major element of the assumptions which drove the Club of Rome-Forrester-Meadows model of the early 70's to a 'Crisis of Mankind' and doomsday predictions.

The weak hypothesis of increasing scarcity, if true, of itself only connotes that economic growth might be slowed. It might call for modest policies -- for example, more research and development in minerals sectors -- to raise the rate of technical progress in minerals relative to the level of manufacturing. Or it might justify no interventionist policies -- economic progress still continues even with slower productivity improvement in a relatively small economic sector like minerals.

It is important to address both the strong and weak hypotheses and their respective measures under 1 and 2. We think the weak hypothesis is more interesting and more likely to be valid. But the strong hypothesis is more prominent in public discussion, is more widely believed, and is more strongly publicized. Therefore, we are concerned with testing *both* hypotheses.

Concerning the variant measures within each hypothesis, we think they are all significantly legitimate in concept, but subject to varying defects in applied analysis. Each of the variants has problems of data availability; accuracy of measurement; index number construction; accounting for government interventions in markets and production functions; marginal vs. average information; etc. In light of the practical defects and limitations of each variant, it is desirable that we measure in more than one way. We may then use the varied data with their different perspectives and defects for more and better insight than if we had only a single one of the imperfect measures. Our interpretations and conclusions may be better, from the multiplicity of pieces of evidence, to be gathered by means of not only different measures, but also by testing the hypothesis at different production stages and markets.

Especially in appraisal of the weak scarcity hypothesis, both of the measures in hypothesis 2, relative cost and relative price, are desirable techniques for testing. We offer an example. The cartel scarcity influence operates immediately on imports. The effect is visible in one, but not in the other, of the two major, alternative indicators of increasing scarcity. It does not soon appear in relative labor cost, and might not in relative labor plus capital cost, but does immediately show in relative price. The relative cost measure is average cost of domestic production:

$$\frac{L_M+C_M}{O_M} \div \frac{L_N+C_N}{O_N}$$

The relative price indicator is $P_M \div P_N$. International cartel behavior enters immediately into the latter(price) but not the former (average cost of production). In this case, the two variant measures tell us different things, including information on the increase in cartel returns. However, not all of the difference between the changes in the two indicators is due to the cartel. First, even in the absence of cartel, change in price tends to reflect change in marginal cost, as compared with change in average cost in the other indicator. Second, increases in import prices induce higher cost efforts in domestic supply, and also increase the returns to both capital and labor in domestic supply.

Other Measures

We have brief comments on several other measures which have been proposed for testing minerals scarcity hypotheses. Most are related to the unit cost measures, above.

(a) Environmental Externalities: It was indicated earlier that many economists (including ourselves) have argued that, in testing the resource scarcity hypotheses, costs and price data of minerals should include the adverse spillovers or externalities, such as stream pollution from coal mining. Further, until recently, price data did not include externalities, and even today they may not adequately. Therefore, past cost and price data have not included *all* relevant costs. The criticism is correct. In our construction of data and interpreting them we shall try to take account of externalities. We shall be assisted by the fact that environmental protection costs have been increasingly internalized in prices and production functions during the past decade.

J. Krutilla, A. Fisher, and V.K. Smith have, however, recently argued an even stronger environmental proposition. They state that internalizing observed environmental costs in present decision-making structures and processes of private enterprise are unlikely to capture all environmental costs. They state that so-called efficient economic decisions are biased to short-term welfare and the present and near generations in several ways. Such decisions overlook irreversibility -- e.g. destruction of biological species and natural wonders. Also, the interest rate which equilibrates present and future spending excessively discounts welfare of future populations, who are not yet in market. Further, markets are biased by wealth distribution. Still further, the relatively high income elasticity of demand for a relatively inelastic supply of natural resource, public amenity goods is not well represented in decisions on mutually exclusive use of nature for minerals for future individual nature-experience recreation. Others have also written on these matters, among them A. Kneese, E. Mishan, and T. Page.

Earlier economists, back at least to J.S. Mill and including more recently A.C. Pigou and W.C. Mitchell (and even ourselves), have been concerned with environmental externalities questions. But mostly these concerns were of the nature that they could be handled by internalizing the externalities and manipulating the interest rate. The Krutilla, Fisher, Smith, Kneese, Mishan, Page, writings of the past decade are much stronger indictments of the market system.

We hope to consider these issues sometime, and offered some preliminary thoughts in part III of this paper, above. The current project, however, does not permit serious consideration of these important, over-arching challenges; our object here is more conventional and limited.

(b) The Marginal Supplier

In concept, the real cost of production per unit of output from marginal, long-term supply activities would be desirable as an indicator of increasing scarcity. That is, we seek to observe whether the dynamic, long-term marginal real cost curve is rising. If so, this is increasing scarcity. As noted, price data tend to reflect marginal cost, but are subject to aberrations and noise. The marginal supplier's cost per unit would be a more sensitive indicator of resource scarcity than average cost and would also reveal some of the reasons for price movements and tendencies in resource scarcity.

A difficulty, however, is that the marginal supplier is frequently a short-term supplier, bringing in idle, high-cost capacity in response to short-term market imbalances. Indeed, most short-term suppliers are of this nature. Our concern is with the marginal suppliers on a *long-run* supply curve.

In minerals, it may be possible in some cases to distinguish marginal suppliers on the long-run supply curves. In iron ore, taconite has been in marginal supply for a long time, compilation of taconite cost data is possible. Interestingly, a recent study by Kakela indicates that iron from taconite is lower cost. It is stated to be more efficient in blast furnaces, economizing on fuel, capital, and labor per unit of iron output. In copper, the porphyries are the marginal suppliers in the long run. In aluminium, until further development of the enormous reserves of years of highest grade bauxite resources in West Africa, Brazil, and other places, perhaps Australia's lower grade bauxite is the world's marginal supply. In Europe, U.S. and Canada, various nonbauxite ores would become the marginal supply if world supply were cut off, but none of these are presently in commercial use.

In petroleum, the present marginal supply in the United States is secondary and tertiary recovery. Such production is usually viewed as marginal supply short run; but it is also on the long-run curve. If 30 percent of an oil field is viewed as recoverable at a price of $3 a barrel, then clearly the percentage would be greatly expanded at $14 a barrel, and even more at $28. Increased recovery percentages from oil pools certainly will be in the long-run supply curve, but at present prices such recovery will be planned in the development of the resource, rather than tacked on as a go-back activity. Possibly, marginal supply could be viewed as costs from fields just coming in, such as the North Sea, heavy crudes, or tar sands.

The concept of long-term marginal supply is very well known in natural gas, from the U.S. Permian Basin case and subsequent multiprice regulations. Earlier, in World War II, marginal supply at higher prices was used in price incentive schemes for metallic minerals; frequently short-term marginal supply was induced more than long term.

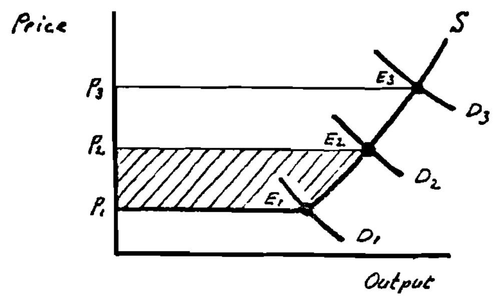
In theory, changes in long-term marginal supply cost would be a fine measure for testing both strong and weak hypotheses of increasing resource scarcity. In practice, in a dynamic, rapidly changing world, the data problems are very great and may be insuperable.

Fisher and Devarajan (1979) have recently suggested discovery cost as a measure of increasing scarcity. This would be related to cost of the marginal units of supply. We shall look into the possibility that data for expenditures on exploration can be compiled and related to discoveries. Beyond this, Fisher and Devarajan have suggested in the article the use of discovery cost as a proxy for economic rent, to test for increasing mineral scarcity. On certain assumptions they observed that discovery efforts to procure additional minerals would be undertaken to the point where expenditure per unit of standard efficiency minerals would (after allowing for production costs) be equal to the economic rent which would have to be paid for a unit of standard minerals in absence of discovery. We discuss economic rent below.

(c) Increases in Economic Rent

It is frequently proposed that we test for increasing resource scarcity by observing changes in economic rent. The sources of the concept are Malthusian or Ricardian long-run, static theory for agricultural land. In a Malthusian case, land is constant quality but at E_1 it is fully utilized, and beyond that point must be cultivated more and more intensively, at rising unit cost.

In a Ricardian case, more land is available beyond E_1, but it is of monotonically declining economic quality, and cultivation beyond that point is at a rising unit cost for the product. Land is characterized by original and indestructable attributes. At time 1 rent is zero. At time 2, demand has grown to D_2 and rent is the shaded area $P_2E_2P_1$, which measures scarcity effect. At time 3, rent has grown to $P_3E_3P_1$; the increase from time 2 is the increased scarcity effect.



If the world conformed to the specifications of this parametrically invariant, no-depletion models, increases in economic rent would reflect increasing physical resource scarcity, and nothing else. Assume for example, the Ricardian model where unhomogenous resources are free goods until productive. Then the rent of standard resources would always equal the cost of converting marginal quality resources to best quality, and would be a precise index of the increase in physical scarcity that had occurred from the beginning of man's economic history.

However, there will be many types of best quality resources; therefore, there will be many different figures for rent; and, for institutional reasons, unhomogenous resources (including those at the margin) command a reservation price in private enterprise societies. Rent will now contain a pecuniary element that reflects, but does not measure, increasing scarcity; and there will be no single figure for rent -- it will be different for each type of resource. As scarcity increases, rents will increase, and rents will also change as the result of changes in general price levels, interest rates, relative demands, and expectations concerning future resource availability. Under these conditions, advances in rent on unhomogenous resources are an ambiguous indicator of increases in scarcity.

A further difficulty with economic rent as an indicator of increasing scarcity is compelling in the case of depletable minerals resources. As the best resources are used up, they disappear from the left-hand portion of the supply curves, and so do the economic rent areas. At the time that Mesabi range hematite ore is exhausted and Mesabi taconite is used, the only visible rent could be the differences among taconites. The magnitudes of economic rents at successive dates would *not* measure long term increase in scarcity; only the period would be covered in which at least two qualities were available.

Rent would be a useful indicator of increasing scarcity in a Ricardian no-depletion world where the resource conversion path for employment of declining quality resources stayed put, and the process of growth involved nothing more complicated than a systematic transversal of the path. But in a world of depletion, of variable reservation prices and degrees of reservation, and especially of sociotechnical change, this is no longer so. The conversion path changes shape and position, with the result that quality differences among resources, their rank in the quality spectrum and, therefore, the rents that they earn vary irregularly over time. Rents on different resources will disappear, decrease or increase as a result of the depletion and economic reordering of resources, of changes in resource economizing behavior, of changes in the technical or social parameters that determine the rank of resources, in order of economic quality. Because of these changes in the resource quality spectrum which are induced by sociotechnical change, depletion, and so on, economic rent is not an operational empirical datum in the modern world. The changes cause capital gains and losses and a variety of income elements to be blended with economic rent and make its determination as a measure of increasing mineral scarcity practically impossible.

We tentatively conclude as follows. First, Ricardian economic rent is a great seminal concept and a rigorous one in constrained static theory. It is not a dynamic concept in a society with technical change, depletion, inflation, and great varieties of resources. Second, we have not yet found it practical to measure economic rent changes in order to measure or test the increasing scarcity hypotheses for various mineral resources.

Finally, some of our colleagues are strongly attracted by the rigor of the rent concept in economic theory, among them; Brown, Devarajan, Field, Fisher, Krutilla and Smith. They are also more optimistic about measuring rent in a relevant and useful way. We hope this is so, and would be happy to join them in the measurement and use.

VII. SEARCH FOR DATA IN MINERAL SUPPLIES FOR EUROPE

Our initial foci are the following countries and minerals:

Western Europe: Belgium, France, FRG, Italy, Netherlands, U.K., Spain, Sweden.

Eastern Europe: GDR, Hungary, Poland, Rumania, USSR.

Minerals:
a) Petroleum, natural gas, coal.
b) Iron, manganese, chromium, cobalt, aluminium, copper, lead, nickel, zinc, tin.
c) Phosphate rock, potash.

(In addition, we are compiling economic time series for regions, other countries, and other minerals, where such data are readily available in library publications.)

Production I. Finding Reserves and Related Markets

We repeat the upper portion of the flow chart previously presented. It will be remembered that our need is for data on minerals prices, labor (and capital) inputs, mineral outputs, and labor (plus capital) cost of output. We need *time-series* data, so that we can observe whether or not minerals costs increased.

Market A prices are usually not available in useful form. Companies do bid for North Sea oil and gas drilling rights but the bids are not really prices. They are rather complicated agreements concerning percentages to the drilling company and host government, taxes, etc., and do not help us. U.S. type data would be more useful for us -- they are lease bonus bids in money terms, plus a royalty agreement. But even here, this is the price for the privilege of drilling a particular area not price per barrel of reserves found.

Also, we do not see any promising price data series in Market A for the other minerals.

In Production I: Exploration/Finding Efforts, expenditures and perhaps breakdowns of data into labor, capital, and other outlays are possibly available for much of the North Sea oil and gas exploration. If we could get time series data on these and on quantities of reserves found (which are the "output" of

Stage I), we could try to observe trends; of course the money figures would have to be deflated by appropriate price indexes.

Speaking practically, however, this avenue is not useful for our purposes at this time. In oil and gas, the period since the beginning of the North Sea development is far too short. We might have more luck with some of the other minerals, in observing expenditure or input effort data relative to reserves found. The better sources would be governmental departments of mines and geology, major companies, and trade associations and journals.

Market I. At this time we do not know whether sufficient identified, quantified reserves have been sold and reported publicly in Europe to help us; we would need data over periods of time. We are not hopeful. If we did find price data, we would have to deflate them appropriately.

In summary, Production I and related markets are not prime targets for data with which to test hypotheses concerning increasing mineral scarcity, except in special situations. One special situation, possibly, is when great new reserves are found, like North Sea oil and gas. Another one is when major reserves are mined out and others have not been found. Even these, however, are qualitative indicators -- incomplete and possibly misleading. Good data on reserves found and their economic characteristics are rarely available. Also, by themselves, magnitudes of reserves do not answer the questions we have asked. In fact, also oil is *more* scarce in Europe in the 1970's, despite North Sea finds because of OPEC led price increases. The test for increasing economic scarcity, we must emphasize,is that mineral supplies become economically more costly through time, relative to demands. If we can get good evidence of this, then qualitative evidence on reserve funds/ exhaustion become extremely useful in interpretation of the reasons, significance and implications. For example, USA withdrawal of major lands for availability for mineral exploration does not demonstrate increasing economic scarcity; but if increasing economic scarcity is ascertained from price or other cost data, then we can turn to land withdrawals evidence for possible explanation.

Production II and Market II: Mining and Supply of Minerals and Concentrates.

This is the stage which is most promising for ascertaining possible increasing economic scarcity due to physical and certain other limitations.

Prices. Price data are available in Market II from several sources. One is world markets -- quotations from London, New York, and elsewhere. Another source is customs data related to imports and exports. Still a third, for some commodities, is internal country price quotations. The data are for identified commodities.

Note some problems:

(a) Which price series should be used? For a single commodity, there will be multiple grades for virtually all minerals; and even for a single grade, there may be alternative price series. For example, tin quotations of pure tin (99.9%); standard tin (min. 99,75%); high grade tin (min. 99.85%) in the U.S., the London Metal Exchange, and Hamburg.

(b) Which price deflators should be used? The problem is very serious in periods of major price change like the 1970's. For example, the U.K. wholesale price indexes for 1977 (1970=100) range from (358 for basic materials), 260 for finished goods to 241 for textiles. The consumer price index for 1977 was 249.

(c) In some cases, the bulk of the trading is in long-term contracts or intra-company transfers, which may differ substantially from prices in spot markets. Bauxite has been one example.

(d) Short term price movements in some minerals are extreme, much more so than in deflators. It is difficult to ascertain 'trend' for relatively short periods like a decade or so. For example, assume we look at the price change since 1970, LME copper price was £444 per L ton in 1971, £878 in 1974, £556 in 1975, £780 in 1976, etc.

(e) If we are interested in all minerals, or groups, we must aggregate into indexes.

If a country is engaged in mining itself, then it would be very desirable to be able to ascertain price per unit of domestic production (related to domestic costs), separately from import price. In a free market economy, the prices tend to converge.

It will be recalled that one can compare the price of mineral with the price of labor, to compare their scarcity, relative to the strong hypothesis. This can be readily done for most of the countries.

Factor cost. Turn now to the other major variant for testing increasing resource scarcity -- labor or labor plus capital per unit of output. Such time series can be compiled, subject to limitations. For most countries, there are published data on numbers of workers and output for the overall mining industry. For some countries we can compile these data for up to four or five mining groups -- petroleum and gas, coal, metal mining (sometimes ferrous versus nonferrous) and nonmetallic mining -- but the data will be subject to more error than for total mining. Capital input data for mining are not available for most countries, so the best we can do is to use time series on labor cost of mining output.

We try to remove the contribution of purchased inputs other than capital and labor by weighting the physical output index numbers by value added or labor; or by computing output in the first place from value added data in constant national prices.

Deflated value added data are usually inferior to weighted physical output index numbers; this is especially true during periods of substantial price changes.

Price and Factor Cost. Each of the measures -- prices and labor cost -- has defects and virtues. Prices are commodity and grade specific and are available in the press. Under certain limited circumstances they may indicate marginal cost of domestic suppliers. In Europe, however, they tend to be world market prices, sometimes very different from domestic or foreign marginal cost.

Labor cost per unit of minerals output relates to the whole mining industry. Data are compiled by government bureaus from censuses, surveys or estimates; and depict *domestic* industry. They show *average* labor cost per unit of minerals, rather than marginal. Capital input data are scarce.

More evidence can be offered with both sets of data than with one. Moreover, considerably more can be said in interpretation of what has occurred, since price trends tend to be world market supplies for import, while labor or labor plus capital cost data represent domestic circumstances. It is useful to compare evidence from domestic production with that of net imports. Also, in some cases it is possible to distinguish sources of import supplies, and this is further enlightening.

Production III and Market III: Supply of Refined Products.

In general, the discussion just presented concerning Stage II applies also to production of refined petroleum products, steel, aluminium, copper, fertilizers, etc.

Prices. Good price data are available. The volumes of international trade are relatively larger. Standardization of products is greater than for crude minerals. The prices are product-specific. Price quotations are plentiful. There are relatively more arms-length inter-company sales. The open market places accounts for more of the transactions. Im summary, strong market evidence concerning prices of standard commodities can be expected here, and price statistics will be good relative to the scarcity hypothesis, after deflation.

However, interpretation of the price data may be more difficult than for crude minerals. The extent of manufacturing value added relative to cost of finding and mining reserves is much greater for certain minerals. That is, most of the price of refined metals and fertilizers is manufacturing activity, rather than minerals cost. To the extent that the scarcity hypotheses rely upon physical limits, depletion, location concentrations, producer country agreements, etc., the evidence in refined minerals prices has been attenuated or diffused. This problem does not apply significantly to petroleum, gas and coal. Most of their value, even when sold in refined form is that of mineral finding and production.

In summary, price evidence is very ample and of good quality, better than that of crude minerals. It is, however, the evidence of both the mineral production and early manufacture, and must be interpreted with this in mind. Moreover, in European countries, indigenous production of refined mineral products is much larger relative to imports than for crude minerals. Indeed some European countries are major exporters.

It is very convenient, and also meaningful, to compare the price of the refined mineral with the price (wage rate) of labor in manufacturing or in the economy. Both labor and the refined mineral are major inputs to the manufacturing, construction, service, and consumer sectors of the economy. If relative mineral price rises relative to the wage rate, this would be evidence of increasing scarcity, relative to the strong hypothesis. And vice versa.

Factor Costs. We consider, now, the other major variant, labor or labor plus capital cost per unit of net output. Again, the situation is relatively favorable for measurement. Petroleum refining, ferrous metals, nonferrous metals, and non-metallic, non-fuel mineral products are usually major production categories. More often than for crude mineral categories, these breakdowns are distinguished in the national statistics of European countries. Somewhat more often than for crude minerals, the employment in the refined mineral categories is broken down. Production indexes of the outputs are sometimes more reliable. This favorably affects our ability to measure labor or labor plus capital input per unit of net output.

However, as was true of price evidence for refined minerals, the ratio L or (L+C) to net output will be more influenced by manufacturing costs than cost of finding reserves and producing from them. Interpreting evidence will not be easy.

Production IV: Non-Minerals Production, Consumption and Markets.

This stage and these markets are our reference portion of the economy -- 10 to 20 times as large as the aggregate minerals sector -- against which mineral costs and price data are viewed relatively. The Stage IV activities thus include the effects of what happens in minerals, but these are far outweighed by what happens in the rest of the economy.

We could manipulate the Stage IV data to remove minerals from it, but this seems unnecessary. For example, assume that a minerals price index went from 100 to 150 from t to t+1, the prices of all goods were unchanged, and therefore we observed that the relative price index of increasing mineral scarcity was

$$\frac{P_m}{P_{all}} = \frac{150}{100} = 150$$

Assume minerals were 10% of the economy at t+1. Then, in fact, it must have been the case that:

	t	t+1		weight		t+1 weighted index
Non minerals	100	y	x	.9	=	.9y
Minerals	100	150	x	.1	=	150
All products	100	100	x	1.0	=	100

We solve for the non-minerals index at t+1, and find that it equals 94.4. Therefore, the true relative price of minerals is 150/94.4 = 159. This compares with the relative index of 150/100 = 150, which we found by comparing mineral price changes with the whole economy.

We find it more convenient to compare minerals with the total economy, rather than to follow the stronger logic of comparing mutually exclusive categories. The distortion is small, particularly in the light of other data defects, and does not affect conclusions.

Price Deflators and Foreign Exchange Rates

We have already indicated that this is a major problem. The time series of prices all have to be deflated. Especially in the 1970's. Many governments have given priority to unemployment abatement, social security systems, etc., and spent more than their revenues. Together with other causes considerable and world-wide inflation has been the result. In most cases, it is not possible to look at mineral price series and say its movements primarily relate to supply scarcity. Also, output indexes are contrived in part by deflating data on values, so our measures of labor cost per unit of mineral output are affected.

Unfortunately, respectable price deflator series are numerous and divergent in movements. Each has its own special definitions and meaning and differ from country to country. Should a deflator series for mineral price be -- of other materials; of the Gross Domestic Product; of consumer prices; of prices in international markets where exports are sold; of domestic prices; of U.S. prices from whom a major volume of imports come? Of four deflator series which the World Bank considers major relative to international trade in mineral products, the increase levels from the 1970 index base of 100 to the year 1978 are as follows: 166, 190, 252, 268!

Moreover, there is the further problem of foreign exchange rates, which we have not yet mentioned. Foreign mineral products are usually brought in dollar or pound sterling prices, by offer of the countries' foreign exchange. The trend of real cost of minerals to the purchasing country depends heavily on the price movements of its money relative to the dollar, and not merely on price movements of GDP, manufactured goods, consumer prices, or whatever other deflator is being considered.

In summary, our interpretation of price trends relative to the scarcity hypothesis cannot be simple, in view of OPEC, worldwide inflation, wide price movements, and substantial changes in foreign exchange rates in the period of the 1970's, which primarily interest us.