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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 Three

Technological Change and Productivity in Individual Industries

"Mineral economics, therefore, is the record of struggle between opposing forces. On the one hand is the factor of exhaustion, with its burden of accumulating handicaps. On the other is mineral technology, aided by its allies, exploration and transport. Finding of new deposits gives the mining engineer new ground to work upon and expansion of the transportation network may open up deposits known but previously inaccessible. The result of the struggle differs from place to place. In thousands of individual mines and scores of districts depletion has the best of it. If the world were dependent on the copper mines of Cornwall, or the silver-lead of ancient Laurium, the best of its technology could not avert a huge increase in price and a curtailment of supply. But taking the world as a whole, technology and its allies have generally the best of it, and their victory has nowhere been more striking than in the United States." F. G. TRYON

Chapter 8

Bituminous Coal Mining

IN THE preceding chapters we surveyed the mineral industry as a whole from the standpoint of physical efficiency. We investigated trends in output and employment during the past forty years, and made some comparisons between the experiences of different branches of mining. We sketched the history and development of the technique of mineral extraction and reviewed its present condition. The purpose of the more detailed studies in this and the following chapters is to round out the picture. The various minerals present quite different problems in their extraction, but in every case the physical conditions of their occurrence are of fundamental importance. Some minerals remain readily accessible and of excellent quality. In the case of others the highest grade or most easily mined deposits have long since been exhausted: here techniques unknown to the miners of the past must be used if workable material is to be obtained. We shall endeavor to appraise the results of the perennial conflict between resource depletion and advancing technology as it has affected the more important individual mining industries.

Among these industries coal deserves pride of place. Despite the substitution of other fuels, and the rise of water power, coal still furnishes about half of the nation's energy supply, and the mining of coal continues to employ more than half the workers engaged in mineral extraction. The production of solid fuel in this country falls naturally into two major divisions: (1) the bituminous coal industry, geographically scattered, and including all mines other than those in the Pennsylvania anthracite region, and (2) the Pennsylvania anthracite industry, concentrated in a rather small area within that state. We turn first to the larger of these two industries—that producing bituminous coal.

The bituminous industry, then, embraces all coal mines except those producing Pennsylvania anthracite. This peculiar definition has to be adopted because the industry's product is so diverse that no single positive criterion can serve as a convenient touchstone of classification. Diversity of product manifests itself in two forms: variations in rank[1] of coal, and variations in quality. Variations in rank range all the way from the sub-bituminous lignites of Texas and the Dakotas to the anthracites produced outside of Pennsylvania (notably in Arkansas and Virginia). However, the lignites and the non-Pennsylvania anthracites constitute a quantitatively unimportant segment of the bituminous industry's total output. Of greater significance are differences in quality of product, which cover such diverse factors as size, and content of ash, sulfur and moisture. These variations may, in fact, be but slightly disguised divergences in rank, which is greatly influenced by the amount of volatile matter contained in the coal.[2]

Despite variations in the product of the industry, output is generally measured by a single figure representing total tonnage produced. We have followed the customary usage in this respect; hence our index of physical output is a series of such figures expressed as relatives of a comparison base which is either 1899 or 1929. Whether any significant shifts in the internal composition of coal output have occurred during the period covered by our analysis we have no way of knowing with certainty.[3] If, as seems likely, the distribution of the output of coal with regard to rank has not shifted in any marked degree, our index is probably adequate on this score. It is possible, however, that the progressively greater acceptance of fine sizes over a period of years has led to an increase in their relative importance in the total picture, with a resultant upward bias in the movement of the index.[4] To a cer-

[1] By rank is meant the degree of metamorphism, or geological change, through which the coal has passed from its original deposition to the present.

[2] See *Report of the Committee on Prices in the Bituminous Coal Industry*, prepared for the Conference on Price Research (National Bureau of Economic Research, 1938), pp. 6-7.

[3] Ideally, in the absence of price changes, an index of output should vary directly with value of products, but it will not do so if shifts have occurred between differently priced varieties.

[4] It is important to note that our impression that some of the new sizes and varieties are of a relatively lower grade than the coal produced at the turn of the century is, in part at least, illusory, since their growing importance is a byproduct of technological advance both in the production and in the utilization of coal. Improvements in coal preparation techniques have made smaller sizes marketable because they have raised the quality of so-called fine coals. It is likely, then, that the "fines" of today are really something other than the "fines" of the early part of the century. Writing in 1927, F. G. Tryon concluded that since 1913 any change in the average quality of coal as a whole, measured in heat units per ton or otherwise, had been very slight (*Mineral Resources, 1926*, Part II, p. 445). In addition, there is the factor of increased efficiency in coal utilization, which has perhaps increased the efficiency of a ton of "poorer" coal to such a degree that it lessens appreciably the gap between the "high" grade coal of 1899 and the "low" grade coal of 1939.

tain extent, though, this putative bias must have been counteracted by the tendency of coal mines to pay more attention to the specialized needs of individual consumers, giving greater care to sizing, sorting, etc.

So much for the products of the industry. There remains the task of defining the limits of the production process that we call mining. Adjacent to the underground mine or open pit which yields the raw mineral is usually found a preparation plant where the run-of-the-mine coal is sized and perhaps cleaned. The functions performed by such a plant are generally considered as part of "mining." Hence, the industry, as defined for our purpose, is one that includes all processes preliminary to the movement of coal from the mining property for shipment to the consumer. Coking, like other forms of processing, we regard as manufacturing and exclude from the scope of this report.

THE RELATION BETWEEN OUTPUT AND EMPLOYMENT

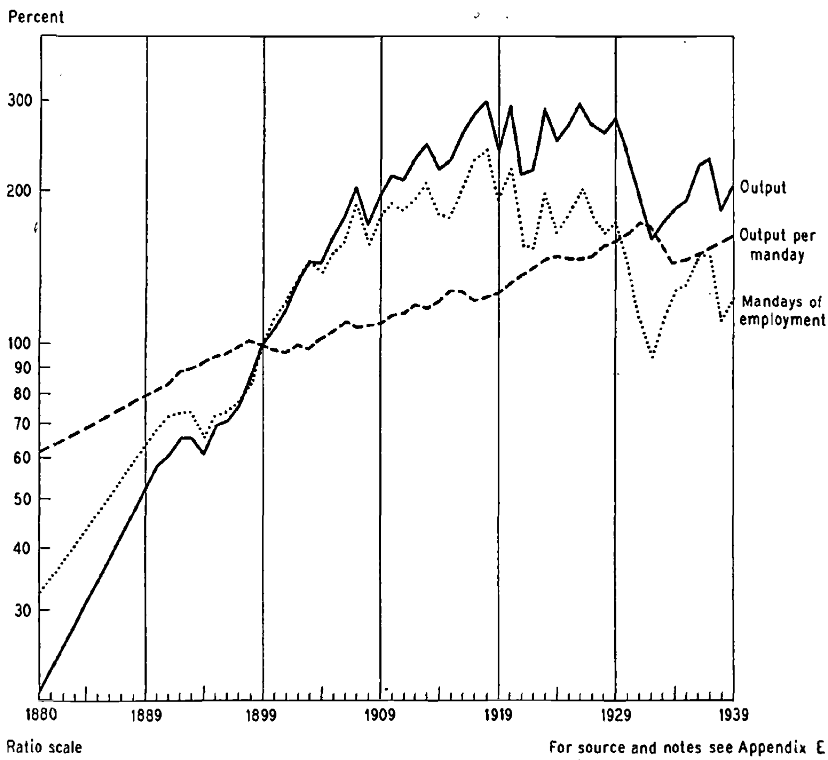
The peak in both production and employment [5] in bituminous coal mining came during the first World War, and that conflict may, therefore, be taken as a convenient dividing point in the history of the industry. Before the war one may trace a general upward movement in both series which culminated in their wartime peaks. Thereafter the direction of movement was reversed. The impression conveyed by Chart 36 is one of rapid rise, followed by gradual decline, in both production and employment.

Although the general direction of movement of output and employment is similar in both periods, it is clear that the relation between these two quantities underwent a gradual alteration. As the coal industry expanded, the growth of production outstripped the gain in employment: between 1899 and 1918 the increase in the former amounted to 200 percent, in the latter to only 140 percent. In like fashion, the post-war contraction was accompanied by a steeper fall in employment than in production: between 1918 and the low point in 1932 output declined 47 percent, employment 61 percent. During the period before the first World War output rose so rapidly in relation to advances in pro-

[5] As explained in Chapter 4, we shall regard the manday as the basic unit of employment.

ductivity that the level of employment also rose. After 1918 the trend of output was apparently downward, and in this period employment fell more rapidly than production. The decline reached its lowest point in 1932, when for the first (and as yet the only)

Chart 36
BITUMINOUS COAL
Output, Employment and Productivity, 1880 - 1939
(1899 : 100)



time since 1899 mandays worked fell below the 1899 level. Thereafter a recovery set in, but in 1936–37 employment was still no greater than it had been 30 years earlier in 1904–05. Thus the expansion in output per manday is seen to have been continuous in tendency, and to have proceeded at about the same rate, whether the trend of production was rising or falling.

As we saw in Chapter 2, the decline in bituminous coal mining from its peak in 1918 is in large degree the obverse of the meteoric rise of oil and gas wells as a source of fuel. Nevertheless, more people are still employed in mining bituminous coal than in any other mineral industry. In 1937 manhours of employment in this branch of activity were about equal to the composite of manhours at oil and gas wells, in the metal mining group, and in the dimension and crushed stone industries, with phosphate rock and gypsum mining thrown in for good measure. For this reason alone the factors that have determined the volume of the industry's employment would be worthy of close study. But there is an additional contrast, for in value of production this industry, with its extremely large labor force, has relinquished first place to the petroleum and natural gas industry, which in 1937 absorbed only about one half as many manhours of labor. Again, the group of industries listed above, whose composite of manhours was about equal to that of bituminous coal in 1937, had products with a combined value about three times as great as the worth of bituminous coal produced in that year. This contrast suggests that the extraction of coal, judged by its consumption of labor, is an extremely expensive business. So it is, in terms of dollar value of product, or of energy units produced, per manhour.[6] To be sure, we cannot conclude on this account alone that the technological state of the industry is backward. But these considerations may suggest either that the technological problems encountered by the industry are peculiar, or that its resource conditions are less favorable than those obtaining elsewhere. We shall find that there are elements of truth in both these suppositions.

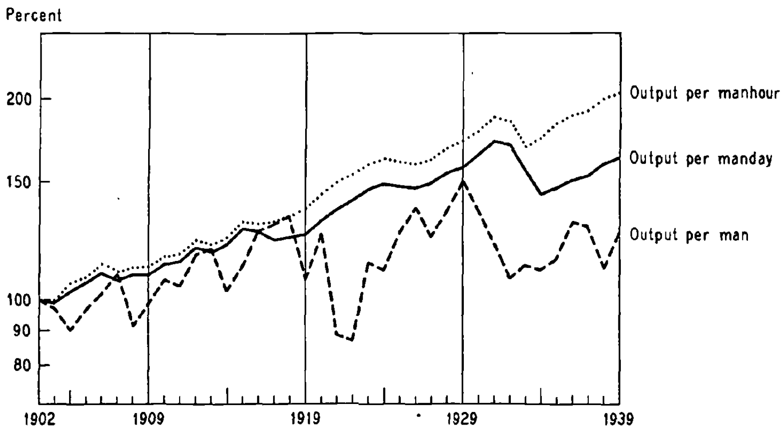
Among the mining industries for which we have productivity measures, bituminous coal ranks low in the increase registered between 1902 and 1939. Output per manday increased 63 percent, output per manhour 104 percent (Table 11). Among the more important mining industries, only Pennsylvania anthracite failed to better this record. The metal group, the stone industries, and oil and gas wells all showed substantially larger increases in productivity over the period. When compared with the average change in productivity for mining as a whole (excluding oil and gas wells), the record of bituminous coal mining appears less unfavorable, but chiefly by reason of the relatively large part that the industry itself plays in the determination of this average.

The two coal industries—bituminous and anthracite—are the only branches of mining for which we have continuous annual

[6] See also Tables 13 and 14 above.

employment data back to 1902. In Chart 37 a comparison is made between man, manday and manhour productivity for bituminous coal. The divergence between output per manday and per manhour (plotted to intersect in 1902) reflects the shortening of the workday (from 8.8 hours in 1902 to 7 hours in 1939: see Table 10 above). Differences in movement between output per manday and output per man are a function of the number of days worked per

Chart 37
BITUMINOUS COAL
Productivity, 1902–39
(1902:100)



For source and notes see Appendix E

year. The latter curve reflects year-to-year variations in output which scarcely influence manday or manhour productivity. We must attribute the slower rise of output per man than of output per manday, and the tendency of these two curves to move farther apart as the period advances, to a decline in the number of working days per year, i.e., to more intermittent operation of the average mine than was formerly common. This change has been regarded by many as a symptom of overcapacity.

Among the complex factors which have influenced productivity in bituminous coal, as in other mining industries, are two that deserve special attention: (1) resource conditions, that is, the extent to which depletion has occurred, the circumstances wherein currently exploited deposits of the mineral are found, and the ease or difficulty of extraction; and (2) technology, considered broadly to include all mechanical and engineering, and even some managerial, aspects of coal mining. These two factors, in their joint and several operation, are commonly the most important influences upon the productivity of any mineral industry. Yet the manner in which they exert their influence differs markedly from one industry to another. Let us turn first to resource conditions, and then consider the part played by technology.

RESOURCE CONDITIONS

In the mining of many minerals deterioration in the quality of resources over time may constitute a drag on the growth of industrial productivity. We should therefore seek to determine whether this basic factor, whose effect can be delayed only if exploitation of the mineral is renounced, has been at work in the bituminous coal industry.

To a certain extent all mineral industries are beset by natural difficulties which increase as extraction proceeds, for it usually happens that the most readily accessible and the highest grade deposits are brought into production early during the life of any branch of mining.[7] As these deposits become depleted (that is, decline in grade or become less readily accessible), and as demand continues and perhaps expands, it becomes necessary to bring other deposits—which in one way or another are inferior to the deposits first exploited—into production. And so, in broad outline, the process continues. However, for purposes of comparing one industry with another the broad outline is less important than the variations within its framework. Thus, in the present context, we are more interested in the deterioration of the country's bituminous coal resources compared with rates of depletion of other minerals than we are in the absolute change in the quality of workable bituminous coal deposits as such. Only then can we discover whether the relatively smaller rise in the industry's productivity is attributable, in part at least, to a greater deterioration of bituminous coal resources.

The quality and accessibility of our deposits of bituminous coal have not yet seriously declined. As recently as ten years ago, for example, Tryon and Berquist remarked: "There is such an abundance of thick and easily accessible coal that mining condi-

[7] See Chapter 5 above.

tions are nearly, if not entirely, as favorable today as they were 50 years ago." [8]

It is doubtful that such a statement could be made about any other major branch of extraction, with the possible exception of petroleum and natural gas. Certainly, since the beginning of mining, the deterioration of bituminous coal resources has been slight in comparison with the situation in the metal mining industries.[9] To be sure, the statement that 3 thousand billion tons of recoverable coal remain in the ground—enough to last perhaps 70 centuries at current rates of exploitation—conveys somewhat too favorable an impression. The supplies of high grade coking coal, for instance, are relatively much more limited: the Connellsville seam may be exhausted within a few decades, and supplies of coal of comparable quality for metallurgical purposes are not widely distributed. The best steam coal is somewhat more common, but it too forms only a small fraction of total coal reserves.[10]

Nevertheless, when all suitable qualifications have been made, the broad generalization seems justified that in the bituminous coal industry depletion has not yet led to appreciable deterioration in the physical conditions under which the mineral is obtained. This observation is confirmed by such a simple (although not definitive) measure as depth of shaft. Depth of shaft averages a few hundred feet in the bituminous coal fields, as contrasted with a few thousand feet in the metal mining camps.[11] We should note also that not all underground bituminous mines are shaft mines, but that many bituminous deposits are still reached by slopes and drifts, some even above the ground-water level.[12] Except in bituminous coal, such a condition is rarely encountered

[8] F. G. Tryon and F. E. Berquist, "Mineral Economics—An Outline of the Field" in *Mineral Economics,* ed. by F. G. Tryon and E. C. Eckel (McGraw-Hill, 1932), p. 27.

[9] See also Willard E. Hotchkiss and others, *Bituminous-Coal Mining* (National Research Project, Philadelphia, 1939), p. 8.

[10] Glen L. Parker, *The Coal Industry* (American Council on Public Affairs, Washington, 1940), pp. 2-3.

[11] In 1926 the average depth of all underground bituminous mines was about 320 feet; averages for individual states ranged from 730 feet for Utah to 70 feet for North Dakota (Hotchkiss and others, *Bituminous-Coal Mining,* pp. 58-60). See also F. G. Tryon, "The Changing Distribution of Resources" in *Migration and Economic Opportunity* by Carter Goodrich and others (University of Pennsylvania Press, 1936), p. 264.

[12] F. G. Tryon and Margaret H. Schoenfeld, "Comparison of Physical Conditions in British and American Coal Mines," reprint from *Coal and Coal Trade Journal,* Sept. 1, Sept. 8, Oct. 7, and Nov. 4, 1926, p. 4.

in any but the very early stages of mineral exploitation, and is a far cry from the elaborate measures used to gain access to the typical underground metal deposit. It seems reasonable to conclude, therefore, that bituminous coal mining has been more fortunate than most other mineral industries with regard to the mining conditions encountered. If we wish to explain the comparatively slow rise of output per worker in bituminous coal mining we must, evidently, look for other causes.

TECHNOLOGY

Besides the character of resource occurrence, the chief determinant of productivity in an industry is its level of technological attainment. Since we are interested in relative behavior, we must ask how technological advance in bituminous coal mining compares with that in other mining industries. What are the other industries most relevant to such a comparison? The productivity of anthracite mines has increased even less rapidly than that of bituminous coal mines; and the technology of oil and gas production is so dissimilar that useful comparisons cannot be drawn. Consequently the discussion resolves itself, at this point, into a comparison of technological conditions in bituminous coal mining and in the metal mining industries. Certainly in each of the three main divisions of metal mining, productivity has increased more rapidly than in the soft coal industry.[13] How far, if at all, can these differences be explained in terms of divergence in technological background?

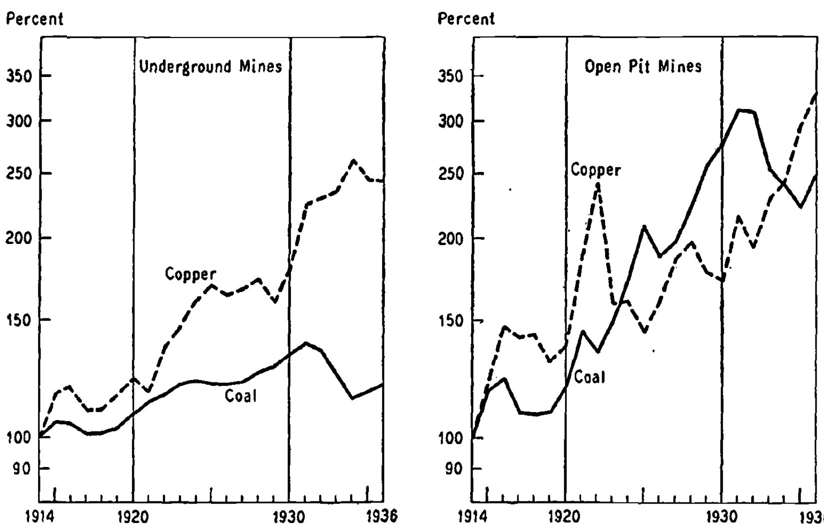
First, we should notice a significant difference between the coal industry and metal mining. As we shall see, iron ore and copper, which among the metals have made the greatest strides, depend heavily upon open pit mining. Power-shovel strip mining of soft coal, this industry's version of the open cut mining technique, is a response to special resource conditions and is rather unimportant.[14] Despite the increasing share of strip methods in the mining of coal since the first World War, these operations accounted for less than 10 percent of bituminous output in 1939. The typical coal mine is therefore an underground mine. Compared with stripping, underground mining has two disadvantages. Mechaniza-

[13] Table 11 and Chart 30, above.

[14] It is not at present practiced where the coal lies at greater depths than 60 to 80 feet.

tion is more difficult to achieve in cramped spaces below ground; and the benefits of scale are less easily obtained, since maximum practicable daily tonnages are limited by the capacity of underground transportation systems and of hoisting equipment. Yet its greater dependence upon underground production does not account for the apparent backwardness of bituminous coal mining in comparison with other forms of extraction. For between 1914 and 1936, at least, underground copper mines increased their productivity almost as fast as open pit mines, and very much faster than underground coal mines (Chart 38). It is to the backwardness of the underground coal mine, therefore, and not to the back-

Chart 38
UNDERGROUND AND OPEN PIT MINES
Output per Manday, 1914 – 36
(1914 . 100)



Ratio scale

For source and notes see Appendix E

wardness of underground mining in general, that we must look if we wish to explain the laggard behavior of productivity measures in bituminous coal.

In making comparisons between coal and copper, or some other type of mining, we must remember that the mechanization of certain functions in a given industry may be delayed through physical conditions peculiar to that industry. Thus, even after a machine has been successfully utilized by a mine producing one mineral, another mine producing some other mineral, or even the same mineral, may be balked in its attempt to use the machine by a set of geological circumstances entirely different from those encountered in the first mine. Often it can adapt the machine to its own needs, but sometimes it cannot do so. Another difficulty we face in making comparisons between the technology of different industries is the fact that certain functions are of more importance in one type of mine than in another. For example, drilling is a much more vital operation for the hard materials encountered in metal mines than it is for bituminous coal mines, where softer materials occur. On the other hand, the many miles of haulageways to be found in bituminous mines, partly because of their age, make transportation a far more serious problem in these mines. It has been said that there are more miles of railroad track below the surface in the coal mines of Pennsylvania than above ground in the entire state.[15]

It is clearly inadvisable to attempt to compare the degree of mechanization of each mining function considered separately. Yet a meaningful comparison can be made between the general level of technology in bituminous coal and in other types of mines. At this point we may note merely that many of the production techniques that have come into prominence in these other industries (especially metal mining) during the past four decades depend on a careful organization of production with an integration of functions within the mine, as well as upon an articulation of mine and beneficiating plant.[16] This is eminently true both of open cut metal mining and of certain techniques (especially caving and other gravity loading methods) for the mass production of ores underground. How does the bituminous coal industry compare in this respect?

In 1921, several years before the emergence of mechanized loading, the managing editor of *Coal Age*—the industry's principal trade journal—wrote: "Mining [of coal] is still in a way a 'cottage' industry, only the cottage is a room in the mines." [17] This state-

[15] Thomas T. Read, *Our Mineral Civilization* (Williams and Wilkins, Baltimore, 1932), p. 8.

[16] See Chapters 11 and 12 on iron ore and copper, respectively, and the discussion of technological change in Chapter 5 above.

[17] R. Dawson Hall, "Have Mining Engineers Accepted All That Developments in Machinery for Handling Coal Imply?", *Coal Age*, July 7, 1921; quoted in Carter Goodrich, *The Miner's Freedom* (Marshall Jones, Boston, 1925), p. 19.

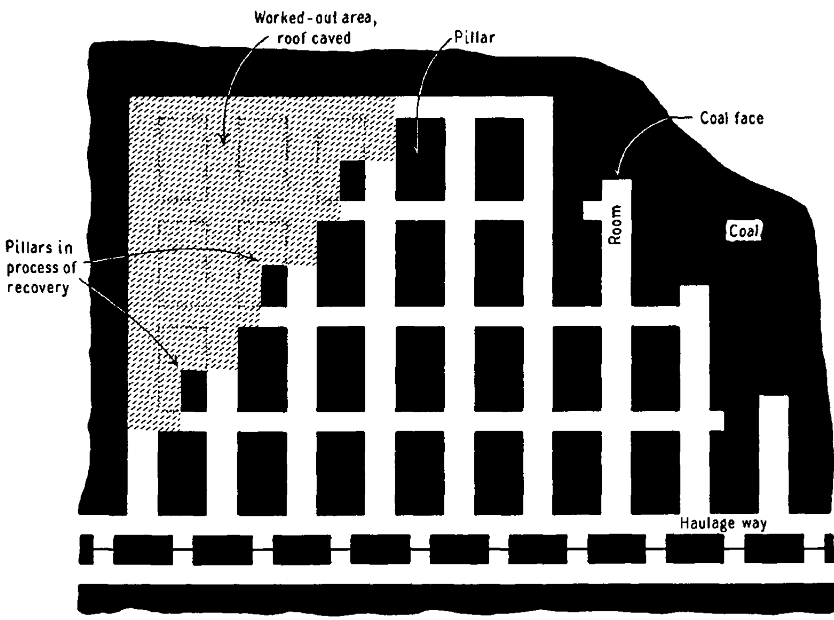
ment answers the question posed at the end of the preceding paragraph, but it does more than that. It takes us to the crux of the problem by leading us to the heart of the coal mine. For it is in the room where the miner works that the problems of coal production have to be solved.

The prevailing system of mining in the bituminous coal mines of this country is the room-and-pillar method (Chart 39). This title aptly describes the technique, for the actual breaking and

Chart 39

ROOM-AND-PILLAR MINING OF BITUMINOUS COAL

Diagrammatic Plan of Workings



For source and notes see Appendix E

loading of the coal is done by miners working in rooms separated by pillars left in place to support the mine roof. Work goes on at one end of the room—known as the working face—and the room is constantly being pushed toward the boundary of the coal seam. The mine is broken up into many of these rooms, each with a working face large enough only for one or two working miners.

When the mines were small, as they must have been when the method was first utilized, the working faces were probably fairly close to each other. But with the growth of the mines the number of rooms and working faces has increased, and the area over which they have been scattered has grown constantly larger. An expansion in the volume of output from any mine was usually met in only one way—by the development of more working rooms. Since resources were usually abundant, this sort of expansion was quite feasible.

As the mines grew, and operations became less concentrated, the problem of supervision became increasingly difficult. So long as mining remained a craft industry the miners who worked a room were completely responsible for mining the coal it contained. They performed all the functions, from making the undercut and drilling blast holes to cleaning and loading the coal. As a result there was little need for supervisory control (especially since the miners were piece workers) or for coordination, and the system no doubt worked tolerably well.

Then came the mechanical cutter. In the mines in which it was adopted, undercutting of the coal seam ceased to be part of the hand miner's craft. As the device caught on and its use became more general (see Table 15), a new group of mine workers came into being—the machine runners. Because each room could not be provided with cutting machines it was necessary to have a group of men whose job it was to go from room to room and cut the coal for the miners. Since the miners were now obliged to wait for the machine runner before they could break down the coal, there arose an obvious need for coordination of activities. The lack of supervision associated with the room-and-pillar system of mining should have become a source of concern. Perhaps it did, but apparently the condition was not remedied. Machine cutting was somehow worked into the prevailing mine routine, and it was probably less effective than it would have been if there had been more intensive efforts to coordinate the new development with the customary layout of the work.[18]

Machine cutting did not force any important modification in the room-and-pillar system of mining. Loading was still a hand operation, and as long as mechanization was confined to cutting it could readily be absorbed into existing mining practice. The center of activity was still the room in which the miner worked;

[18] See Hugh Archbald, *The Four Hour Day in Coal* (H. W. Wilson Co., 1922), p. 48; also U. S. Coal Commission, *Report*, Part III (1925), especially pp. 1944-51.

TABLE 15

BITUMINOUS COAL: MECHANICAL CUTTING AND LOADING IN UNDERGROUND MINES[a]

Year	Mechanically Cut		Mechanically Loaded[c]	
	Quantity (Mil. s.t.)	Percent of Total Underground Output[b]	Quantity (Mil. s.t.)	Percent of Total Underground Output
1899	44.0	22.7	..	..
1900	52.8	24.9	..	..
1901	57.8	25.6	..	..
1902	69.6	26.8	..	..
1903	78.0	27.6	..	..
1904	78.6	28.2	..	..
1905	103.4	32.8	..	..
1906	118.8	34.7	..	..
1907	138.5	35.1	..	..
1908	123.2	37.0	..	..
1909	142.5	37.5	..	..
1910	174.0	41.7	..	..
1911	178.2	43.9	..	..
1912	210.5	46.8	..	..
1913	242.4	50.7	..	..
1914	218.4	51.8	..	..
1915	243.2	55.3	..	..
1916	283.7	56.9	..	..
1917	306.4	56.1	..	..
1918	323.9	56.7	..	..
1919	276.0	60.0	..	..
1920	339.8	60.7	..	..
1921	272.7	66.4	..	..
1922	267.0	64.8	..	..
1923	377.4	68.3	..	..
1924	336.3	71.5	..	..
1925	366.7	72.9	..	..
1926	410.9	73.8	..	..
1927	374.0	74.9	..	..
1928	369.7	76.9	21.6	4.5
1929	403.6	78.4	37.9	7.4
1930	362.4	81.0	47.0	10.5
1931	302.3	83.2	47.6	13.1
1932	244.0	84.1	35.8	12.3
1933	267.0	84.7	37.8	12.0
1934	284.7	84.1	41.4	12.2
1935	293.7	84.2	47.2	13.5
1936	348.3	84.8	67.0	16.3
1937	d	d	83.5	20.2
1938	278.3	87.5	85.1	26.7
1939	314.0	87.9	110.7	31.0

For footnotes see opposite page.

and miners continued to perform the several mining operations as they had in the past—largely unaffected by any fixed routine of underground operation. In brief, even after cutting machines were used widely, the industry as a whole could be characterized as unaffected by "modern methods of quantity production, modern labor saving machinery, modern methods of management." [19] With the exception of the machine runners, and to a much smaller extent, of power drilling crews, there was no division of labor of the sort found in other types of mining. Division of labor implied coordination of functions, and the coal industry had not yet solved the problem of over-all supervision.[20] Indeed, the failure of mine operators to work out a system that could cope with problems of supervision and coordination acted to a large extent as a positive deterrent to greater mechanization of the coal mines.

This, then, was the situation in the early 1920's—about half way through the period covered by our indexes—as established by the many studies of the industry made at that time.[21] These studies were, however, carried through when the industry was presumably on the threshold of a technological rebirth, and when observers were looking forward to seeing bituminous coal engulfed in the "onward sweep of the machine process." What bulked large on the technological horizon was the loading machine, which was destined to revolutionize the tasks of the mine worker. Since the early 1920's machine loading has grown considerably (see Table 15), and today about 30 percent of the underground output is

[19] Walton H. Hamilton and Helen R. Wright, *The Case of Bituminous Coal* (Macmillan, 1925), p. 61.

[20] See Carter Goodrich, *The Miner's Freedom* and Hugh Archbald, *op. cit., passim.*

[21] In addition to the works by Goodrich, Archbald, and Hamilton and Wright already cited, mention should be made of a study of "Underground Management in Bituminous Coal Mines" prepared by Sanford E. Thompson for the U. S. Coal Commission, and included in Part III (1925), pp. 1893–1969, of the Commission's *Report.* The industry also was the subject of discussion at the annual meeting of the American Economic Association in 1920 (see *American Economic Review*, March 1921, Supplement).

Footnotes to Table 15.

[a] All data are from *Minerals Yearbook* and its predecessor, *Mineral Resources.*

[b] For 1913 and earlier years the figures in this column are percentages of total output. Since strip mining of bituminous coal was zero or almost zero in these years, no error is involved in this procedure.

[c] Mechanized loading began to be adopted widely in 1923. The Bureau of Mines collected figures for the first time in that year, but before 1928 it excluded certain types of loaders which it included in later years. Figures for 1923–27 are not, therefore, strictly comparable with those for later years, and have not been reproduced.

[d] Not available.

loaded by machine. This development has recently been covered in a report of the National Research Project, which analyzes performance records of mines employing hand and machine loaders and indicates the many factors that influence the adoption and efficiency of the various loading devices.[22] For a discussion of these factors the reader is referred to Chapter 6 above. Here we shall merely deal very broadly with the development of technology in the bituminous coal industry since the early 1920's.

There can be little doubt that mechanized loading, in the mines that have passed beyond experimental use of this technique, has changed mining methods very radically. To the extent that loading machines have replaced hand loading, bituminous coal mining must have become an industry in which many of the old craft traditions have had to be discarded. Each working face does not have its own loading machine; rather loading-machine crews have taken their place with drill crews and cutting-machine crews as workers performing a specialized function in the larger process of mining. Ideally, a single working face is attacked in sequence by cutters, drillers and blasters, and loaders, each group working in close coordination with the others. The coal face is subjected to a kind of assembly-line technique, in which a series of specialized tools is brought to the material to be treated, instead of vice versa. The old routine (or lack of routine) has given way, apparently, to a systematic planning of production with a closely supervised execution of the production process.

The traditional room-and-pillar system of mining—with the isolated mine worker in his room somewhere off in a corner of the mine—exists no more in the mechanized mine. It may still be a room-and-pillar mine in the strictly engineering sense, but even so the design of individual mines undoubtedly has had to be modified to accommodate the cycle of mechanized operations. It is probable, too, that supervision has been made simpler by the fact that production in the mechanized mine can be concentrated in a smaller area without any loss in volume of output.[23]

Basically, however, the mechanization of the mining of soft coal has been superimposed upon a traditional, one might almost say an ancient, method of mining and mine layout. The completely mechanized coal mine is still an exception, despite the general

[22] Hotchkiss and others, *op. cit.*
[23] U. S. Coal Commission, *Report*, Part III, pp. 1914-15.

spread of mechanization in recent years. Hand loading accounted for about 70 percent of underground production in 1939, and it seems evident that even today many mines are correctly characterized by our description of nonmechanized room-and-pillar mining.[24] No such radical innovations as the block caving and gravity loading methods of underground copper mining, for instance, have been found applicable in the winning of coal. The simultaneous removal of valuable mineral and of quantities of waste material, all to be separated at a later stage of the mining process, distinguishes contemporary metal mining from the mining of coal.

It remains for us to consider whether depletion has stimulated technological advance. We have seen that the direct effects of depletion, i.e., reduction of productivity through increased difficulty of extraction, have probably not been important in coal mining. Indirectly, however, the exhaustion of easily worked sources may have influenced productivity either by inducing or by retarding technological change. Depletion of minerals reacts upon the technological state of the producing industry in two principal ways: (1) the individual establishment may find that a decline in the grade of its own resources makes it unable to compete with other establishments in the field unless it can manage somehow to reduce its costs of production; and (2) depletion throughout the entire industry may increase interest in new techniques and in deposits formerly regarded as unprofitable fields for exploitation. The latter situation is probably not serious in bituminous coal mining: from what we have already learned concerning this country's soft coal resources[25] we may conclude that major changes in technology have not so far been required to offset the pressure of demand upon dwindling sources of raw material. As for the first situation—in which the individual mine is forced to revise its techniques of exploitation and recovery because of a decline in the grade of its own resources—such conditions must have developed at times, though not too frequently, for high grade material has

[24] It has been observed that old mines have lower manday output than new ones. This is due partly to the longer underground hauls necessary in old mines, and partly to their less frequent mechanization (either because mechanical methods are impossible without a change in mine layout, or because the approach of exhaustion discourages expenditure for mechanization): see Hotchkiss and others, *Bituminous-Coal Mining*, pp. 79-80.

[25] See pp. 167-69 above.

also been a characteristic of most individual mines. It appears, then, that depletion, which has clearly been a stimulus to technological advance in certain other extractive industries—notably copper mining—cannot have affected the techniques employed in the winning of bituminous coal in any significant degree.

Evidently technological advance can scarcely have been stimulated by the necessity of counteracting the effects of depletion. Some other features of the industry's history may actually have retarded progress in this direction. For example, coal miners are, and always have been, predominantly piece workers. They are paid by the ton.[26] Thus the cost of inefficiency is in large measure transferred from the business enterprise to the individual miner, for the operator has little incentive to seek an increase in output when much of the increment in his revenue is mortgaged in advance. Any innovation that is not sufficiently important to justify a reduction in piece rates therefore has small chance of adoption. It is true, of course, that a change as far-reaching as the introduction of cutting machines did lead to a reduction in piece rates: miner and operator shared the benefits of greater efficiency. The question was naturally whether the benefit received by the latter was great enough to justify mechanization. In Illinois, in particular, it was claimed that the "machine differential," i.e., the reduction in piece rates on the advent of machinery, was so small as to retard mechanization, but this does not seem to have been its effect. On the other hand, the object of the United Mine Workers in limiting the differential was apparently to prevent machine-cut coal from underselling pick-mined coal, and so to avoid the elimination of pick mines where the use of machinery is impracticable.[27] To this extent methods of wage payment may have preserved inefficient forms of production.[28]

Furthermore, the bituminous coal industry has been plagued by intermittency of operation during the entire period covered

[26] The impression, derived from recent wage controversies, that miners are paid by the day is quite erroneous, so far as concerns workers who actually extract the coal. Of course when the daily rates of those who work for time wages are changed, a corresponding adjustment to piece rates is made.

[27] Isador Lubin, *Miners' Wages and the Cost of Coal* (McGraw-Hill, 1924), Chs. VI and XIII.

[28] In reviewing the manuscript of this report, Mr. F. E. Berquist suggested that (at least until recently) the responsiveness of the wage structure to the pressure of low prices eliminated a tendency toward mechanization which might have arisen with a more rigid wage level. He added that in many mines loading could be mechanized only with specially designed equipment.

here. Out of a possible 308 working days,[29] the number of days actually worked per mine in the years since 1899 has ranged from 142 to 249, with an average working year of 200 days for the entire period.[30] Where production is so irregular the willingness of the operator to take on additional fixed costs is reduced considerably.[31] And technological advance means that the operator must assume a burden of fixed costs not only because of carrying charges, etc., on machine installations, but also because the relatively high priced technical and supervisory personnel required for mechanized mines are usually paid whether the mines work or not. An operator who can keep his mine in operation only 200 days a year should not be judged too harshly if he prefers the easy adjustments possible with the nonmechanized mine to the relative rigidity of the modern mine. His choice would be a difficult one even if workers were paid regular wages. The prevalence of piece rates makes it doubly hazardous.

The emphasis of the foregoing discussion has been placed deliberately upon changes in productivity. We have tried to suggest some of the factors that help to explain the comparative backwardness of the soft coal industry in improving its productive efficiency. For there is no doubt that, according to the criterion we have chosen to set up, many other branches of extraction have made much more rapid progress during the past forty years than has bituminous coal. Yet we might well apply other standards that would provide a much more flattering picture. In tonnage terms, output per manday in the bituminous industry is nearly twice as high as in anthracite.[32] Again, in the United States the soft coal industry is apparently far more efficient than it is abroad. In a comparison undertaken during the 1920's, it was found that manday output was about four times as great as in Britain.[33] Moreover,

[29] U. S. Coal Commission, *Report,* Part III, p. 1111.

[30] The average-days-active figure is found together with the data on employment in *Minerals Yearbook* and its predecessor *Mineral Resources of the United States.* It is not possible here to enter into a discussion of the reasons for the short work year prevailing in the bituminous coal mine. We should note, however, that irregular production is something the individual enterprise can do little to correct.

[31] See Harry Jerome, *Mechanization in Industry* (National Bureau of Economic Research, 1934), pp. 336-37.

[32] The figures are 4.8 and 2.9 tons respectively per manday for 1937–39; see Appendix Tables A-1 and A-3.

[33] About 4.1 and 1.0 long tons for an eight hour shift, respectively; see Harold M. Watkins, *Coal and Men* (Allen and Unwin, London, 1934), pp. 109-25, for a most interesting comparison of physical conditions of mining in the two countries. Mr. Watkins explains the difference in terms of the greater age of British workings

it would appear that productivity is actually declining in British coal mines.[34] Standards of comparison are entirely relative. If we have spoken of the backwardness of soft coal mining in this country, we have done so only because of the much more rapid progress made in other mining industries, which frequently are subject to quite different physical conditions.

(average depth 1,020 feet compared with 260 feet in U. S.), longer haulage underground, less frequent mechanization, due partly to greater roof pressures, tilted beds, and more numerous faults. However, in this country the accident rate is apparently higher than in Britain.

[34] From about 450 tons per manyear in the 1880's to 350 immediately before the first World War, and perhaps less than 300 in recent years (F. G. Tryon and F. E. Berquist, "Mineral Economics," in *Mineral Economics,* ed. by F. G. Tryon and E. C. Eckel, McGraw-Hill, 1932, p. 28). Since days worked per year have probably declined, the fall in manday output may be less severe.