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Volume Author/Editor: Harold Barger and Sam H. Schurr

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Chapter Author: Harold Barger, Sam H. Schurr

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Part Four

Summary and Conclusions

". . . a capital which yields no annual interest, but once turned to light and heat and force, is gone forever into space." JEVONS

"Sisyphus in vita quoque nobis ante oculos est, . . . et semper victus tristisque recedit." LUCRETIUS

Chapter 14

Mining in the Nation's Economy

For the mining industries as a whole the growth in output and in output per worker between 1902 and 1939 was greater even than in manufacturing, and very much larger than in agriculture (Table 12). This rapid growth in production and productivity is attributable in large measure to the contribution of oil and gas wells to the total; if the petroleum industry is excluded from the computations, the results are much less impressive. For mining other than oil and gas, the rather moderate changes in output and productivity resemble the history of agriculture—also an extractive industry and a purveyor of raw materials—more closely than the history of manufacturing. There was little if any change in manday employment between 1902 and 1939 for mining as a whole; if petroleum is excluded, employment was actually about 18 percent lower in the latter year than in the former (Table 8). In this respect, whether or not we include petroleum, mining is less like manufacturing, in which there was a substantial increase in employment,[1] than it is like agriculture, where employment was less at the end of the period than at the beginning (Table 12).

Considered as a form of economic activity, the mining industries are unique, for they are concerned entirely with the exploitation of exhaustible resources. The amount of a particular mineral in the earth's crust may be large, but it is limited. The amount accessible to the miner, and available in sufficient concentration to obviate an excessive expenditure of effort, is still more limited. Known reserves depend upon the progress of discovery and the rate of depletion in the past. They are conditioned also in some degree by the state of the arts and the price of the product, for deposits not regarded as workable, and therefore not counted as reserves, at one time, may come to be so regarded at a later date. Reserves

[1] The increase, however, took place entirely during the first two decades of the century. Between the close of the first and the opening of the second World War employment in manufacturing underwent no further expansion. See Solomon Fabricant, *Employment in Manufacturing, 1899–1939: An Analysis of Its Relation to the Volume of Production* (National Bureau of Economic Research, 1942), p. 331.

may be replenished by fresh discoveries, and their accessibility may be improved by technological advances, in mining or elsewhere. Meanwhile depletion is a gradual process. Rarely does it appear, even in the case of a single ore body, in the form of sudden and complete exhaustion. Its effects are much more often reflected in a slow decline in the grade of ore mined, or of gradually increasing difficulties of extraction because of the need to work narrower or poorer seams at greater depths.

Depletion has greatly influenced productivity in the mining industries, but this is not the whole story. As in other branches of economic activity, notable advances have been made in the technology of mining. In addition, the amount of effort required to obtain a ton of mineral has been sharply cut from time to time in this country's history through the discovery of fresh bodies of ore superior to those currently exploited. These are the favorable factors. They have had to contend, in most branches of mining, with slowly but steadily increasing difficulties of extraction. The history of output per worker in any given mining industry is a reflection of the current phase of the long drawn out struggle between these conflicting tendencies. Where new discoveries and technological advances counteracted successfully the depletion of existing deposits, output per worker tended to rise; where they failed to offer sufficient counterpoise, productivity declined.

In some industries—iron ore mining and phosphate rock, for instance—depletion has not so far led to increased difficulties of mining. Here output per worker has increased sharply, because the effects of technological change have not as yet been dissipated to any important extent through the exhaustion of favorably situated reserves. In the case of oil and gas wells the exhaustion of individual deposits has frequently occurred, but up to this time depletion has been fully offset by new discoveries (Chart 43). In certain other industries—for example, anthracite mining and the production of mercury—technology has been fighting a rather unequal battle with resource depletion, and technological benefits have been largely absorbed by increased difficulties of extraction.

DIMINISHING RETURNS AND THE MINING INDUSTRIES

Except in the mining of anthracite, which is still produced in much the same localities, and sometimes by almost the same methods, as it was a century ago, the depletion of mineral resources and the increased difficulty of working them have become important factors in this country only within very recent times. This statement is not true of individual deposits: the cream has long since been skimmed from many a rich pocket of the early days. But during most of the nineteenth century the discoveries of the prospector and the spread of rail and water transportation opened up new sources of mineral wealth which more than offset the effects of depletion in the older deposits. Not only did the total amount of known ore reserves increase; in many instances the same minerals could be won more easily in the new locations than in the old. Compared to the working of minerals in Europe, mining in the United States is still young. It is not surprising, therefore, that output per worker appears to have increased faster in this country than in the Old World.[2]

Despite these indications of good fortune, we should still inquire what evidence there is, among the industries for which we have data, of the onset of diminishing returns. But the concept of diminishing returns is an elusive one. We should apply it, in the classical sense, to a situation where output per worker declines as current output rises. This may indeed describe the mining industry, as it has been held to apply to agriculture. But we are prevented from making short run comparisons of output and productivity, of a kind that would bear on this point, by the evident unreliability of reported short term movements in the latter. In any case the concept of diminishing returns in which we are interested primarily is a different one. For the distinguishing feature of the mining industries is the fact of depletion, and the increased difficulty of extraction which results therefrom. We are concerned, that is, with the question how far productivity is a diminishing function, not of current output, but of output cumulated to a given date. This is a legitimate use of the phrase diminishing returns, but it is not the use in which classical theory made these words famous.[3]

Let us, then, attempt to interpret the principle of diminishing returns as it applies to the depletion of minerals. We should expect in actual practice to observe, as time went on, a decline in

[2] *Mineral Economics*, ed. by F. G. Tryon and E. C. Eckel (McGraw-Hill, 1932), pp. 24-35.

[3] See Alfred Marshall, *Principles of Economics*, 8th ed. (Macmillan, London, 1920), pp. 166-67.

output per worker chargeable to increased difficulties of extraction. But we should also expect this decline to be interrupted by improvements in technology. And we should be forced to regard such improvements as more or less spontaneous in character and not themselves the result of resource depletion. In discussing diminishing returns classical literature clearly regards innovations as exogenous—when it mentions them at all. Indeed it seems obvious that, if sense is to be made of the concept, the technological state of the industry must be regarded as a parameter. Returns can be relied on to diminish, as a result of depletion or of a scarcity of high grade resources, only under the umbrella of a strict ceteris paribus clause.

According to this interpretation diminishing returns would show their effect as a consequence either of a failure in the supply of innovations, or of difficulties of extraction which increased so rapidly that rates of technological advance of the sort we have experienced in the past would prove inadequate to prevent a fall in productivity. Moreover, we might reasonably expect difficulties of extraction to increase more rapidly, and opportunities for technological improvement to be more restricted, in an old industry than in a young one. On this score we might feel inclined to say that the decline in output per worker in the mining of anthracite and mercury—both old industries—observed during the first quarter of the present century (Charts 30 and 31) showed that diminishing returns had set in. The sharp recovery in productivity in these industries during the past 10 or 15 years we should have to attribute to adventitious circumstances such as a sudden and unexpected revival of technological advance.

But this, which might be called the textbook version of the doctrine, appears too simple to fit the facts. There are numerous cases in which innovations appeared on the scene, and changes were made in mining methods, as the direct result of alterations in the conditions of resource occurrence. The invention of elaborate and extremely efficient techniques for concentrating copper and other nonferrous ores is clearly the result of the necessity to mine low grade minerals, and would never have been developed but for that need. It seems equally clear that the advent of modern drilling techniques in the petroleum industry was no accident, but arose because deeper wells had to be bored. Most of the mining methods of today represent the solution of a problem raised in the exploitation of some particular ore body or class of mineral deposit. The interaction of resource conditions and technological advance has been continuous. So has the spread of technological improvement from one branch of mining to another: we may mention the migration of the power shovel from the Mesabi Range to the copper deposits of the West and to the modern crushed stone quarry.

If increasing difficulty of extraction has so frequently produced its own antidote, how can we speak of diminishing returns in any orthodox sense? Instead of a persistent downward tendency in productivity, interrupted only by discontinuous and autonomous changes in technique, we have a tendency that seems, in some degree at least, to be self-reversing. Nor is it safe to predict that productivity will decline when a given stage of an industry's development is reached, or when specified deposits are exhausted, even if such a trend appears certain on the basis of technical methods so far developed. The experience of copper mining is sufficient warning against any such rash generalization.

If necessity is the mother of invention, she has been prolific in the past and may perhaps be equally prolific in the future. Clearly the story hinges on the type of response that technology is able to give when difficulties of extraction are encountered. The responses that are possible in a given case are limited by geological circumstances. For instance, if deposits lie deep below the surface it is impossible to improve their accessibility by adapting open cut techniques, so efficient elsewhere, to the problem at hand. Again, the introduction of mechanical coal cutting, which has staved off any tendency for the productivity of bituminous coal mining to decline, was found of no assistance in meeting the problem created by depletion in anthracite. One could cite other instances in which lines of technological advance, successful in some places, have been prevented by geological circumstance from being useful in others. Whether—within these geological limitations—new and more efficient methods of mining are developed, perfected and adopted seems to depend upon a wide range of circumstances, mainly economic in character, at whose nature and importance we can only guess. Certainly the existence of piece rates, and the reluctance to incur fixed costs that one finds under conditions of intermittent operation, seem to have retarded mechanization in coal mining. We may guess, too, that the competition of foreign mines in the case of copper, and of other fuels in the case of anthracite, have stimulated the mechanization of production in these industries.

The response of technology to increased difficulties of extraction may not always be as favorable as it has been in the past. To some extent the age of the industry may be a factor in limiting this response, although the recent introduction of mechanical loading devices in many anthracite mines should warn us against hasty generalization in this regard. Nevertheless, however favorable the technological situation is today, it would seem that, if one takes a long enough view, the effects of depletion must eventually be of a kind which cannot be fully offset, as they have been so frequently offset in the past, by changes in mining methods. In the petroleum industry, for instance, when oil can no longer be obtained from wells it may still be mined from shale or oil-bearing sand. It seems inevitable that such a drastic change in resource conditions should be accompanied by a fall in productivity. Even if the technological response were sufficient to prevent this, eventually exhaustion of deposits must occur, and productivity become zero as the industry closes down. A more reasonable expectation is a gradual failure of technology adequately to offset the effects of depletion. But this may happen only in the very long run. Despite declines in output per worker—declines extending from a few years to decades—the data we have assembled provide no real evidence that diminishing returns have already set in, in the sense that increased difficulties of extraction have failed to elicit corresponding changes of technique. On the contrary, output per worker, at the end of the period studied here, was close to its all-time high in every industry considered. If a stage of falling productivity must eventually be reached, the American mineral industry is too young, or our period of study is too short, for us to observe it.

THE OUTLOOK FOR THE MINING INDUSTRIES

What, then, is the prospect for the future of mining operations in this country? Shall we use more, or fewer, domestically produced minerals in the future than we have in the past? Will the rise in output per worker slow down, or even be reversed in direction? Should we expect more, or fewer, persons to find their livelihood in mining? Questions of this order cannot, of course, be answered outside the context of the particular branch of mining under consideration. In the discussion to follow we shall distinguish three broad groups of industries: metal mining, coal and petroleum.

We saw in Chapter 2 that metals are used primarily for the manufacture of durable goods and for purposes of construction. Taking the long view, we find little to suggest that the demand for durable goods is approaching saturation. Whenever the demand for particular types of equipment has been reduced to a replacement basis (e.g., railroad equipment) technological advances have created a demand for new types of durable good (e.g., highway vehicles). There is no reason to suppose that the last chapter of this story has been written. In other fields, too, large unsatisfied demands remain: for example, the continued growth of the electric power industry suggests that large amounts of metal will still be needed in this field in the future. On the other hand, it is plain from the evidence of Chapter 2 that we ought not to conclude that correspondingly large amounts of metallic ores will be required, for increasing quantities of scrap metal have become available in recent decades. For the most part metals embodied in durable goods or structures disintegrate rather slowly, and the stock of metal in all forms which civilization possesses above ground is large, and continually increasing. Clearly, much of the replacement demand for metallic objects can be satisfied from the junk pile. The future demand for metallic ores evidently depends upon the rate of wastage in our stock of metals and the rate at which we wish to increase this stock. Both will be much influenced by technological changes outside the mining industry—developments at whose nature and scope we can scarcely even guess.

The prospects for coal and petroleum are closely related, and turn upon the course of our need for power. In a civilization which depends as heavily upon elaborate manufacturing and extensive transportation facilities as does our own, continued and increasing consumption of vast amounts of power seems to be a certainty. For power is fundamental to our technological circumtances: innovations which have led to an increase of power consumption vastly outnumber the few that have reduced it. So far as concerns the mining industries, the question turns upon the probable future importance of different sources of power in relation to one another. At the present time these sources are confined almost entirely to coal, petroleum and natural gas, and water power. If we include heating and lighting, we may say that forty years ago about nine tenths of the power supply came from coal. Today about one half our power comes from coal, two fifths from petroleum and natural gas, and a tenth from water power.

Petroleum has displaced coal both through the development of the internal combustion engine and through the growing popularity of fuel oil for heating and steam raising. Natural gas has largely displaced gas manufactured from coal, both for industrial uses and in the home. In the picture as a whole the place of water power is still relatively unimportant, for in modern practice it is used only for generating electricity. The transmission of electric power over long distances and its application in the propulsion of vehicles both present obstacles which have been very incompletely surmounted. In the future, as in the past, the relative importance of different sources of power will depend upon their relative cheapness and convenience for different purposes. On these grounds alone a substantial expansion of water power seems certain to occur, even if the technology of its use progresses no farther. Should there be developments which broaden the scope of centrally generated electric power—for example, in the propulsion of vehicles and ships—it may continue to displace mineral fuels. From the viewpoint of resource conservation, water power has the supreme advantage that the problem of depletion does not have to be faced.

Insofar as hydraulic power is unsuitable or unavailable, and so long as vegetable materials (e.g., alcohol from wood) remain an unimportant source, it would seem that the power supply must continue to be furnished either by coal mines or by oil and gas wells (possibly including the mining of shale). To be sure, the situation may one day be radically changed through the development of a cheap and efficient electrical storage battery, through the harnessing of solar radiation, or through extensive utilization of tidal energy. The eventual release of atomic power for industrial purposes would doubtless alter the picture still more drastically. But in the absence of such striking events the choice remains, at least for the immediate future, between coal and oil. Despite marked economies achieved in the use of coal, it seems likely that greater convenience and adaptability will maintain or expand the place occupied by oil and gas. This situation may presently be reversed, conceivably through striking advances in the utilization of coal, but more probably through depletion of oil reserves. In terms of known deposits, the coal supply is to be measured in centuries of potential use, the petroleum supply in decades only.[4] If and when our oil reserves are used up, our coal deposits will have to supply, apart from imports of foreign oil, not only the need for heating and steam raising (which they do only in part today), but also for gasoline and lubricants (which in this country they do not do at all at present). Moreover, if petroleum should vanish from the picture, or even if it should become much more expensive, the production of alcohol and other fuels from vegetable matter would doubtless have to be given serious consideration.

It may be that we, and possibly the entire world, will eventually be forced to return to greater dependence on coal, rather than on oil, as a source of power. Nevertheless, the situation may not be as serious as the relative size of the known reserves of the two minerals might imply. The nation's coal deposits are extensive, and we have fairly accurate estimates of their size. Experts do not expect really important new discoveries in this country. In the case of petroleum, on the other hand, pessimistic predictions of early exhaustion have been repeatedly falsified through fresh discoveries, which in turn have been the consequence, at least in part, of improved prospecting techniques. Of course the more oil that has been found, the less remains to be discovered: we may not be so fortunate in the future. But the life of oil fields can be prolonged through conservation; and oil may be obtained by other means than the drilling of wells, e.g., by mining shale, though by present methods only at a considerably enhanced cost. There is the possibility, too, that if oil becomes scarce we may prefer to import it rather than to manufacture it extensively from coal. There is at least as much known oil outside the United States as at home, and many fresh deposits may still remain to be discovered in distant parts of the earth.

Evidently the future output of different minerals is conditioned largely by the extent of reserves and by the rapidity of their de-

[4] Of original reserves discovered to date we have used perhaps one hundredth part in the case of coal; one half in the case of oil (see Willard E. Hotchkiss and others, *Bituminous-Coal Mining,* National Research Project, Philadelphia, 1939, p. 53; Table A-18 below).

pletion. If the cost of mining a given metal increases, its users may obtain it from abroad, or may substitute other materials. When oil becomes more difficult or expensive to obtain, coal may be used in its place.

If patterns of consumption will ultimately be determined by what is left to consume, the future level of output per worker depends even more directly upon the effects of depletion. Except to the extent that it is delayed by technological advance or by the discovery of fresh deposits, the operation of diminishing returns must eventually set in. For a long time successive advances in technology may maintain output per worker at present levels or above; but the opposite possibility must also be considered. Reserves of natural gas, for example, may one day be more or less completely exhausted; or the decline in the grade of metallic ores may eventually be such that not even the most striking advances in technology can prevent a drop in output per worker.

The cost-raising effects of known amounts of depletion in the past, or of prospective rates of depletion in the future, cannot be accurately assessed. This is true partly because the results of technological change cannot be distinguished quantitatively or separated from the increased difficulties of mining which frequently gave rise to them, and partly because there is not enough exact knowledge concerning the character and extent of ore reserves and oil deposits. To be sure, we know that the grade of copper ore mined has declined sharply since the opening of the present century, and that this has not prevented an increase in output per worker. We know, too, that depletion had seriously reduced productivity in anthracite and in mercury mining until the recent recovery in output per worker in these industries set in. We do not know, however, just how output per worker would have behaved if there had been no changes in the technological state of these industries. Nor can we say to what extent the innovations which actually appeared were induced by greater difficulties of extraction, and to what extent they occurred independently. But, even if we cannot make exact statements about the effects of depletion, those effects are nonetheless real.

CONSERVATION AND THE TARIFF

The rapidity with which mineral deposits are exhausted is primarily a function of current rates of output. It is determined in large part, therefore, by the level of industrial activity, and by the roles assigned to different minerals as industrial raw materials. But it is affected also in an important and increasing degree by two different but closely related aspects of public policy. The first of these comprises direct measures of conservation; the second is the manner in which fiscal policies, and especially tariff measures, affect mineral extraction.

Conservation policies designed to retard the rate of depletion of minerals were first applied in the case of petroleum and natural gas. Laws against the waste of gas date from the 1890's, and production control began to be applied to petroleum during the 1920's. At first resisted by the industry, the principle of control was accepted only after overproduction had forced down the price of oil to levels which many producers considered unprofitable.[5] Texas, Oklahoma, Kansas, New Mexico, Louisiana, Mississippi, Arkansas, and Michigan now have proration laws. Recently the National Resources Committee has suggested that conservation would be more effective if undertaken by the federal government,[6] and the Cole bill was introduced in the House in 1940 with this end in view. It should be added that the United States is itself the owner of lands containing about 15 percent of the nation's oil resources.[7] A move toward the conservation of bituminous coal was made by Congress in the Coal Act of 1937; while this act does not directly restrict production, it may do so indirectly through the establishment of minimum selling prices. The need for the conservation of coal is of course much less urgent than in the case of oil and gas, and applies chiefly to the higher grades of coking coal.[8]

The principal effect of fiscal policy upon mineral extraction is through the tariff.[9] The United States is on an export basis with respect to coal and petroleum, but it imports significant quantities of zinc, lead and copper ores (mainly in the form of concentrates),

[5] Leonard Logan, "Production Control in the Petroleum Industry" in *Mineral Economics.*

[6] National Resources Committee, *Energy Resources and National Policy* (Washington, 1939), pp. 2-3, 214-36.

[7] *Ibid.*, p. 24.

[8] *Ibid.*, pp. 15-19.

[9] There is some evidence that other types of fiscal measure have retarded conservation. For example, the taxation of mineral lands by Minnesota on an ad valorem basis has apparently had the effect of penalizing the development of low grade in comparison with high grade iron ores (see Nicholas Yaworski and others, *Iron Mining*, National Research Project, Philadelphia, 1940, p. 171).

which are in large measure subsequently exported in metallic form. A major portion of the domestic consumption of manganese, tungsten and mercury is supplied by imports. Practically all our tin, nickel and chromium comes from abroad. In spite of opposition by smelters or other users of their product, most domestic mining enterprises subject to foreign competition have sought and obtained tariff protection. Probably the first to do so was the infant lead mining industry, which has been sheltered from foreign competition ever since 1790. Copper and mercury received protection in 1883, zinc and tungsten in 1909, and manganese in the Tariff Act of 1922. The original tariff on copper was repealed in 1894, but was reimposed in 1932. Little iron ore has been imported since the Mesabi Range came into operation, and the duty imposed in 1883 was abolished in 1913.

From this brief description of the relevant tariff provisions, we turn to the principles involved. The impact of tariff policy upon the rapidity of depletion of mineral resources is clearly the obverse of the effect of the conservation measures mentioned above. Whenever the enactment of an import duty leads us to satisfy a larger fraction of our needs from domestic, and a smaller fraction from foreign sources, the output of domestic mines and the rate at which they are depleted will tend to increase.[10] For example, in copper mining the grade of ore in the United States is much below that produced in other parts of the world. This disadvantage is compensated, at least in part, by specially developed techniques of extraction and concentration, although there is evidence that foreign costs, especially in the newer African mines, are lower than in this country, mainly because the ores are richer.[11] However, in the case of copper, as in the case of lead and zinc, reserves of ore in the United States are still substantial, and the danger that a policy designed to stimulate domestic production may greatly hasten exhaustion seems remote. It is rather in the mining of manganese, tungsten and mercury that tariff protection has been criticized on the ground that early exhaustion is in prospect.[12] In none of these cases, despite some degree of tariff protection, do

[10] The effect upon world (including United States) mineral reserves is of course an opposite one: they will be depleted more slowly than would otherwise be the case.

[11] See U. S. Tariff Commission, *Copper*, Report No. 29, Second Series (1932); also a release by E. W. Axe and R. E. Houghton, "Copper" (E. W. Axe and Co., 1934).

[12] J. W. Furness, "Tariffs and Exhaustible Resources" in *Mineral Economics*.

domestic mines satisfy anything like the whole of our needs. A tariff high enough to secure self-sufficiency, which has been urged at different times by the producers of each of these three metals, would therefore involve sharp increases in rates of domestic production and of the depletion of these particular resources. Known reserves of the three minerals mentioned appear to be quite small. In one case at least, that of mercury, the United States Tariff Commission refused to recommend an increase in the duty, giving as one of its reasons the importance of avoiding rapid depletion of domestic deposits.[13]

CONCLUSION

To what extent can technological advance be expected to overcome the effects of resource depletion? We can judge only in very rough fashion, from what has happened in the past and from what is known concerning the characteristics of different types of deposits. Where the mineral is rigidly limited in amount, and depletion shows itself not so much in greater difficulty of extraction or declining quality of mineral as in approaching exhaustion, technology can obviously accomplish little—except indeed by producing substitutes for the missing mineral. Few minerals are so situated that exhaustion can occur suddenly without any prior rise in the cost of mining: perhaps natural gas reserves are as near to this situation as any of our mineral deposits. Oil wells can be exhausted too; but even after resort has been had to pumping, much oil remains in sands and other oil-bearing strata. This oil can of course be recovered—at a price; here there is a possibility of further technological advances to which little thought has so far been given.

The exhaustion of most other minerals is likely to be a much more gradual process, and efforts at its postponement would appear to provide far greater scope for technological progress. In anthracite mining depletion has led to the working of narrower seams at increased depths: but that fact has not prevented the adoption of power loading, even if the mechanical cutting of anthracite still lies largely in the future or perhaps will never be achieved. The potential exhaustion of bituminous deposits is important mainly with respect to the better grades of coking coal.

[13] U. S. Tariff Commission, *Quicksilver,* Report No. 92, Second Series (1935), p. 2.

Immense resources of low grade bituminous coal and lignite remain to be exploited; but here the need for innovation may lie rather in the methods by which fuel is utilized than in the actual operation of winning it.

As we have seen, it would be a mistake to regard technological innovation as proceeding independently of resource depletion, at a given speed, and without reference to the rate of exhaustion. It was in fact only because conditions of resource occurrence became less favorable that many technological improvements were devised. Much of the innovation of recent decades would have been entirely inappropriate to the (often small scale) exploitation of the richer ores of the past. This has been notably true in copper mining, and doubtless in other industries as well. Most of our copper now comes from ores that are much leaner than any worked forty years ago. The decline in the grade of ore stimulated the development of large scale mining and concentrating methods which have in good measure overcome the disadvantage that gave rise to them.

Indeed it is virtually impossible for our copper reserves to become completely exhausted. There are available indefinitely large supplies of ores still leaner than those now being worked—ores containing perhaps but a few tenths of one percent of the metal. It remains to be seen whether advances in technique will make possible the working of such ores without a sharp rise in costs.

Few, if any, American mining industries are confronted by total exhaustion of their deposits within the foreseeable future. The primary problem has been, and will remain in times to come, to counteract a deterioration in the quality of resources—a deterioration which would otherwise lead to a decline in output per worker, and to correspondingly augmented mining costs. This is the task of technology. That the task has so far been discharged with notable efficiency in the majority of mining industries may be attributed in part to the comparative youth of mineral workings in this country. It is obviously unwise to assume that the effects of depletion in raising mining costs will be overcome as easily in the future as they have been in the past.

If it be true that output and productivity in the mining industries reflect the result of a struggle between advancing technology and gradually increasing difficulties of extraction, what can be said of employment? In a purely formal sense, the same factors determine the number of persons engaged in the industry. If we know how large output will be, and also the level of output per worker, we can specify the draft the industry will impose upon the labor force. Unfortunately, however, the future level of employment in the mining industries is peculiarly difficult to forecast. It, too, represents the outcome of conflicting tendencies. We have seen employment reach a peak during the first World War, and decline rather steadily since that time. If the mechanization of mining operations and the improvement of concentrating methods proceeds as rapidly in the future as in the recent past, if further advances in fuel economy and in the use of secondary metals occur, and if the effects of depletion are not seriously felt for some time to come, it is possible that the decline in employment will be resumed shortly after the conclusion of the present war. But sooner or later this downward trend may be reversed. In the first place, exhaustion of oil reserves, or vigorous measures of public policy designed to conserve these reserves, may lead to a substitution of coal for oil as a source of power. Since the amount of mining labor needed to produce a unit of energy in the form of coal is several times that required in the case of oil, the result would be an immediate upturn in total employment in mining. In the second place, productivity in anthracite and in many kinds of metal mining may presently decline through greater difficulty of extraction, insofar as technological advance is unable to counteract it. The same may be said of petroleum, if it should be found necessary (or desirable as a measure of conservation) to obtain oil by mining oil-bearing strata, instead of allowing it to flow freely from wells, or pumping it, as is done today. In that case the fraction of the labor force engaged in mining may increase.

The conclusion that, whatever the immediate outlook, the effects of depletion must eventually lead to greater employment in mining in this country is rendered hazardous, not only by further possibilities of technological innovation of which we know nothing, but by two other factors already noted. Domestic deposits are not the only source of mineral raw materials. Should innovation eventually fight a losing battle with depletion in the United States, it is possible that a rise in the price of domestically produced minerals may lead us to satisfy a larger proportion of our needs from abroad. Declining productivity and higher costs of mining, if they should occur, will be a symptom of an aging industry. The mining industries of Europe are even older than our own, and many of them have suffered severely from the effects of depletion. But there are also younger industries: the copper mines of Africa and South America, the oil wells of South America and Asia. It may be that these, or other undiscovered deposits in distant parts of the earth's surface, will eventually supply a much larger fraction of the world's needs—and of our own—than they do today. Increased dependence upon foreign supplies may indeed be accompanied by a simultaneous need for more miners at home, but the expansion of mineral imports (should it occur) would mitigate the increase in domestic employment occasioned by greater difficulties of extraction.

And in the second place we may come to depend in larger measure upon water power, or other nonmineral sources, for our supply of energy. Moreover, our need for metals may be satisfied in increasing, perhaps eventually in overwhelming, degree from the junk pile. The realization of these possibilities would, like the increased importation of minerals, counteract the tendency of depletion to force an increase in mining employment.

These conflicting characteristics render predictions about the future of the industries treated in this volume—whether considered separately or as a group—peculiarly difficult. So much is obvious. It is not perhaps so obvious that they are also, in large measure, the characteristics which distinguish mining most sharply from other forms of economic activity. To take one example: manufactured goods are produced and, once consumed, must be produced all over again, whatever may happen to the materials of which they are made. But the metal mining industries, which contribute to these materials, are distinguished by the fact that much of what they produce is wrung from the ground once and for all and can be used over and over again. In the case of metals, it has become the function of the junk pile to provide, in the accounting of society if not of the extractive industry concerned, a partial offset to depletion. However, comparative indestructibility of product, shared perhaps by certain forms of construction activity, is a peculiarity, in mining, of the metal mining industries.

Two other characteristics—localization and depletion—are common to all forms of mineral extraction and serve to distinguish mining even more sharply from other forms of production. Mining operations can be carried on only in certain definite localities where minerals are to be found, and are best concentrated (in the absence of deliberate conservation) on those parts of the earth's surface where minerals of highest grade may most easily be extracted. No other industry is subject to geographical limitations of a like nature; the resources of no other industry show a like contempt for political boundaries. Mining, moreover, alone among types of economic endeavor, must reckon with depletion of its resources. In manufacturing or transportation there is nothing to prevent the attainment of a given technological level from yielding a permanent increment in the productivity of human effort. Not so in mining, for it is an enterprise which must constantly repair its fences. No level of productivity can be considered secure, for, once attained, it must be buttressed continually with fresh innovation. The inevitable deterioration in the conditions of mining offers a challenge which has been met in the United States in recent decades, as we have seen in this volume, with significant and sometimes spectacular success. We can hope that the efforts of the mining engineer will be equally effective in the future, but of this, of course, we can have no positive assurance.