Productivity in Longwall Mining of Hard Coal

by

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Table of Contents

Page

Appendices

List of Figures

Page

Synopsis

The thesis investigates productivity and its measurement in longwall hard coal mining, considering firstly the general state of the art. Productivity is defined, and the varying disciplinary approaches to it are critically compared. The state of productivity in practice is reviewed, leading to the concepts of total productivity. The facets of technological change and international comparison are scrutinized.

A more specialised discussion is then introduced on the state of the art in underground coal mining. Weaknesses of the partial measure of labour productivity, as well as critical observations for improvements, are revealed. The subject is put into a technological and economic perspective, with special emphasis on mechanisation and safety. The inadequacies of international comparison to date are examined in order to construct a firm base for this study.

A total productivity model is then built on rigid definitions. It is based on physical and economic data related to longwall coal mining in Britain and elsewhere in Europe. The problems pertaining to the statistical information are fully discussed and validated via the physical equations. Utilising the model and its supporting equations, the longwall hard coal mining industries of the United Kingdom, West Germany, France, Belgium, Poland, Czechoslovakia and the Ukraine, are analysed for the period 1960 to 1976. Also, twenty-two mines, in these

countries, are similarly monitored for the period 1972 to 1976.

The conclusions reveal that total productivity, measured in base-year prices and exchange rates, is the best yardstick for ascertaining underlying trends in the international comparisons. This total productivity measure shows little correlation with labour productivity over time. In all countries, the industries achieve meagre return for their investment in longwall face technology.

The model itself is demonstrated, both nationally and for the individual mine, as an integrated tool for analysing historical trends. It can be an efficient instrument for planning and forecasting at all levels of longwall coal mining.

Acknowledgements

This work would never have been accomplished but for the kindness and consideration of mining engineers, mine managers and academics of various disciplines, who have given me such useful information and fine hospitality across Europe. Also, to the host of mining men, at pits, meetings and conferences, in Britain and overseas, whose modesty prevents me from naming in person, I should like, nevertheless, to record my sincere gratitude.

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In carrying out research, especially in the initial stages, one appreciates how important is a competent library system. I would thus like to thank the library staff of the Middlesex Polytechnic, the National Coal Board at Hobart House, and the British Institute of Management.

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Introduction

After a twenty years stint in industry, with much vague talk on productivity, the writer's thoughts on the subject were galvanized after being asked to teach this subject. After perusal of much literature, it became apparent that there were many approaches but little clarity on the question of productivity.

In the past, the engineer seemed to think of productivity mainly as labour productivity and the glorification of work study. The economist spoke of marginal productivity in grandiose terms, whilst the accountant never indulged in a clear definition. There were gaps in the field of thought, and an area of useful research seemed apparent.

To study productivity in isolation, as a theoretical problem, appeared to be rather a blind alley. As a former student of fuel technology, as well as an industrial manager concerned with its utilisation, the writer decided to research into underground coal mining. This was certainly aided by the fact that the University of Loughborough is physically situated near a major coalfield, as well as being directly concerned with this industry.

The natural warmth and comradeship of the men involved in mining further encouraged a deeper interest and commitment. This was considerably helped by the kind and understanding attitude of professional mining engineers.

In the last six years, the involvement embraced not only research but the plans, thoughts, aspirations and disappointments of the mining industry. At meetings, conferences, over pints of beer and cups of coffee, the writer has lived "coal", not only in the United Kingdom, but across the coal-producing areas of Europe, East and West. As a committed European, a detailed survey of the performance of the European coal industry in recent years was considered, as it would make a useful contribution to knowledge, especially that, in the West, the coal mining industry had appeared to lack, until recently, clear objectives and seemed to be at the whim of politicians.

When the writer first became interested in underground coal mining, it was in the early 1970s, a time of much industrial unrest in the United Kingdom's coal industry and of much cynicism of its future. The 1973 Middle East crisis changed the economics of, and the thinking towards, coal. Whereas a few years ago there was little general interest in coal, today articles and books on the subject abound. Suddenly, it is realised, when other sources of energy will decline, in the words of Aneurin Bevan, Britain will still be an "island made of coal".

SECTION 1

Productivity and its Measurement
- The General State of the Art

"Productivity is a word more misunderstood, more abused, more misapplied than any other except capital and sex"

Graham HUTTON

1.1. What is Productivity?

Productivity is something that has been spoken about in woolly terms for decades by politicians, economists and the media, usually to try and justify a point of view. Indeed, Hutton[1] was correct; very little has been more talked about in management discussions and national economic debates and less understood. Fenske[2] analysed fifteen different definitions of productivity and categorised them into five areas relating to :-

(a) efficiency;
(b) the utilisation of resources;
(c) an input/output ratio;
(d) a measure of performance; and
(e) the quality of being productive.

The Oxford Illustrated dictionary defines productivity as "efficiency in industrial production". However, even a basic definition, such as this, can be challenged. Firstly, productivity is not strictly a measurement of efficiency. The British Institute of Management[3] showed that efficiency is not just related to productiveness but also linked with effectiveness, which can be defined as the degree of success in achieving objectives. This implies a measurement of actual performance against a standard. Also, it is not, as is widely spoken of in the media, a measure of production in isolation. Indeed, productivity need not necessarily be related to the production of a physical output. It is true that, historically, the attention has been focused on manufacturing industries; however, as illustrated by Smith[4], Sevin[5] and Jefferys et al[6], it can be applied to service industries. Indeed, Holzer[7] and Ross & Burkhead[8] have attempted to apply the concepts of productivity to local and public organisations. The productivity of the Police Force is hardly allied to "production". Thus, just on a basic definition, we can see what productivity is not.

Thorelli[9] talked of the pluralism of productivity, but the truth seems to lie in the fact that productivity can only be related to the objectives to which it is being considered or measured.

To gain an idea of the objectives of productivity, one must briefly look at its origins. Its roots lie in engineering, economics and accounting, all of which have been embraced in management or management science. As Belcher[10] showed, any concept of productivity can be applied at various levels of activity : the man, the plant, the firm, the industry, the nation. The engineer's interest was mainly at the lower level of the man and the plant. This is illustrated in the jungle of work and method study. Bahiri & Martin[11] considered that, to engineers, productivity implies productive efficiency at these lower levels. Economists have historically, since the time of Adam Smith in the late XVIIIth Century, been interested in the higher level in a macro sense trying to relate the effect of productivity on economic growth. In recent years, the accountants, in their slow but sure progression, have taken an interest in productivity by trying to apply accounting data to the concept. However, as illustrated by Harding[12], Hodgson[13] and Sansbury[14], their approach has been rather hindered by their professional straight-jackets.

It has been stressed what productivity is not, but let the focus now be on what productivity could or should mean. The welfare of individual companies, industries or nations is often regarded as dependent on their comparative productivity. A brief mention has been made to the contribution, if any, made by engineers, economists and accountants which will be fully elaborated upon. The writer takes the practical view that productivity must be meaningful and relative to the practising manager. Thus, an integrated approach is required, hopefully gaining the best from the experiences of the past.

1.2. Productivity from a Management Viewpoint

Teague & Eilon[15] quite correctly stated that, from a management viewpoint, productivity can be observed and measured for four reasons :-

(a) for strategic purposes, to compare with other firms or organisations;

(b) for tactical purposes, to control and monitor performance;

(c) for planning purposes, relating to resource utilisation; and

(d) for interface purposes, such as collective bargaining, price controls, etc.

From a managerial point of view, looking at the above objectives, productivity can now possibly be defined. Much of the talk on productivity only really relates to partial productivity, that is

$$\frac{\text{total output}}{\text{partial input}}$$

the most popular being with the partial input of labour.

Engineers have been fond of using completely physical measures such as tons per man-hour. Also, ratios have been used similarly based on added value. This ratio does not even meet the strict definition of a partial productivity ratio just given. It is calculated by beginning with a sales volume to total input ratio, and removing the value of raw materials and purchased parts from the numerator and denominator. The value added index, therefore, equals partial output over partial input.

The rate of return on capital employed has also frequently and mistakenly been offered as a measure of the partial productivity of capital. However, it is merely a relationship of profit/capital, and thus is not even a partial measure.

Many observers, over the years, have criticised the use of partial productivity measures as only telling a part of the story. Is it fair to compare the output per man-hour of a plant highly mechanised with one with little capital investment? Many attempts have been made to try and have some form of all embracing measurement. Norman & Bahiri[16] attempted to produce a model involving the best from the engineers', economists' and accountants' approaches. It is unfortunately highly complex and has never got much further than a theory.

Economists have attempted to produce a more comprehensive measure by what is termed total factor productivity. This combines the two major inputs of capital and labour into a joint index of inputs, and relates its movements to an index of outputs. As shown by Scheppach & Woehlcke[17], this is some improvement on partial measures as a monitor in productive efficiency in that the residual (the measure of productivity) reflects the net savings of both inputs. As a measure of productive efficiency, this is certainly one step nearer, an overview. However, the economists neatly avoid all other inputs except capital and labour; indeed, Karl Marx would have even excluded capital.

From a practical, and even from a resource, viewpoint, to ignore all other inputs, except capital and labour, is an undoubted weakness. This has been hopefully corrected by what is termed total productivity, that is :-

$$\text{total productivity} = \frac{\text{total output}}{\text{total input}}$$

Accepting that some measure of total productivity is the objective, the definition of productivity can be revisited.

Ksansik[18] stated that :-

> "Productivity is the overall measure of economic effectiveness on the basis of real output per unit of resource(s) utilised"

This basically means :-

Real OUTPUT per unit of one or more INPUTS

OUTPUT ↑ Production of Goods or Services

INPUTS ↑ Labour, Capital, and Materials

Faraday[19] had a similar definition of productivity :-

> "A prescribed output is created solely by the input of the productive factors of manpower, materials and capital equipment"

$$\text{Total productivity} = \frac{\text{Prescribed Output}}{\text{Input of manpower, materials and capital equipment}}$$

Obviously, the inputs could be further broken down, as illustrated by Craig & Clark Harris[20], who showed that total productivity (P) can be stated by the formula :-

$$P = \frac{O}{L + C + R + Q}$$

where L = labour input factor
C = capital input factor
R = raw material and purchased parts input factor
Q = other miscellaneous goods and services input factor
O = total output

Total productivity can therefore be seen as the ratio of output to the total inputs of resources which, in financial terms, is the equivalent to the ratio of costs plus profit (or surplus) to costs. We are thus getting closer to the managerial pulse and Gilpin's[21] definition :-

> "Productivity is the efficiency with which productive resources are used; the motive for increasing productivity is to produce more goods at a lower cost per unit while maintaining quality"

What are the advantages of the total productivity method of approaching productivity? It is certainly flexible inasmuch as it can accommodate either physical or financial measures of output, though inputs can only seriously be combined and expressed in financial data with all their attendent problems, as discussed later. Nevertheless, unlike added-value, and rate of return concepts, the method can be used where a financial measure of output is not available, such as in the service industries, or where profitability is not the aim of the activity or enterprise.

The battlefield has now been chosen, that of managerial purposes relating to total productivity. However, it would both be foolish and discourteous to ignore the work carried out in partial and total factor productivity.

1.3. Labour Productivity

Since the end of the last war, more attention, both nationally and internationally, has been given to the partial measure of labour productivity than any other. This is not surprising when viewed in its context of collective bargaining. Also, the measurement of labour productivity was one of the earliest to be indulged because of its more physical nature, often relating a physical output to an input of man-hours.

Several comprehensive works were produced discussing the problem of measuring labour productivity, especially by the Organisation for European Economic Co-Operation[22], Dunlop & Diatchenko[23] and the International Labour Office[24]. The Anglo-American Council on Productivity was set up to study the experience of the United States in raising labour productivity and attempting to apply this to the United

Kingdom. Jenkins[25] described how the then Chancellor of the Exchequer, Sir Stafford Cripps, asked these post-war productivity teams to be missionaries. They produced much good background information, including a Symposium[26], and culminated in the work of Hutton[27]. There was even a National Productivity Year, 1962/63, with Royal Patronage, which produced much hot air and at least one good Conference[28], still with the emphasis mainly on labour productivity.

The art (or science) of labour productivity and its measurement owes much to engineering and the engineers' strive for efficiency. At the lower level of the man and the plant, much progress has been made in the area of method study and work measurement. There is even a highly professional Institute of Practitioners in Work Study, Organisation and Methods, who, in private conversation, admitted that they have reached the limits of this basic measure. There have been more progressive approaches by engineers to labour productivity, based on variants of ratios of output to labour input or relating them in more detail to one industry, such as those described by Swann & Waddington[29] and Sanders[30].

Also, in the area of labour productivity, there has been a substantial contribution from the behavioural scientists. This is possibly best summed up by McBeath[31] when he talked of "achieving productivity through people". Katzell & Yankelovich[32] have discussed how improved job satisfaction can enhance labour productivity. This was echoed by Latona[33], who emphasized the various management and leadership styles that are conducive to higher labour productivity. Similarly, Ross & Murdick[34] described how organisational structures might achieve such improvements. Most of these approaches paint an interesting background to thoughts on labour productivity, but, unfortunately, because of the difficulties in obtaining clear evidence in behavioural sciences, they can be no more.

A significant deviation from the normal approach to labour productivity measurement with a behavioural slant was presented by Rice[35] in his description of the Ahmedabad Experiment, where productivity was measured by its relationship to the percentage of output rejected.

Obviously, behavioural science can make a considerable practical contribution in the design of incentive payment schemes related to collective bargaining, as illustrated in Marriott[36], Shimmin[37] and Belcher[10].

In recent years, the interest in labour productivity measurement, other than for collective bargaining purposes, has wained, possibly because "it ain't worked". However, it raises its head occasionally in management journals, often bemoaning the lazy British. On a deeper, more academic level, Fleming[38] distilled some underlying facts on inter-firm differences in labour productivity, in attempting to show their relationships to various physical and financial inputs.

The exponents of total productivity owe much to the labour productivity merchants, as will be illustrated in the discussion on input measurements. However, it is becoming clear that, in a modern society that is more capitally intensive, labour productivity measurement is becoming more and more partial.

1.4. Added Value as a Measure of Productivity

Accountants, in true professional style, appear to have ducked the issue and gone off on a tangent of added value as if it was a new panacea in the art of productivity. Actually, the concept has re-emerged after many years of neglect. It was first recognised as long ago as 1790 by Tenche Cox, an American Treasury Official, who noticed that adding value was the basis of wealth creation and economic activity. In later years, the idea was further enhanced by Rucker[39] and Bentley[40]. Although there is no precise definition of added value, it is generally accepted that, in essence, added value is simply :-

{ Income (Output) (from sales or services rendered) } - { Expenditure (Input) (on materials and services) } = Added Value

It is, therefore, the difference between the VALUE of goods produced or services rendered and the COST of the materials and other purchased services.

There have been many articles on added value (or value added), increasing in number, since the recommendations of the Corporate Report[41] that companies should produce an added value statement with their published accounts. The best critique from the accounting point of view was that of Morley[42]. However, the exchange of correspondence in "Management Today", following Woolf & Allen[43] on the point whether to include or exclude depreciation, just shows the early stages of thinking in the modern approach to the subject. The added value concept has almost become a cult with numerous seminars on the topic with the best discussions coming via Smith[44], Gilchrist[45], Ball[46] and Wood[47]. Added value has also wetted management's appetite since the days of Rucker[39] as a basis of self-financing productivity schemes, illustrated by Swannack & Samuel[48], Grange Moore[49], Marklew[50] and Smallwood[51].

Unfortunately, added value does not live up to its fanfare of monitoring wealth creation, or, at least, as it is currently being presented. This is because it is purely a financial accountants' tool and incorporates all the strengths and all the weaknesses of the current financial accounting scene. Leading thinkers on the subject, such as Morley[42], discussed the way this might be resolved. One is at present bound to side with Broster[52] and, even the champions of the subject, the British Institute of Management[53], whilst admitting that added value can give a more meaningful measurement of output than sales, agree it is not a measure of productivity. A further criticism is that it is basically related to sales, even though these are adjusted for stock movements and often bare little, or no relationship, to production.

1.5. Productivity Costing, and all that

A further contribution of the accountant is that of financial ratios, where a structure of interlinking ratios are built up, often in a form of a pyramid. In this way, the various elements, both physical and economic, can be interpreted. However, these reflect mainly the financial aspect of productivity relationships. Probably the best example, relating this form of ratio to productivity, came from Risk[54] whose starting point was the return on investment which was then subdivided into various components.

The accountant has only really taken a passing interest in productivity. However, Davis[55] attempted to escape from main stream thinking and produced a practical guide to the measurement of industrial productivity which he defined as "the change in product obtained for the resources expended". This was certainly a bench mark, even though never seriously applied.

Another approach supposedly integrating the engineering and cost accounting disciplines was that of productivity costing, which emphasizes the contributions to the productivity of a firm of individual products, rather than of operating units or functional activities. Thus, the productivity of a product is measured by its efficiency in making a profit. Bahiri & Martin[11] and Norman & Bahiri[16], being the main disciples of this technique, advocated measuring only work which is truly productive in relation to the objectives of the organisation concerned. Tolkowsky[56] said that productivity costing highlighted the costing of manufactured goods, the significance of the degree of utilisation of capacity and the impact of idle time on the costs of production. However, productivity costing, as its name implies, relates entirely on costs and revenue and ignores the underlying flows of physical resources and the input of the prices of factors (Figure 1).

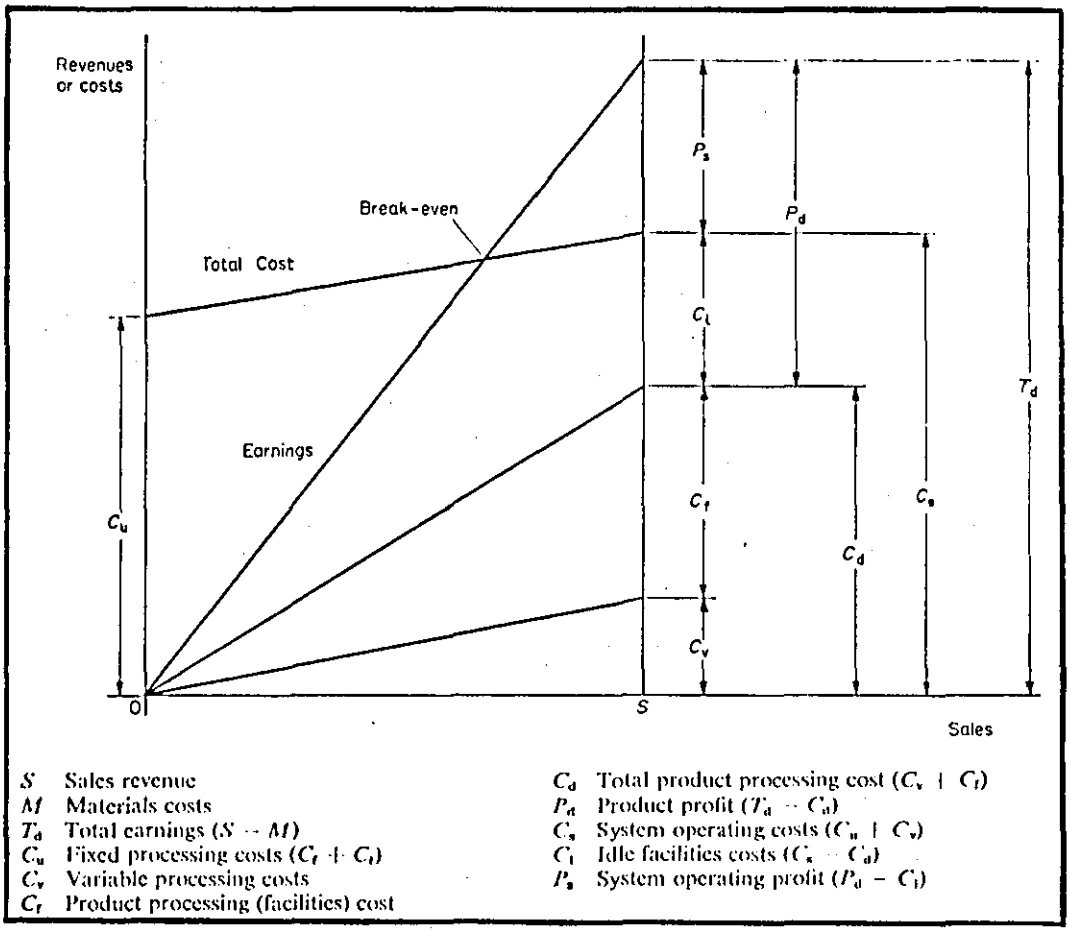


Fig. 1. Productivity costing, breakdown of components (Source: Bahiri & Martin[11])

Smith[57] attempted to develop what he rather grandly called measuring productivity by the systems method, hoping it could be related to collective bargaining. This is an index based on what he defined as the average marginal cost, related to the output changes. Unfortunately, his method was rather obtuse, and one seriously cannot see its practical application at the bargaining table.

1.6. The Economist's Role

Practical discussions on productivity, such as by the British Institute of Management[3], completely ignored the contribution and approach of the economist. The economist's general insistence on only using the two major input factors of capital and labour, plus his general interest in economic growth at a macro level, have alienated him from the management's sphere. Also, much of the economist's work revolves round production functions, showing the relationship between input of production services and output of product, per unit of time. Production functions are descriptive of techniques or systems of organisation of production services. Thus, the problem of production basically consists of selecting the most appropriate production function, and then determining the input which would minimise costs. However, any practitioner would increase his depth of knowledge by observing the works of Fabricant[58], Banock[59], Lomax[60], Maverick[61] and Jorgenson & Griliches[62]; possibly the best résumés on the total factor approach came from Nadiri[63] and Domar[64].

One major contribution to practical thinking on productivity, which has evolved via the economist, is Verdoorn's Law[65]. This basically states that those industries which have the largest increases in production usually show the largest increases in output per worker, and vice versa. Pryke[66] pointed out that Britain has been no exception to the Law because, over the period 1958 to 1966, the rank correlation co-efficient, calculated on Spearman's formula, between the increase in output and the increase in output per worker, in twenty-three manufacturing industries, was +0.79. However, like other correlations, it did not reveal the cause or causes. On the one hand, increases in total production stimulate productivity both by enabling increased economies of scale and, as a result of an increase in the proportion of new plants, enable more use to be made of the most modern equipment and technology. On the other hand, increases in productivity must lead to an expansion of output through the effect of reduced costs upon demand. The causal factors here are obviously inter-related. Cairncross[67] reported that Caves[68] rejected the Law as having no significant body of evidence to support it. Either way, Verdoorn is a starting point for any discussion on the economies of scale vis-à-vis labour productivity.

Reddaway & Smith[69], using total factor productivity, also found there was a close relationship between the change in total factor productivity and the growth of output per man-hour. The manufacturing industries with large increases in labour productivity normally had large increases in total factor productivity, and vice versa. Matthews[70] used a slightly different procedure and produced the same result.

1.7. Productivity Networks

To any student of productivity and its measurement, looking for an integrated and possibly a more practical approach, the most exciting and meaningful event has been the emergence of free-thinking managerial economists, such as Gold[71,72], and his combined approach with management scientists, such as Eilon & Soesan[73].

Gold's basic approach was to build up an interlinking productivity network that is all embracing, including a cost structure, as well as managerial control ratios (Figure 2).

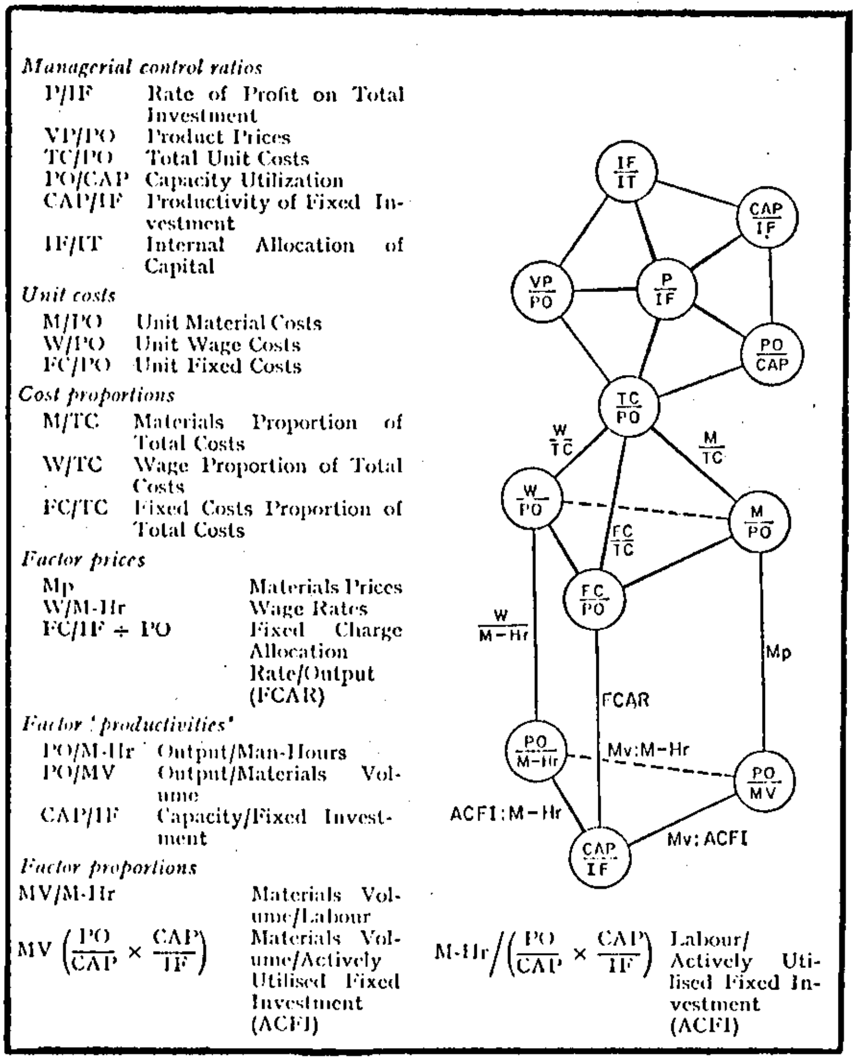


Fig. 2. Relationships among physical productivity ratios, unit costs and other profit determinants (Source: Gold[71])

This was an improvement upon the Craig & Clark Harris[20] approach, illustrating more clearly interdependencies, both physical and financial.

The major problem with Gold's productivity network was that, although it was fully integrated, it was by definition rather large and possibly cumbersome. Eilon & Teague[74] have pruned and distilled the Gold approach by showing the various flows within a manufacturing organisation. As with Gold, they separated physical and financial flows and showed their relationship to factor prices and factor productivities (Figure 3).

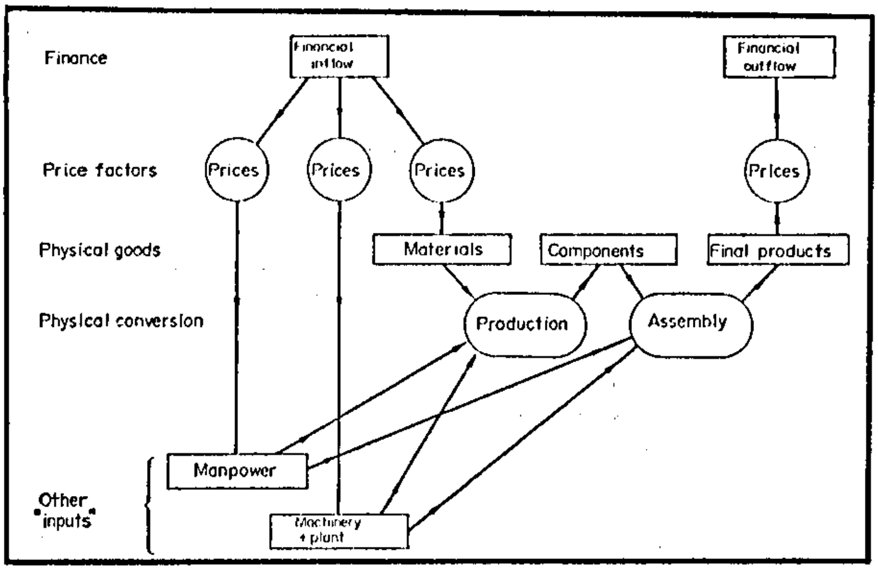


Fig. 3. Financial and material flows (Source: Eilon & Teague[74])

A financial input is converted through price mechanisms into a series of physical inputs : manpower, materials, machinery and plant, even components and final products where appropriate. Through the conversion process of production and assembly, the final products emerge as physical outputs, which are then converted by a price mechanism into a financial outflow. Each operation, or series of operations, in this flow can be monitored as to how well it is being applied, any any measure devised to analyse the performance in question may be described as a productivity measure. For instance, the number of units of a given component produced per hour on a given machine, the number of units of a given product produced per man, the revenue produced per unit cost of raw materials - all these are examples of ratios that describe different aspects of performance.

One great advantage of the productivity network à la Gold is that it stresses the important fact that no single measure that relates output to one single input is sufficient on its own. Indeed, improvements in some ratios of this kind (such as output per man-hour) may be the result of changes in other ratios (such as increase in fixed investments as a percentage of total investment) and detrimental to the total productivity of the organisation.

Another version of Figure 3 is shown in Figure 4.

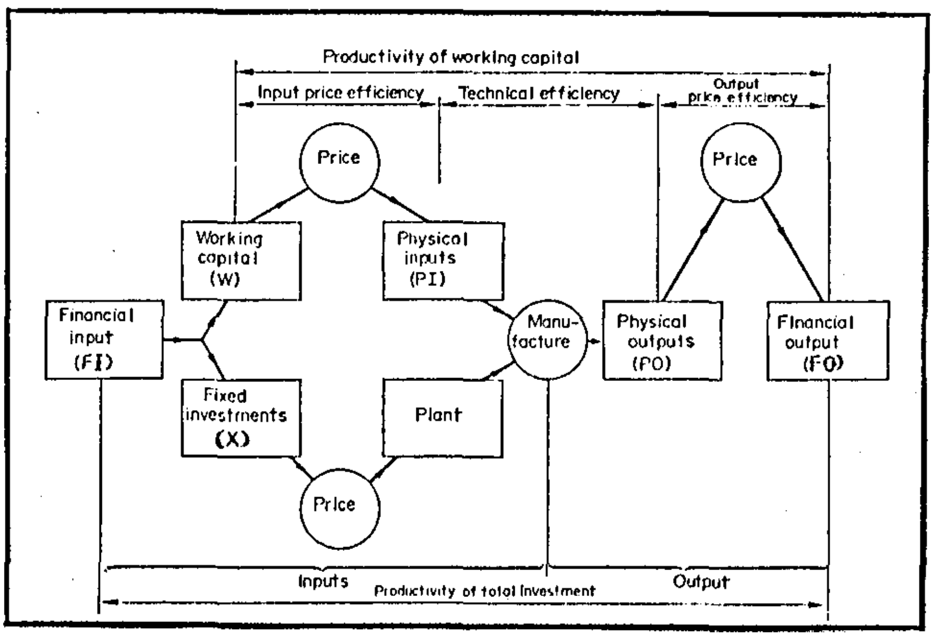


Fig. 4. Inputs and outputs, and their inter-relationships (Source: Eilon & Teague[74])

Thus, the following relationships apply :-

Total investment (T) = working capital (W) + fixed investment (X)

Working capital (W) = physical inputs (PI) x unit price inputs
= physical outputs (PO) x unit cost

Financial outputs (FO) = revenue (U)
= physical outputs (PO) x unit price outputs

Profit (P) = revenue (U) - financial inputs (FI) utilised in producing physical outputs (PO)

Eilon & Teague[74] took the idea a stage further, by regarding the overall productivity of the system as the return (r) on the total investment. This ratio, which was a variation of the formula proposed by Gold, may be expanded to incorporate other ratios, and was christened the r-model.

$$\frac{\text{profit}}{\text{total investment}} = \left\{ \frac{\text{product value}}{\text{output}} - \frac{\text{total costs}}{\text{output}} \right\} \left\{ \frac{\text{output}}{\text{capacity}} \right\} \left\{ \frac{\text{capacity}}{\text{total investment}} \right\}$$

or

$$\boxed{\begin{aligned} r &= (b - c)\,ek \\ &= aek \end{aligned}}$$

where r = return on total investment
= profit/total investment
b = unit price for the output
c = unit cost for the output
a = (b - c) = unit profit for the output
e = output/capacity
= capacity utilisation of the plant
k = capacity/total investment

Thus, the total return on the total capital invested may be regarded as the product of three factors :-

> The unit profit (a) - which can be increased by raising the unit price and/or by reducing one or several cost components.
>
> The plant utilisation (e) - which may be regarded as the conversion efficiency of the production facilities, and which may be increased by raising output for a given level of capacity.
>
> The capital/total investment (k) - which reflects the total capacity provided by capital expenditure and may be regarded as a measure of the productivity of capital.

Eilon[75,76,77] elaborated upon this, improving its analysis but not really adding further to the concept. The basic ratios in this type of model are closely inter-related, as shown by Gold[71]. The r-model has the advantage in that it takes the guts from the Gold approach and figures it in a more simplified form.

The Gold-Eilon models must be recognised as a major practical landmark in productivity thinking. However, one must query the fact that r was chosen, a rather nebulous return on total investment as the ultimate aim. In the present controversy on what is investment or capital, their target is rather ill-defined and possibly naive, ignoring factors such as working capital investment in liquid funds, including debtors and cash.

Over the years, as the earlier references indicate, there has been much talk on total productivity, much to wet the appetite from practical people such as Norman & Bahiri[16] and Butcher & Mountford[78], but never really have these ideas got off the drawing board. The best approaches in recent times have come from Craig & Clark Harris[20] and the Gold-Eilon power house.

1.8. Problems in Measuring Input and Output in Productivity Measures

Returning to basic definitions of any form of productivity reveals that it is fundamentally an output/input relationship in varying complexity.

Whether output is measured in physical or financial terms is determined primarily by the product or service involved. A physical measure of output is often more appropriate with the homogeneous or near-homogeneous product, such as in the steel industry where one can refer to tons of crude steel. The problem arises when there is more than one product. If there is close relationship between products, they may be converted into an equivalent physical standard, as described in Faraday[19] and Smith & Beeching[79]. The problem gets more complex with a multi-product operation where the output is diverse, as well as with service industries. Here one might have to resort to financial measures of output. If sales turnover is used as a measure of output, then it is imperative for the net increase or decrease in the stocks of finished and semi-finished goods to be accounted for in order to reflect production. A good discussion on the problems of measuring the output on non-homogeneous products was given by Dancy[80].

A major problem arises in attempting to assess the output of certain public and other services. A physical indicator of output might prove difficult to identify, and criteria based on the efficiency in the utilisation of resources might be more appropriate, as described by Holzer[7] and Ross & Burkhead[8]. Crude indicators of physical output can be established even in non-marketed services; for instance, a hospital might be measured in the number of patients treated over the year; however, some allowance must be made for the quality of service.

A further vital point strangely neglected by Gold, when making comparisons of productivity over any period of time, which are based on any financial detail, is the effect of inflation. Various price and wage indices can be used but are sometimes coarse; this was well discussed in Kendrick & Creamer[81], Greenberg[82] and Craig & Clark Harris[20].

The accountant's thinking on inflation has been dramatically altered in recent years since the publication of the Sandilands[83] and Morpeth[84] Reports. The discussions on inflation and how to incorporate it meaningfully into accounting-type data have been numerous, possible the best being the readings edited by Dean and Wells[85].

On the input side of productivity measurement, each factor has its own intimate problem of measurement. For instance, labour input could be expressed in a number of ways : How does one allow for part-time workers? Should one measure it in man-years or man-hours? Should it be in hours worked or hours planned? One could spend infinite detail on each input, but this discussion will be expanded upon further in a later section, especially the problem of measuring, or at least estimating, what was considered by Craig & Clark Harris[20] and Fabricant[86] to be the red-hot potato - the input of capital.

1.9. Productivity Measurement in Practice

With all the discussions and references already mentioned, one would expect a great wealth and variety of productivity measurement in practice. Unfortunately, this does not appear to be so. Partial productivity measurements, especially labour productivity using physical inputs and outputs such as tons per man-hour, have been widely used in industry mainly as a tool for collective bargaining. Also, there has been some use of the added value approach by utilising such measures as ratios of added value to labour input. However, in the sphere of total factor or total productivity, or anything approaching their style, there has been little evidence of use in industry or commerce. In fact, an unpublished survey by the Institute of Works Study Practitioners Organisation & Methods found little or no application of productivity measures in the United Kingdom other than partial measures.

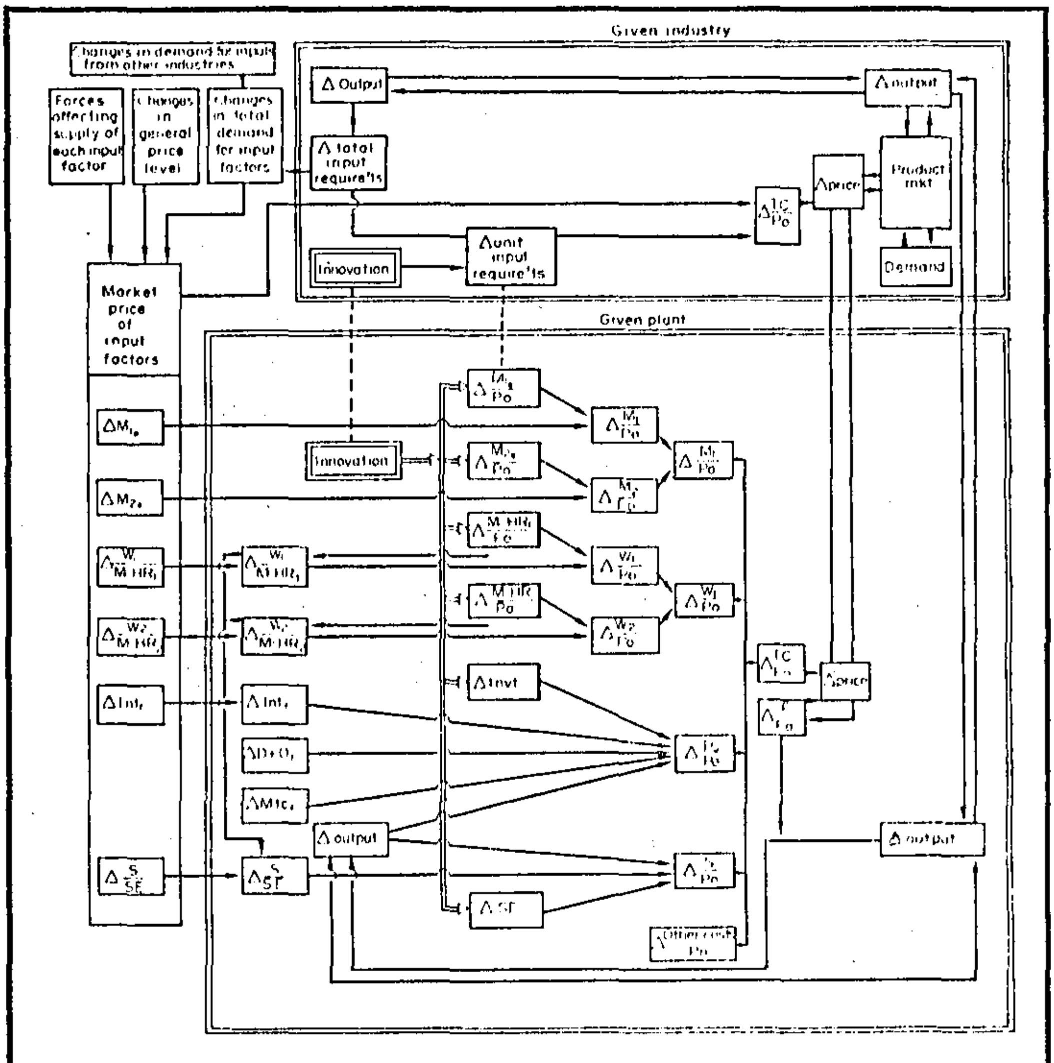
The Gold-Eilon approach has certainly been used in the chemical and steel industries, as reported in Eilon, Gold & Soesan[73] as well as in an unpublished report of Teague[87]. Also, the total productivity of the iron and steel industry was well analysed and documented by Waring & Dennison[88], Grieve Smith & Miles[89] and Wykeman[90]. One hopes that it is not a reflection on the fact that the steel industry's interest in total productivity is related to its present financial state.

There have been several reports based on total factor productivity, using the sole inputs of labour and capital; however, none of these were generally accepted or showed much depth in analysis. The latest survey was undertaken by the National Economic Development Office[91] on the nationalised industries. Unfortunately, traditional economists, like faith healers, seem at present to be discredited, at least in the eyes of management.

1.10. Technological Change

We live in an age of relative technological advance. Technology is changing more rapidly than in practically any other time in history. The engineer and technologist know this, the economist thinks he knows this and the accountant, even after Sandilands[83], does not really want to know this. The truth of the matter is : if defining productivity or inflation is a problem, then certainly technology is one. Rosenberg[92,93] gave a good background to the problem, as did Mansfield[94,95]. Here again, as with productivity, there have been several approaches via the technologist and via the economist.

Gold[72] produced a comprehensive discussion along the lines of Mansfield[94,95] on the diffusion of innovation, and incorporated the effect of innovation in his basic model (Figure 5). Unfortunately, he never seemed to have taken the idea further.



	Inputs			Other
	Quantity	Price	Unit costs	
Materials	M_{1q}, M_{2q}	M_{1p}, M_{2p}	M_1/Po, M_2/Po,	Po; physical output
Labor	$M-HR_1$, $M-HR_2$	$\frac{W_1}{M-HR_1}$, $\frac{W_1}{M-HR_2}$	W_1/Po W_2/Po	TC: total costs
Salaried	SE	S/SE	S/Po	P: profit
Capital	Inv_t	Int_r; Depr + Obs_r; $Maint_r$	FC/Po	Subscripts: t = total; r = rate; 1, 2 = different kinds of inputs

Fig. 5. Model for estimating effects of technological innovations (Source: Gold[72])

The most detailed discussion on the economist's approach came from Brown[96], with useful contributions from Griliches[97], Salter[98], Abernathy & Townsend[99] and Solow[100]. Their stance was to try and explain the role of technological change via production functions, such as the Cobb-Douglas function. Much of the discussion was unfortunately rather complex and obscure. One can only agree with Domar[101] who, after a full discussion on the subject, concluded that any reader who had managed to get that far had his sympathy, and that his justification for his long journey on the swampy land of technological change was to help the understanding of the process of economic growth.

Even after reading the wide-ranging discussion by Heidecker[102], one comes to the conclusion of Mansfield[95] that, in the eyes of the economist, technological change results in a change in the production function or in the availability of new products. There is no satisfactory way of measuring technological change directly, only by its effects.

In this respect, there has been an interest in technological forecasting, that is by observing and analysing the patterns of technological innovation and their diffusion, and by trying to anticipate various futures. These techniques and ideas were well illustrated by Jantsch[103], Bright[104], Wills et al[105,106] and Ayres[107]. Although some of the work in the area will undoubtedly prove valuable, several of the techniques are rather crude. Technological forecasting is a young and relatively undeveloped art, as admitted by Gordon & Helmer[108], but could be established as a useful tool if properly combined with mainstream economics.

Before moving on to more practical approaches, one should mention the work of economists in two other areas of concern : Firstly, the importance of the age of machinery, as well as its capability; Bacon & Eltis[109] have built a model for comparative purposes, looking at the age and performance of machinery in the United Kingdom and the United States. Secondly, the use of price indices and quality change, as discussed by Griliches et al[110], who introduced various techniques for observing the effect of quality and the increase in utility.

The engineer's approach, occasionally used by economists like Levine[111], Hutton[27], Foss[112] and Melman[113,114], is to look at basic physical measurements, such as kilowatt-hours or horsepower, relating them to manpower and other inputs in order to reflect technical change.

One may wonder why there is this emphasis on technology, when it has been so conveniently forgotten by many commentators previously. The reason is that any meaningful discussion on economic activity or productivity must take into account the factor of technology. This was even partially recognised by the accountants in the Sandilands Report[83], which was subsequently criticised by Lemke[115]. He stated that the effect of technological change was the Achilles Heel of that Report.

The weakness of ignoring technology was best summed up by Pryke[66] who, in his discussion on the depreciation practices of public enterprises, quoted Maurice[116] as saying that, in these industries, capital consumption estimates failed to allow for technical change. He also pointed out that if an industry's rate of technical advance is sufficiently rapid, then the cost of replacing a given amount of capacity with the largest equipment could, despite inflation, be lower than the original cost of the plant, let alone the cost of replacing it with modern equipment of old design.

Unfortunately, in practice, there appears to be little or no allowance for technological change by analysts in all areas of productivity and its measurement.

1.11. International Comparisons in Productivity

For decades, a favourite hobby of economists, politicians and the media has been to make international comparisons in the field of productivity. These were often ill-defined attempting to make or underline some set point of view, usually to try and illustrate how lazy and inefficient the British are. Hence, one must concentrate only on serious attempts to make comparisons based upon relevant empirical data.

International comparisons in productivity as a background to any discussion on economic growth has been an area of interest to economists. Taking economies as a whole, or major sectors within those economies, such as the manufacturing industries, comparisons have been made on output, either in physical or financial terms to the population, i.e. per capita, or to the actual working population based upon a per capita analysis, taking into account the number of persons actually engaged in producing that output. The latter can be described generally as a labour productivity comparison.

These basic approaches form a useful background, and a good overview in the field of growth, and were fully described by Kravis[117]. However, they were often far too general and far too aggregated to be but of passing interest to the practising manager.

To make any comparison is difficult, but to make an international one is obviously even harder. There are the problems of definitions, interpretations, and social and economic differences, before one starts.

Beginning at the simplest level of basic labour productivity, there are many problems mainly of definition on such mondaine points as : what constitutes a working day or a working shift? are we talking about a ton or a tonne? a long ton or a short ton? Probably the best guidance on such matters came from the Conference of European Statisticians[118]. When introducing such terms as wages and remunerations, there is a host of pitfalls, including what is meant by overtime, holiday pay, social benefits, etc. The International Labour Office[119] have at least made an attempt to rationalise the matter.

It would be near impossible in any international comparison to try and include, or account for, all social and economic differences. However, they should at least be borne in mind. Many errors have been made in comparing two dissimilar countries or industries. Economists specially have had an obsession with comparing the United Kingdom to the United States, though, as described by Jenkins[25], this was officially encouraged, just after the Second World War. Therefore, one should note the basic differences, such as the fact that social payments affecting wages vary throughout the European Economic Community. As Hayward & Narkiewicz[120] pointed out, economic and planning systems are very different in Eastern Europe. Bailey[121,122], Staubus[123] and Bernolak[124] reminded us that accounting methods differ throughout Europe, East and West. Even comparing with our French neighbours, Thomas[125] illustrated the obvious difficulties with such definitions as manpower cost or depreciation.

Sometimes, there is the problem of incomplete data, especially on such matters as prices; a good analysis of this was given by Summers[126]. As discussed earlier, in an analysis incorporating any form of financial data, there is the problem of inflation. Comparisons at the international level are further complicated by two factors : firstly, exchange rates, and secondly, the purchasing power parities of the currencies. The first point is clearly demonstrated by the fact that the Deutsch Mark in the 1960s was steady at just over 11 DM to the £, and had fallen to below 4 DM to the £ in 1978. Thus, any direct international comparisons in, say, German production costs would be highly distorted.

Indeed, there is a strong argument for not using current exchange rates in some international comparisons. Hibbert[127] stated that there is good ground for believing that the use of market rates of exchange can possibly be misleading, since these exchange rates are set by the supply and demand for foreign currencies, which in turn are derived from transacting between countries for only some of the goods and services sold on the domestic market. In recent years, attempts have been made to construct an alternative, more satisfactory, method of making international comparisons, especially in wages. This has led to the development of purchasing power parities based on a representative basket of goods and services in each country. The Ford Wage Claim[128], the Department of Employment Gazette[129], the Confederation of British Industry[130] and Fourastié[131] fully debated this. However, as shown by Gilbert & Kravis[132] and Kravis et al[133], this approach, although most interesting, is still at an early stage and rather frail except for specific commodities.

As Kravis & Lipsey[134] have rather laboriously analysed, there can be considerable international differences in the quality and price of similar goods. For example, is a 50-horsepower machine supposedly identical, really the same economically and technically, if manufactured in West Germany or Detroit?

Kravis[117] listed nineteen international comparisons of productivity in the manufacturing industries. There are others, of course, involving solely Eastern Europe, such as those summarised by Drechsler, Kux & Nyitrai[135]. However, looking at Figure 6, one can see the differences in such comparisons. The methodology has been based on par exchange rates, quantity or price of output. Also,

	Author (1)	Date (2)	Countries (3)	Weighted mean index* (4)	Number of industries (5)	Unweighted mean index* (6)	Coefficient of variation (7)	Method† (8)
					Largest number of comparisons for mutually exclusive manufacturing industries			
			Comparisons of U.S. and U.K.					
1	Flux	1909	U.S./U.K.	226	12	248	0·140	Ex. rate
2	Flux	1929	U.S./U.K.	293	12	316	0·162	Ex. rate
3	Rostas	1937	U.S./U.K.	225	12	229	0·181	Ex. rate
4	Rostas	1937	U.S./U.K.	216‡	33	231	0·493	Quantity
5	Frankel	1947	U.S./U.K.	269‡	36	247	0·478	Quantity
6	Paige-Bombach	1950	U.S./U.K.	273‡	70	280	0·360	Quantity
			Other countries compared with the U.K.					
7	Rostas	1936	Ger./U.K.	111	12	119	0·199	Ex. rate
8	Rostas	1936	Ger./U.K.	104‡	20	102	0·318	Quantity
9	Rostas	1937	Sweden/U.K.	103‡	7	103	0·327	Quantity
10	Heath	1948	Can./U.K.	163‡	14	170	0·184	Quantity
11	Netherlands§	1958	Neth./U.K.	116‡	15	119	0·167	Quantity
			Other countries compared with the U.S.					
12	Galenson	1937	U.S.S.R./U.S.	41‡	11	44	0·330	Quantity
13	West	1963	Can./U.S.	66‡	29	79	0·382	Price
14	Yukizawa	1963	U.S./Japan	286	60	350	0·862	Quantity
			Comparisons between other countries					
15	Maizels	1950	Can./Austral.	170‡	21	180	0·420	Price
16	Czech./France§	1962	Czech./France	81‡	33	90	0·230	Quantity
17	Austria/Hung.§	1965	Austria/Hung.	132‡	17	146	0·270	Price
18	Czech./Hung.§	1967	Czech./Hung.	154‡	26	139	0·236	Quantity
19	Yugo./Hung.§	1970	Yugo./Hung.	108‡	14	105	0·155	Quantity

Sources: See References, 136 to 150.

* Productivity of numerator country as percentage of that of denominator country. All the unweighted means and the weighted means on lines 10 and 16 have been computed for the present paper; the other weighted means are from the original sources.

† Where the method varied according to industry, the predominately used method is given.

‡ Geometric mean of Paasche and Laspeyres indexes.

§ Studies prepared by official statistical offices of indicated countries; except for Netherlands/U.K. and Yugoslavia/Hungary, the results have been circulated under the aegis of the Conference of European Statisticians.

‖ Sum of U.S. and Japanese employees used to weight the individual productivity indexes.

Fig. 6. Summary of international comparisons of productivity in manufacturing industries (Source: Kravis[117])

the number of industries has varied greatly within each sample. It was however a comprehensive chronicle of the art over the years in making such aggregate comparisons.

The area of international comparisons involving total factor productivity has been rather sparse, mainly due to the difficulties of comparing differing measurements of capital. As regards any meaningful contribution in the field of total productivity involving all inputs, the cupboard appears bare. A good review, however, of the topic was given by Nadiri[151]; possibly the most thorough and constructive survey based on total factor productivity in recent years was that of Panić[152] who compared the British and West German manufacturing industries between 1954 and 1972.

There have been several worthwhile contributions looking at international productivity comparisons from a specific viewpoint; Pratten[153] analysed the important topic of labour productivity differentials within international companies, an area for which Bossler[154] had initiated a skeleton for the foundry industry several years earlier. Capdevielle & Neef[155] studied labour productivity and unit costs in twelve industrial countries showing that U.S. manufacturing productivity rose sharply in 1971/72, whilst unit labour cost showed little change in contrast with rises in other countries. Keegan[156] analysed, or at least tried to, the factors behind the Japanese economic success by using rather controversial approaches, such as sales per employee. A similar analysis was made by Swann[157] looking at the manufacturing industries of six countries, attempting to pinpoint the British weakness. Although many of these surveys make a useful contribution, they are full of the errors in definition and methodology described earlier.

Unfortunately, to date, international comparisons in productivity have been either too broad or too shallow, and often had the smell of politics apart from their methodological faults.

1.12. The General State of the Art - Conclusions

The title of this section is possibly appropriate, for it is fair to comment that, at present, productivity measurement is probably more an art and less of the science predicted by Goodeve[158]. Productivity often means all things to all men; but for the practising manager, the approaches of Eilon, Gold & Soesan[73] and those of Craig & Clark Harris[20], despite various weaknesses discussed, appear to be those which can provide the answers, or at least some of them, in control and planning. As will be demonstrated later and shown by Gold[71], these can be adapted not just for a firm, but for an industry.

In the area of technology and its effects on the productivity and economic well-being of enterprises, one can really only say that at present there is an awareness, coupled with nervousness, of how to tackle this.

Although over the years there has been a wealth of international comparisons in the field of productivity, these have mainly dealt with whole economies or large sectors, such as the manufacturing industry. Little attention has been focused on meaningful surveys for the men in management, especially at the level of a single industry, such as the coal mining industry.

SECTION 2

Productivity and its Measurement
- The State of the Art
in Underground Coal Mining

"In coal mine productivity, O.M.S. should not read 'output per manshift' but 'output per money spent'"

Keith WHITWORTH

2.1. O.M.S. for ever?

When one speaks to people in the coal mining industry throughout the world and mentions the word "productivity", they will almost certainly regard it solely as labour productivity. This is echoed by Nelson's[159] definition :-

> "Productivity is a term allied to, and may be expressed as, the O.M.S. of a face or a colliery, O.M.S. being the output per manshift".

In terms of productivity, there has almost been a fixation on the partial labour productivity of O.M.S. Evans[160] stated that coal mining is perhaps the most statisticized industry in Britain. It is certainly true that there has been a variety of labour productivity measure almost saying the same thing: output per manshift at the face, output per manshift underground, output per manshift overall. Some analysis has been carried out in output per man-year, and it is even thought that progress has been made by expressing O.M.S. in tonnes instead of tons.

One sympathises with Fenske[2] who considered O.M.S. underground expressed as the ratio

$$\frac{\text{tons of coal}}{\text{manshifts underground}}$$

This has a clear meaning, and is obviously connected with productivity. It is a ratio which can be computed for a single mine, as well as for the whole mining industry. It is a class of ratios, which should be followed with interest by the management of a mine and by those responsible for planning mining policy, for instance on a national scale. However, the question is whether one can say anything more about this ratio, which may depend on factors such as geological conditions, equipment used, skill of the workers and their efforts. If all elements, except one, are constant, the indicator will, of course, measure the changes due to the residual factor. It can therefore, depending on the circumstances, be taken as a measure of :-

(i) the geological difficulty in a particular mine;
(ii) the efficiency of the equipment used;
(iii) the effect of training programme for the workers.

As such it may be useful, but "it all depends".

No single ratio can be considered in complete isolation. As Sangha[161] pointed out, the O.M.S. in the United States is far greater than in any other country in the world; this does not necessarily imply that U.S. miners work harder or faster than their counterparts elsewhere. Indeed, American miners possibly sweat less. The fact is that the mines are more capital-intensive and less labour-intensive. To compare the O.M.S. in the United States with, say, Pakistan, where coal is substantially dug with the use of shovels and carried on heads in baskets, is extremely weak. The state of industrial art helps determine the level of productivity, and one can say that technological innovations lead to greater improvements in output per worker. Even Sangha[161] failed to underline that there can be vast differences in geological conditions, as well as in mining methods. Indeed, many commentators have made the error of comparing O.M.S. in European countries with that of the United States, without stating the fact that a substantial proportion of that country's coal output comes from surface mining where conditions are far easier.

Even a basic ratio, such as O.M.S., has to be looked at carefully. How does one define output? Is it in pithead tonnages, saleable tonnages or calorific values? What is a shift? For instance, if a man works for a fraction of shift, does it count in analysis as a whole shift? How long is a shift? Or even how long is a working year?

Risser[162] was certainly correct that, in coal mine productivity, there are many things that averages, especially an isolated average such as O.M.S., don't tell. However, they can be a warning light for investigation.

An undoubted weakness of a ratio such as O.M.S., taken in a complete vacuum, is the fact that is has a numerator and a denominator. Which of these is influencing the increase in O.M.S.? Output or manshifts worked? The National Board for Prices & Incomes[163] hit the nail on the head in demonstrating that the National Coal Board's increase in O.M.S. in collieries without major re-organisation, i.e. "stable collieries", was related more to the decrease in manshifts than to any increase in output. This is shown by the close relationship of the trend in manshifts and the O.M.S. inverted index (Figure 7).

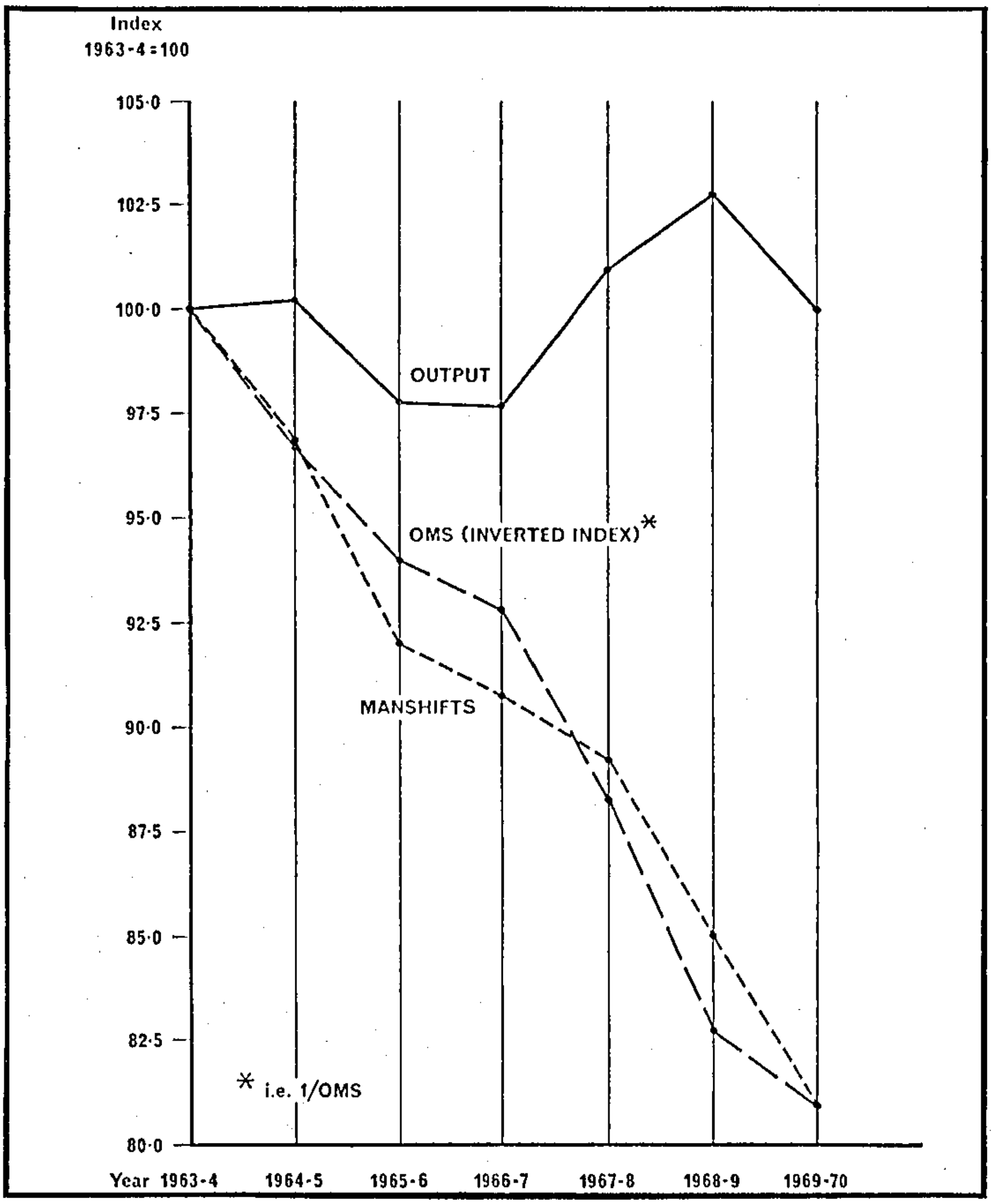


Fig. 7. Output, manshifts and O.M.S. in collieries operating from 1963/64 to 1969/70 without major reorganisation
(Source: National Board for Prices & Incomes[163])

In the coal mining industry, there has possibly been more discussed and more written on productivity than any other, though almost exclusively on labour productivity.

The Institution of Mining Engineers have recently held a wide-ranging Symposium on Productivity through Technology[164] and, in the United States, there have been conferences on mine productivity under the auspices of the Pennsylvania State, Missouri-Rolla and Arizona Universities[165,166,167]. However, the overall approach has been on technical competence, reflected through labour productivity rather than being an overview on the economic aspects of productivity.

2.2. The Yardsticks of Productivity

Wearly[168] has posed the relevant question :-

> "Is the yardstick of productivity high tons per man-day or is it low cost-per-ton?"

He considered that it is both, with labour productivity being achieved through application of new mining concepts whilst lower cost-per-ton can be attained by minimising downtime and using horsepower instead of manpower, whenever possible.

Underground coal mining is a highly complex industry, full of risks, economic, technical and human. The International Labour Organisation[169,170] listed the factors affecting labour productivity as geological conditions, technical factors, organisation and human aspects. They stated :-

> "In general, it is true to say that output per manshift is the product - and not the sum - of an engineering coefficient (mining methods, equipment and plant in general) multiplied by coefficients of organisation and labour (especially the miners' work). Consequently, an improvement in any one of these three groups of factors has a proportionate effect on final output per manshift".

This was most enlightening, but not apparently supported by empirical evidence, such as the work of Malhotra[171], who analysed the factors responsible for variation in productivity of Illinois coal mines. He concluded that, in underground coal mining, there was a positive correlation between labour productivity and seam thickness, the nature of the floor and roof, the efficiency with which available equipment and time were used, the total output of the mine. On the other hand, there was negative correlation between labour productivity and the age of the mine, and the degree of preparation coal receives before despatch. These factors might sound obvious but at least they were backed by detailed analysis, as was the work of Muysken & Tillessen, reported by Nehrdich[172], into the optimum face lengths. Clarke[173] also illustrated that there is a relationship between productivity and the amount of thin and disturbed coal being worked.

Thus, it can be seen there are many factors in productivity in underground coal mining almost unique to the industry. One has to talk in very guarded terms on such matters as : What is a reserve? Or, what is the capacity of a mine? Eilon, Gold & Soesan[73] have chosen the relatively easier pitch of process industries for their studies such as the chemical industry, where a plant is built for a specific capacity. Not so in mining, where there are far more variables, often altering daily. This was illustrated by the following extract from the Annual Report of the National Coal Board, 1957, which stated that :-

"The distinction between new investment, and investment required to replace productive capacity (which is fairly easy to make in manufacturing industry) is almost impossible to make in an old extractive industry such as coal mining. Productive capacity in manufacturing industry is generally in the form of fixed machinery and equipment. But working coal faces are constantly changing, as coal is extracted. The average life of a coal face is about two years, and every week new working places have to be developed for some 3,000 men".

One should therefore avoid the pitfall of comparing any form of productivity in the underground coal mining industry with any other, without clearly stating the underlying differences. One can make the sad error of an eminent economist, Barratt-Brown[174], who attempted to compare the National Coal Board with the empire of Imperial Chemical Industries.

Siddall[175] neatly summed up the problem of current yardsticks in productivity by his comments :-

"The word 'productivity' is too commonly used in a narrow sense as synonymous with Output per Manshift. In this sense, 'productivity' means only the relationship between the committed manpower resource and the output, yet many other important resources are committed to achieve this output : they equally contribute to 'productivity'. More properly, productivity must be regarded as the relationship between output and the input in all its manifestations. The majority of these input components are under the control of the industry's management, either directly or indirectly, both short and long term".

He also supported the view that output is the key to productivity and low costs, by achieving economies of scale especially in an industry with high fixed costs. If one agrees with this theory which appears highly logical, then one should pause and look at the effect of capital expenditure and its relationship to output, illustrated by Parker[176] (Figure 8).

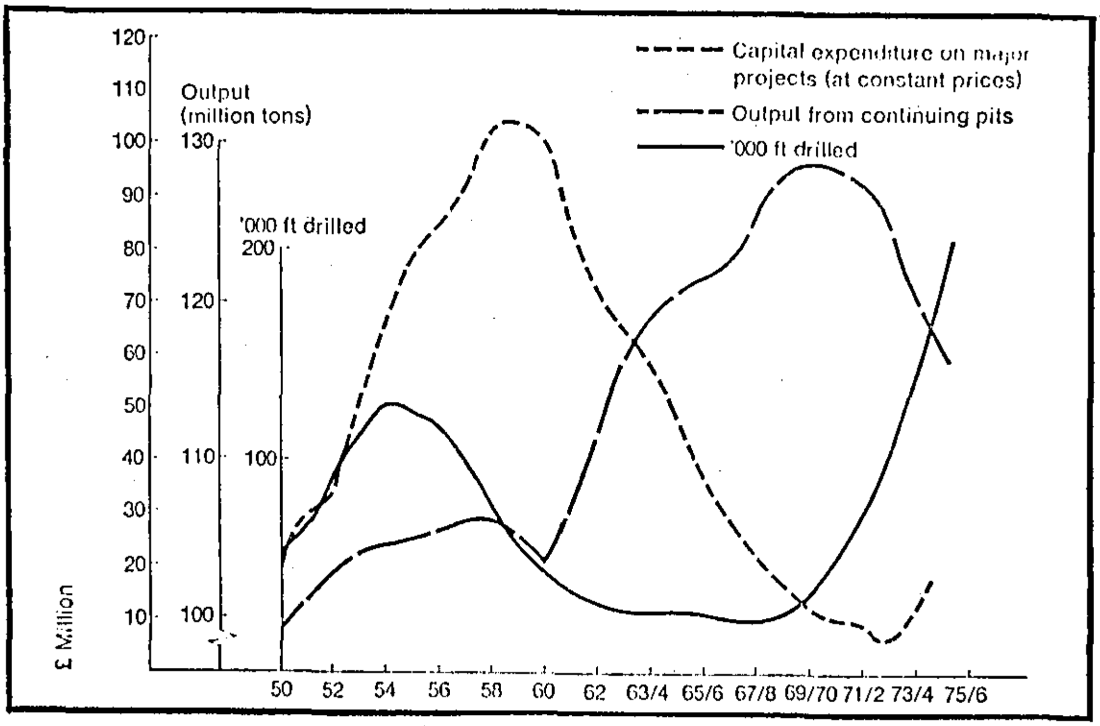


Fig. 8. Trends based on three-year moving averages, 1950 to 1975/76
(Source: Parker[176])

It can be clearly seen that patterns of capital expenditure on major projects are reflected some ten years later in the patterns of output, and that the necessity to maintain exploration activity is vital.

We can therefore perceive a close inter-relationship when discussing any form of productivity in the coal mining industry, between such factors as investment, exploration, geology, technical efficiency, human effort and operating costs. As stressed by Siddall[175], labour productivity, recorded in such terms as O.M.S., is unfortunately only a mirror, and possibly a shaky one at that, in monitoring such a complex industry and its productive performance.

At last, one is moving away from purely labour productivity measurement and the conclusions of James[177]. In his study on productivity in coal mining in Pennsylvania, he stated that to achieve a measure of overall productivity, including all inputs, was near impossible.

2.3. An Historical Perspective

Although labour productivity measurements have their undoubted weaknesses, they, with caution, relate historical trends within the industry. Coal mining has records going back as far into history as any other. Mitchell & Deane[178] showed shipment figures in chaldrons relating back to 1655, whilst official records commenced in 1854.

As coal mining was so clearly related to British history and economic life, especially in certain geographic areas such as the North East of England and South Wales, it has been well documented. Of relatively recent publications, anyone wishing to gain a knowledge of the historic background to coal mine productivity would find a wealth of information in Griffin[179,180], Kirby[181], Simpson[182] and Jackson[183]. The latter dealt mainly with the sociological side of what he called the "price" paid for coal. As regards academic research, the three outstanding contributions came from Bates[184], Kirby[185] and Chakraborty[186], each reflecting the state of the coal mining industry and, to some extent, its productivity performance in different historic periods during this century. Possibly the best record and analysis of long-term productivity movements in the British coal mining came from Sealy[187], covering the period 1873 to 1960.

To help put productivity in its historical context, Figures 9 and 10 have been produced. Benchmark years were used, avoiding the war and strike years, in order to illustrate any changes in dimension rather than show complete historical trends.

year	output per man-year (tons)	horsepower of electric motors per man
1700	c200	-
1873/82	296	-
1913	267	0.58
1924	228	1.25
1937	311	2.78
1950	293	4.41
1960	305	7.93
1966/67	390	11.68
1977/78	434	c22.00

Fig. 9. Labour productivity and horsepower per man, 1700 to 1977/78

The data in Figure 9 was derived from official statistics published by the Ministry of Fuel and Power[188] and the National Coal Board[189], with two exceptions. Nef[190] suggested that the British annual coal output was near three million tons between 1681/90, rising steadily to over ten million tons between 1781/90, though these are only approximations. Griffin[180] showed that, in 1700, the manpower in coal mines in Great Britain was approximately 15,000 to 18,000. If one combines the lower figures of these approximations, it would be fair to say that the productivity in output per man-year in 1700 was probably at least 200 tons. This figure is also supported by Griffin's[180] statement that productivity in the XVIIIth century was around a ton per man per shift. The 1977/78 figure for horsepower per man is related to the 1966/67 Schumacher[191] figure, allowing for the fact that manpower employed declined during the period, that average horsepower per motor increased, and that, although the horsepower intensity rose, the number of collieries and mechanised faces dropped. As Mitchell & Dean[178] stated, early data must be treated with caution, but a few guarded comments can be made from this figure. In the last century, output per man-year only increased by just over 50% despite concentration and mechanisation. The power behind a man's elbow, measured in electrical horsepower, rose by a factor of 1914% between 1913 and 1966/67, and by approximately 3700% from 1913 to 1977/78. Also, in the last 278 years, output per man-year has gone up by an approximate factor of only 117%.

Of course, these figures do not reflect two important elements. Firstly, there was the human suffering that occurred throughout the history of the early coal mining industry, and secondly, the geological conditions were relatively easier. This latter point is supported by Griffin's[180] statement that very few deep mines were in existence by the mid-XIXth century and were technologically backward. However, it is an enlightening reflection on technology and mechanisation to compare the moderate increase in output per man-year with the massive rise in horsepower, relative to manpower.

year	(A) output M.tons	capital employed £M	(B) capital employed £M(1913)	(A)/(B)
1854	64.7	c 30	c 27	c2.16
1913	287.4	c130	c130	c2.20
1924	267.1	c200	c116	c2.30
1937	240.4	c200	c131	c1.84
1950	202.3	335	118	1.71
1965/66	174.1	670	131	1.33
1977/78	104.6	946	55	1.90

Fig. 10. Output to real capital employed, 1854 to 1977/78

The basis for figures on capital employed were provided by Griffin[180], Feinstein[192] and the National Coal Board Annual Accounts, 1950, 1965/66 and 1977/78 (Figure 10). This financial data was then deflated by using the retail price index derived by Feinstein[193] to a base of a constant £ in 1913. Output figures were obtained from official sources[188,189] and Mitchell & Deane[178].

As can be seen, output to real capital employed (at constant 1913 prices) was fairly consistent in earlier years, and is apparently lower in recent times. Although one can say that in real terms our forefathers possibly dug more coal per capital employed than today, several factors must be borne in mind.

The capital employed figures during the National Coal Board era can be expressed as :-

average capital employed	=	total net assets + net current assets + deferred liabilities

The average is the mean of the values as at the end of the previous and current years, and relates to mining activities, including opencast and houses. It is not, therefore, entirely contributing to deep mine production, though the vast majority does.

Pryke[66] pointed out that the capital structure of the National Coal Board was, at least in its earlier years, a disadvantage to it, due to the problems in setting up the nationalised industry and compensating the colliery companies. The National Coal Board have the habit of writing off assets and deficits, as they did in their capital reconstruction in 1965 and 1973. This mainly explains minor discrepancies in the output to real capital employed figures since the Second World War. Also, as mining has matured, more capital was required because levels were deepened, faces were moved further away from the shaft, and technology revolutionised.

Therefore, comparisons must be cautious, but at least the output to real capital employed factor is a great tribute to early mine workers and mining engineers.

2.4. Mechanisation and Technological Advance

Over the last forty years, as demonstrated by Bourne[194], there has been a technological breakthrough in underground coal mining, replacing manpower with machine power with all its benefits, plus a few hidden pitfalls.

Schumacher[191] claimed that, in the early days of mechanisation after the Second World War, the rise in productivity was largely achieved by increasing the number of electrical machines. A later development was to make available more powerful machines, use them more efficiently, as well as utilise them for a higher proportion of the available working time.

Much attention has been given to productivity at the coal face; it should be remembered, however, that elsewhere underground and surface efficiency are also important to overall productivity.

As faces get further and further away from the shaft, the problem and the cost of transporting both men and materials is becoming a greater challenge. More and more effort and thought is being applied to this. A good discussion on the topic was given by Dunn[195], Harris[196] and Curl[197], the latter producing a full bibliography. Also, the Institution of Mining Engineers[198] and the Commission of the European Communities[199] have produced a colloquium and a symposium respectively on this subject.

Surface efficiency and productivity was well discussed by Humphreys[200], giving an overview on manpower and energy requirements, whilst Spanton[201] illustrated the patterns of change in coal preparation towards further automation.

As shown by Callis[202], the introduction of mechanisation and power supports have improved face O.M.S. (Figure 11) and there was a pattern to the introduction of new techniques (Figure 12).

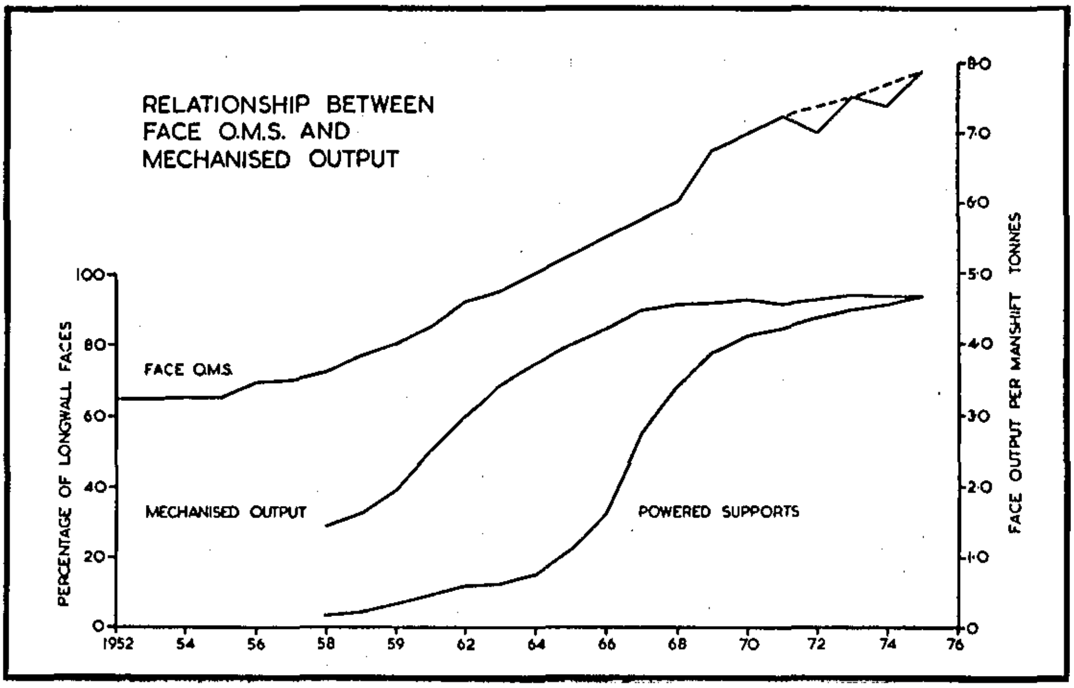


Fig. 11. Face O.M.S. and mechanisation, 1952 to 1975
(Source: Callis[202])

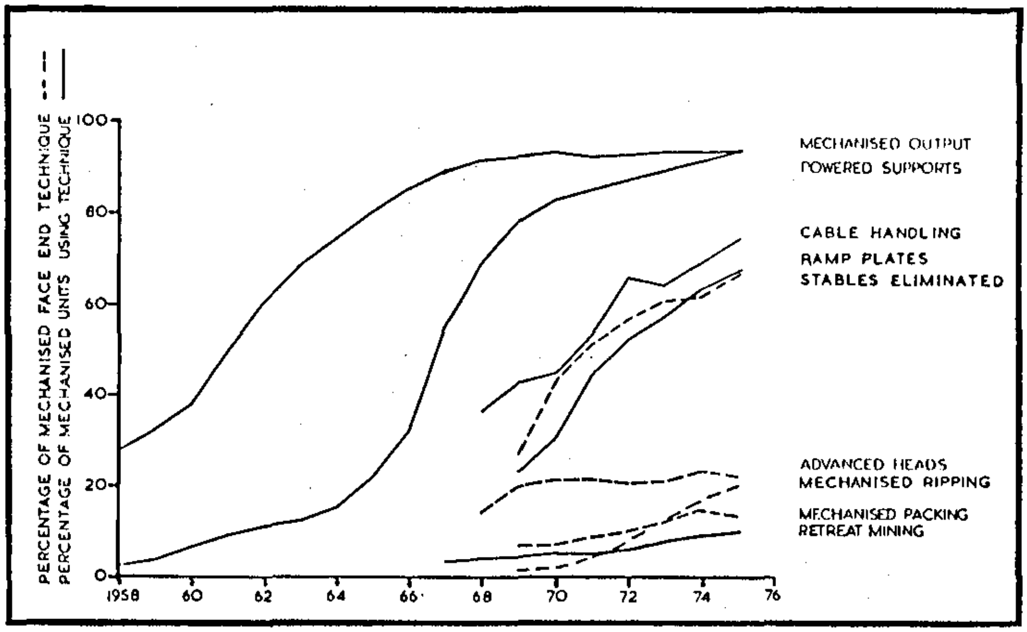


Fig. 12. Introduction of new techniques, 1958 to 1975
(Source: Callis[202])

Initially, the number of installations was often limited until the technique had been proven. Application then rose rapidly to a saturation point, as was demonstrated by power supports and mechanised output. He claimed that a basic face O.M.S. improvement could be achieved by increasing bulk output in conjunction with the concentration of workings and by increased face capacities via technology.

Technological change, mechanisation and its effect on productivity have been well documented. Gold[72], Mansfield[94,95], Rosenberg[92,93] and Taylor[203] have illustrated the diffusion of innovation in the coal mining industry, especially in the United States. On a more practical note, the patterns of technological advance and their relationship to productivity have been analysed by the U.S. Department of Labor[204], Christenson et al[205] and Harlow[206], the latter giving a comprehensive discussion on the advance of mechanised mining in the United Kingdom.

Since the early 1950s, mining engineering journals and conferences have often focused on mechanisation, mainly relating it to face productivity. Relevant contributions were made by Singh & Sen[207] and Anderson & Thorpe[208] on the United Kingdom, Sander[209] on West Germany, Stassen[210] on Belgium, and Young[211] on the United States. Discussion on face mechanisation at a more detailed academic level came in the researches of Paull[212] and Hunter Paterson[213]. The former related to the period 1890/1939 comparing the British and American scenes, and the latter the period 1953/63 covering the Scottish coalfield; both provided a concise background. Probably the best overview on the subject of mechanisation in the British coal mining industry, covering the period 1945/68, derived from Kelly[214].

Townsend[215] has researched into the history and performance of the Anderton Shearer Loader from the diffusion of innovation point of view in U.K. mining. This was one of the few serious attempts of empirically studying innovation in U.K. mining machinery and its effect on production.

The basic engineering economics of mine mechanisation have been well discussed by Mani[216] and Woodruff[217], who attempted to relate the all important factor of "what does all this mechanisation cost?".

Of course, technology is not purely technical, and has its social and economic consequences. The International Labour Organisation[218,219] have reviewed internationally mechanisation and technological improvements with their impact on social conditions, such as hours of work, whilst Hepworth et al[220] discussed their effect in the Yorkshire coalfield.

Certainly, as Bryan[221] pointed out, the dream of mechanisation has come true. However, as Siddall[222] clearly indicated : has the investment in new technology and mechanisation really paid off when one looks at the stagnant figures of the last few years in productivity and output? He posed the relevant question "solutions through technology - when?".

2.5. Safety

Few industries are as conscious of safety as underground coal mining. This is not surprising when one looks at the risks involved as well as the earlier histories of mine disasters and accidents. An authoritative review of the evolution of safety in mines was given by Bryan[223]. Safety is always uppermost in the minds of those involved with mining, and it would be foolish to make any discussion on production or productivity without giving the subject full consideration. It has always been a fear of the National Union of Mine Workers, and a forecast given in private conversation by an H.M. Inspector of Mines, that higher productivity, via say incentive schemes, could lead to higher accident rates. Fortunately, this has not happened to date since the introduction of the incentive schemes, as admitted latterly by H.M. Inspectors of Mines.

It must be great credit to the industry and the inspectorate that accidents and fatalities have sharply declined through the years. On the international scene, the International Labour Organisation[224,225] have produced two reports dealing in safety in coal mines and, since Britain's entry to the European Economic Community, the United Kingdom has contributed data and experience to the Mines Safety & Health Commission. The Institution of Mining Engineers have held a Symposium[226] relating to Health, Safety and Progress which gave a review of the present position and future aims in improving technology from the aspect of safety.

In the United States, there has been a considerable interest in safety, with new legislations to promote that aim; these are often blamed for the stagnant productivity in that country. From the American viewpoint, good discussions on the subject came from Gray[227], Falkie[228], Grant[229] and Barrett[230]; also, Christenson & Andrews[231,232] have reviewed the physical environment and its relationship to productivity and injuries in underground coal mines, as well as discussed injury rates in two eras of mine legislation and control.

The Report of the Mines Safety & Health Commission[233] showed that, in 1976, fatalities per million man-hours worked in the Community of the Six were 0.415, and 0.157 for the United Kingdom. Serious injuries per million man-hours in the Community of the Six were 14.92, and 8.39 in the United Kingdom. Thus, the rate for the United Kingdom was significantly lower than that of the Community as, at least, it has been as far back as 1958 when the combined Community figures first started. This is claimed to be due to the fact that the British place more emphasis on prevention and less on being a fire brigade. Still, one can learn considerably from our continental partners in West Germany, as illustrated by the papers of Hurck[234] and Nieden[235].

Collinson[236,237,238] asserted that the link between productivity and safety is undeniable, the two historic trends being independent of each other with no direct relationship. Tregelles[239] showed that improvement in safety in the United Kingdom has been continuous for the last 100 years (Figure 13); he claimed that technological progress that improves safety does not necessarily advance productivity, although improvement in productivity may well be accompanied by improvement in safety. This is partly due to technology and partly due also to the fact that the law and the management impose solutions by statute or edict.

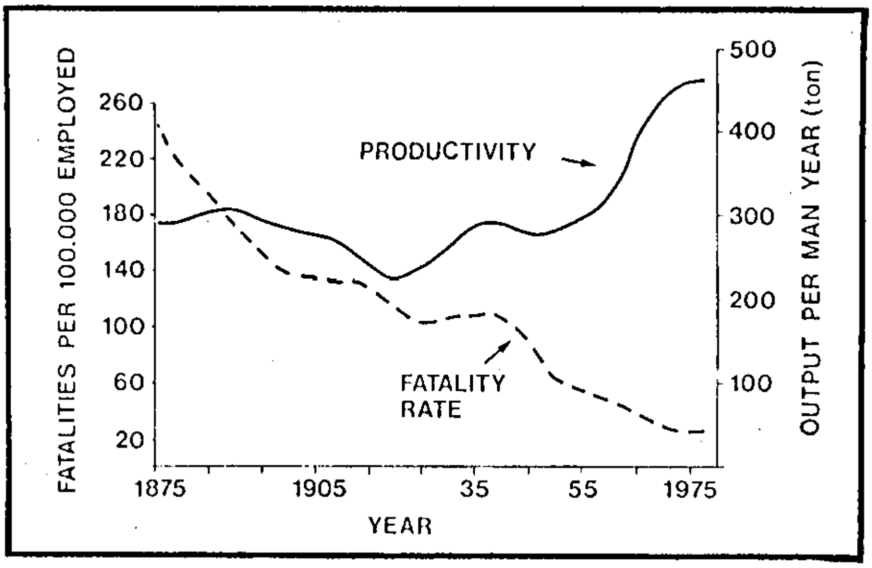


Fig. 13. Fatal accident rate and productivity, 1875 to 1975 (Source: Tregelles[239])

Tregelles[239] stated that progress in productivity has not been so continuous, as in the case of safety. He claimed that, for at least eighty years prior to 1960, there was no such progress, despite all the advances in the production fields; also, that technological advances only offset the greater constraints of law, of social attitudes to labour conditions, and of geology.

Collinson[237] took a slightly different view, stating that there have been six major elements in creating safer mines in the last century :-

(a) legislation;
(b) fundamental research;
(c) safety campaigning;
(d) organised safety resources and effort;
(e) training; and
(f) technology.

In his opinion, they have all made a contribution at different times, and over different periods of time, with considerable and continuing overlap. He asked : are they still relevant? Legislation probably had its major impact during the seventy years following 1890. Training had certainly contributed most during the period of nationalisation. Basic research succeeded in establishing remedies for the major disastrous hazards of mining. He felt that only technology, properly applied, could improve the situation further.

Tregelles & Hartley[240] stated that accidents are unacceptable, not only from a social and humanitarian point of view, but also of their effect on productivity through the temporary loss of key manpower. Accidents at the face have decreased since mechanisation, power supports and stable elimination had become established (Figure 14).

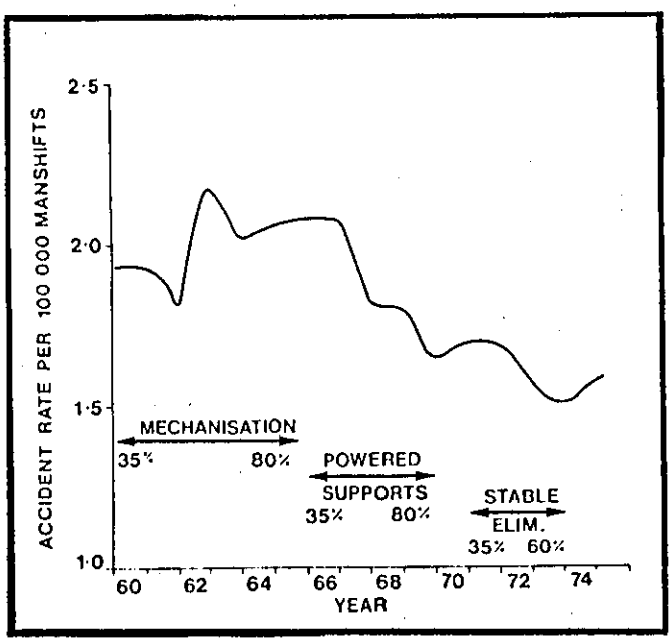


Fig. 14. Fatal and serious accidents at the coalface, 1960/75

(Source: Tregelles & Hartley[240])

In the initial period of mechanisation, the accident rate rose, but, once the new systems and technology were familiar to management and men, it consistently diminished.

Similar patterns can be seen to have occurred in the United States (Figure 15) where the trends in labour productivity and miner safety have been opposite. Falkie[228] showed this was mainly due to technology and legislation. However, a tough new legislation, introduced in 1969, had an adverse effect on productivity.

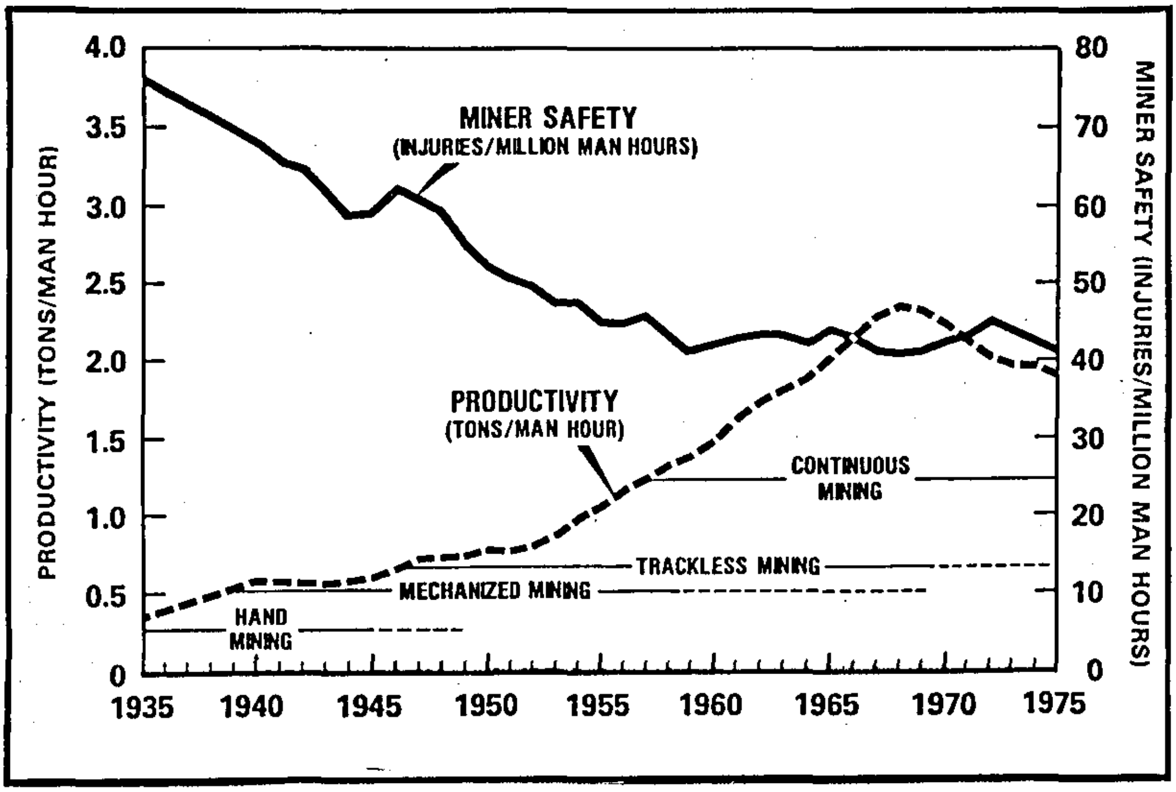


Fig. 15. United States underground productivity and safety, 1935 to 1975
(Source: Falkie[228])

Taking the statistics from the Report of the Mines Safety & Health Commission[233], the direction in Europe has been the same. In the Community of the Six, in the period 1958 to 1976, output per manshift underground rose from 1634 to 3710 kilogrammes, whilst fatalities per million man-hours fell from 0.610 to 0.415.

Gray[227] posed the question : "Safety and mine productivity - are they compatible?" There is a cliché in mining circles that a "safe pit is a productive pit"; is there any evidence to support this?

Andrews & Christenson[241] surveyed economic factors affecting safety in underground coal mines in the United States, and built up an econometric model, including such factors as technology and size of mine. Amongst their conclusions, they showed that there is a positive relationship between technological improvement and the reduction in fatal and non-fatal injuries. They also indicated that there is a negative relationship in the injury rate with the size of mine. This latter fact was in sharp contradiction to the studies in the United Kingdom, reported by Bryan[242,243], that larger mines had higher accident rates.

The truth seems to be that safety correlations built up by comparing individual mines are highly doubtful. Each colliery is a very small sample. There are social traditions in various areas or mines. For example, the workdays lost through accidents per 100,000 manshifts in South Wales appear double to that of the South Midlands. However, the situation has been aggrevated by the tradition that in South Wales, for a minor accident, one takes far more days off than in the South Midlands.

Collinson stated, in private conversation, that there is no direct relationship between mines, correlating productivity and safety. That cliché is as wrong almost as many times as it is right. Often a highly productive pit has the best geological conditions, allowing the best equipment and mining methods. Thus, the natural state of the mine interacts to the benefit of both safety and productivity, even though they are both independent.

There has been much written at a practical level, as illustrated by Holdsworth[244] and Montgomery[245]. Their approach contributed greatly to what Collinson[237] theorised as "making mining safer yet".

It is an undoubted fact that with improved technology, productivity has increased over the years and accident rates have been reduced. However, the direct link between productivity and safety is open to debate.

2.6. International Comparisons

In recent years, there has been an awareness that Europe must be the United Kingdom's centre of interest, unlike earlier futile comparisons with the United States. One cannot look at the British underground coal mining industry in isolation; there are probably few industries that are more international. This is witnessed by the fact that, in Europe, information on coal mines can be obtained from the Coal Committee of the Economic Commission for Europe which is part of the United Nations, the Organisation for Economic Cooperation & Development, the International Energy Agency which is an off-shoot of the O.E.C.D., the Coal Mine Committee of the International Labour Organisation, as well as the Commission of the European Communities.

International comparisons in coal mining are by no means new. Indeed, none less than Harold Wilson[246] was comparing productivities throughout Europe back to 1913 before he became interested in other matters. On the more technical side, the Reid Committee[247], just after the war, reviewed the British Coal Industry with that of other countries. Possibly the most outstanding contribution from a technical point of view came from the Economic Commission for Europe[248] which surveyed the productivity of underground coal workings throughout Europe, East and West, up to 1965, and contained unique data which can form a most useful foundation for subsequent comparisons.

On the European scene, Pounds & Parker[249] discussed the earlier history, and Gordon[250] eloquently reviewed the evolution of energy policy and the reluctant retreat from coal in Western Europe since the Second World War. The Commission of the European Communities[251] have produced a concise but informative history of the first twenty-five years of the Common Market in coal. The earlier years of Europe's Coal & Steel Community are reconsidered in detail in all their aspects by Lister[252]. Putting coal in its larger context of energy, and relating it to Western Europe, was comprehensively described by Lucas[253]. The Reports of the National Coal Board Technical Delegations[254,255], Zauberman[256], Stranz[257] and Stainer[258,259] gave an informative background on the Polish and Czechoslovakian scenes, whilst Strishkov et al[260], World Coal[261] and Bratchenko[262] discussed the U.S.S.R. coal industry. Collins[263] concisely filled the gaps with his reviews on every coal producing country in the world. Each contributor added a little to one's knowledge on labour productivity in the coal mining countries in Europe, East and West.

International statistics abound in the area of coal mining, invariably based on labour productivity. The most relevant were and are produced regularly by the Coal Committee of the Economic Commission for Europe. Much of their annual unpublished work dealt with concentration indices in underground coal mining, as well as capital formation and cost figures.

The Commission of the European Communities held a Symposium[264] on high-output coal winning districts which included several comparisons of mining methods, technology and performances throughout the Community. In the area of finance, the former European Coal & Steel Commission[265] produced comparative balance sheets of the coal mining companies of the Community; these formed a data base to help analyse financial differences and structures. Thus, the European Economic Community is gradually facilitating the process of comparisons.

Kravis[117] showed international comparisons made in labour productivity in coal mining from 1910 (Figure 16). Nearly all these comparisons were made by economists, and some of them were rather crude and must be questioned. Mining productivity is heavily influenced by the richness of the deposits and the ease of access to them. In coal, shortly after the Second World War, over 20% of the United States' output came from strip mining where labour

(U.K. = 100, unless otherwise indicated.)

c. 1910	c. 1935	c. 1950	c. 1965
U.S. (T 11, W) 227 (T 14, W) 245 (R 13, M) 317	U.S. (R 38, M) 381	U.S. (I 49, M) 496 (P 50, E) 382	Czechoslovakia/France (K 62, W) 220
Ruhr (R. 13, M) 92	Ruhr (R 38, M) 132	Germany (Fed. Rep.) (I 49, M) 90	Czechoslovakia/Hungary (CH 67, E) 361 (CH 67, W) 356
Upper Silesia (R 13, M) 111	Upper Silesia (R 38, M) 159	—	
Saar (R 13, M) 78	Saar (I 37, M) 89 (R 38, M) 98	Saar (I 49, M) 72	
Prussia (T 11, W) 95 (T 14, W) 103	Germany (Fed. Rep.) (I 37, M) 134	—	
Belgium (T 11, W) 59 (T 14, W) 52	Belgium (I 37, M) 66	Belgium (I 49, M) 54	
France (T 11, W) 72	France (I 37, M) 70	France (I 49, M) 60	
Nova Scotia (T 11, W) 185	Poland (I 37, M) 146	Poland (I 48, M) 118	
New South Wales (T 11, W) 187 (T 14, W) 214	Czechoslovakia (I 37, M) 118	Czechoslovakia (I 48, M) 97	
India (T 11, W) 42 (T 14, W) 47	Netherlands (I 37, M) 150	Netherlands (I 49, M) 119	
	U.S.S.R./U.S. (G 39, M) 29 (G 39, W) 42	U.S.S.R./U.S. (G 50, M) 23 (G 50, W) 30	

The material in the parentheses preceding each productivity index provides information on (*a*) source, (*b*) reference year and (*c*) the nature of the input-measure in the denominator of the productivity ratio. The codes used for each are as follows:

(*a*) *Source:* CH = Conference of European Statisticians. G = Galenson. I = I.L.O. K = Kux, Mairesse, Drechsler. P = Paige and Bombach. R = Rostas. T = Taussig.

(*b*) *Reference year.* Last two digits of year. (The reference date for the numerator country has been entered in cases where the reference dates differ for the two countries being compared; when the years are not the same they usually differ only by 1 or 2 years.)

(*c*) *Input measure in the denominator.* E = Employees (or workers). M = Man-shift. W = Wage earners.

Fig. 16. International comparisons of labour productivity in coal mining
(Source: Kravis[117])
(References: CH = 148, G = 142, I = 169, K = 267, P = 139, R = 137, T = 266)

productivity was high, whilst only around 5% was obtained in this way in Great Britain. According to Frankel[138], the remainder came from average depths of 190 feet in the United States and 1170 feet in Great Britain. This probably does much to explain Taussig's[266] early XXth century data showing productivity levels in the new regions of the world, two or three times those of areas with a longer history of intensive exploitation of natural resources.

The Paige & Bombach[139] survey was based on what they referred to as the "ring-fence" method, in which the group of energy industries was treated as a single entity for purposes of measuring inputs and outputs, making the comparison even more remote from coal mining. The Kux et al[267] study between Czechoslovakia and France also used the output expressed as a calorific value, halving the relationship because of the poorer quality of coal in Czechoslovakia.

One could laboriously discuss the various methodological faults in some of these earlier studies, which reveal the weaknesses in international comparisons mentioned in Section 1. A major error was to compare mining industries, ignoring completely differing mining methods, such as open-cast or underground, and different types of coal, such as hard coal or lignite, showing all the discrepancies of these aggregations. Fortunately, over the years, international data has become more refined and more readily available to the eager researcher, as has the feeling of international cooperation.

Unhappily, there has been minimal comparisons in depth other than the generation of bigger and better European coal mining data; the exceptions were that of Oakland[268] who plotted statistical trends in the underground coal mining in Europe, both physical and economic, and actually dared to introduce such terms as exchange rates and inflation. Also, Pryke[66] produced international comparisons in fuel and power with a well documented section dealing with coal mining. His approach was particularly revealing as he attempted to introduce the effects of geology and mining conditions on O.M.S. throughout Europe. Unfortunately, his analysis was more with words than empirical data, though it provided a firm foundation for discussion on the subject.

2.7. New Measures for Old

So far, discussion on productivity relating to the coal mining industry has been purely and simply on labour productivity mainly measured in O.M.S. in solitary confinement. Several commentators such as Siddall[175] and James[177] have freely admitted to the weakness of using solely labour productivity in an industry that is becoming more capital and less labour intensive. Sadly, attempts to break away from traditional patterns of thoughts on productivity and its measurement have been few and often weak.

Efforts have been made to try and place labour productivity in its context as regards costs, prices and profits. Atkinson & Walker[269] produced a study of coal mine profitability; Landsdown[270] gave a detailed analysis of productivity and costs, whilst Dickins[271] related these specifically to high production faces, and Oakland[272] studied the effect of variations in output on colliery profitability. Mining journals, such as the Mining Engineer, regularly carry extensive articles relating to the cost factor of various technological systems. All too often, these economic details are not really fully integrated into discussions on productivity.

From an accounting point of view, there has been little progress since the papers of Hodgson[273], de Paula[274] and Carr[275] in 1952, setting out the standard cost and budgetary control system of the industry, and relating it to productivity. Ewing[276] produced an accounting/econometric model to analyse mine operating costs and capital expenditure, but paid scant detail to productivity. Coal mining has also not escaped the attention of the added valuers. Wood[277,278] showed various financial details based mainly on census of production, including gross and net output (value added) per employee, wages and salaries as a percentage of gross and net output, net output per £ of wages and salaries, as well as various other added value ratios. These were not very revealing and could have been obtained by any moderately informed reader of the National Coal Board's Annual Accounts and Reports. He also weakly compared the industry's performance to manufacturing industries, making little allowance for its uniqueness.

More integrated approaches have come from King[279] and Siddall[176,280] who, whilst still talking mainly on the O.M.S. front, strongly related it to costs and the general economic welfare of the industry. King[279] discussed what he called "the quest for greater productivity"; he at least crudely allied it to real costs and proceeds, allowing for inflation.

It would be wrong to think that mining engineers only spoke of labour productivity. There are other measures which they might not think as productivity but could probably be a better measure of partial productivity, especially in an era of machine power. Surely output per machine shift is a direct measure of the partial productivity of machines. Daily output per face is an indirect measure of the combined productivities of man and machine. Birch[281,282] early realised the importance of performance indices based on the machine rather than on the man, and much analysis today, especially for planning purposes, is based on these measures, as illustrated by Erasmus[283] on the West German scene; Hunter[284,285], Rawlinson[286] and Caunt & Fennelly[287] on the British scene; and Sharkey[288] on the American scene. It should, however, be remembered that, in isolation, daily output per face and output per machine shift are still partial measures and suffer from the weaknesses of being taken in a vacuum.

Behavioural science in various forms has attempted to monitor performance, usually utilising conventional methods of measuring labour productivity. Lister & Harper[289] have shown variations in performances and productivity in certain U.K. mines from a behavioural slant. Mason[290] advocated the use of an accountability checkpoint technique (ACT) to increase productivity, which is really a version of responsibility accounting, without giving much indication of how it would be measured or monitored.

Considerable attention has been given to the area of productivity by the forward thinkers in economics and operational research. Lomax[291] produced coal production functions for Great Britain for the period 1927 to 1943; unfortunately, his approach suffered from the traditional economists' weakness mentioned earlier in that he only allowed for the inputs of labour and capital. Strangely, he took, as the input of capital, the proxy of coal cut by machinery and obtained by pneumatic picks. He did, however, introduce a further factor of average seam thickness. Although his results were rather crude and produced way back in 1950, they illustrated the futility of the approach to give any meaningful results to the practising manager. Indeed, the National Economic Development Office[91], twenty-six years later, was possibly even worse in its analysis, for in reviewing the National Coal Board, unlike other nationalised industries, it failed to produce an index of total factor productivity for the industry claiming it could not find a worthwhile measure of capital stock.

More practical approaches from economists came from Posner[292] who, like Sealy[187], analysed the effect of closures, major reconstructions, mechanisation and general progress on O.M.S. He built a model showing the effects of closures on overall productivity. Reid et al[293] illustrated the relationship of productivity and pit size, as did Sales[294] some years earlier. These avenues were more analytical, based on labour productivity than really introducing any new concepts, but they did add a further dimension, though their statistical foundation could be challenged.

From an operational research point of view, Young et al[295] constructed a model that could be used for planning purposes at various levels within the industry, and introduced such measures as profit per man required on the face. This, however, suffered as does added value from the fact that profit is rather an accounting contrivance, is ill-suited for performance monitoring, and may have a scant relationship to face production.

Gregory et al[296] have surveyed the effect of the physical properties of coal reserves on deep mine productivity in the United Kingdom, not unlike the survey of Melhotra[171]. Statistical relationships were established between output per manshift for longwall advancing faces and coal rank, mined thickness of seam, dip, depth and distance inbye of the face. Their results were rather damned by their own comment that only 31% of the variance in face productivity might be explained by their analysis; at least, they were honest. Ormerod[297] produced a strategic model for national overall productivity, from 1950, based on O.M.S. to explain historic movements. Regressing O.M.S. against three factors over twenty-five years, 1950 to 1975, gave a surprisingly good fit. No iffing and butting, and "significant at the 5% level" was required, he claimed, for the equation :-

$$\text{O.M.S.} = 0.11\ (\%\ \text{mechanisation}) + 0.13\ (\%\ \text{powered supports}) - 0.12\ (\text{dispute tonnage})$$

He also derived the equation :-

$$
\begin{aligned}
O.M.S._t = {} & 24.3 + 0.011\ (\text{cumulative capital expenditure})_{t-5} \\
& + 0.07\ (\%\ \text{powered supports})_t \\
& - 0.12\ (\text{dispute tonnage})_t
\end{aligned}
$$

the cumulative expenditure being only major schemes, and being lagged by five years (t-5) to allow effect, where t is the year in question. This again, when actual was plotted against calculated, gave a good fit. Ormerod[297] admitted he was only giving some of the factors leading to increased productivity based on O.M.S., improving historical analysis but not measurement.

From America has come the attempted linking of labour productivity to economic evaluation. This was illustrated by Weir & Clark[298] who produced a conventional discounted cash flow (DCF) analysis of a proposed coal mine but, just as an addition, showed the labour productivity required without really integrating it into the model. The ultimate in this approach came from Lavin et al[299] who have created an elaborate life cycle description of underground coal mining based on DCF techniques. They incorporated what they called labour productivity, capital productivity and other factors in their model. Their approach was interesting and well documented but highly complex, not really showing the inter-relationships of various inputs.

The most exciting attack came from Cahen[300] who reported a survey based on the measurement of total productivity in the French coal mining industry, as early as 1961. After deriving it mathematically, she stated that the total productivity index was in inverse proportion to the unit cost of the production calculated at constant prices. The survey was carried out on the nationalised section of the French coal mining industry, Charbonnages de France, in the period 1950 to 1958. Instead of using the crude measure of inflation as the retail price index and applying it to all inputs, this survey split up the various input costs and deflated each one separately by an appropriate index. In this way, the approach was very similar to that recommended later by Craig & Clark Harris[20].

A total productivity index was produced, not only for the whole industry, but for each of the nine coal-fields. Cahen[300] found a close relationship between total productivity and face manpower productivity indices, which were laboriously explained but can best be summed up by the fact that, in 1958, the Spearman rank correlation between the two indices for the nine coalfields was +0.92.

Cahen[300] gave a full discussion on the problems involved in measurement and the new horizons in the field of total productivity measurement, especially related to coal mining. A criticism which she freely admitted was that each French coalfield, as described by Nehrdich[173], was highly individual in geology, methods of working and type of coal; but no direct allowance was made for this. Also, like Craig & Clark Harris[20] but unlike Gold[71], she did not fully integrate labour productivity into her total productivity model.

2.8. Underground Coal Mining State of the Art - Conclusions

The coal mining industry has a long history of productivity and its measurement, almost exclusively relating to the partial measure of labour productivity. Over the years, with the introduction of more mechanisation, the industry has become more capital intensive but few efforts have been made to introduce new methods in assessing productivity. Safety is a vital issue in underground coal mining and, over the years, in the United States, Europe and the United Kingdom, productivity has risen whilst incidents of fatalities and accidents have dropped. It is claimed that technological advances are partly responsible for both improvement in safety and productivity. However, their direct relationship is open to debate. International comparisons have been made since 1910, and, although international data and methodology of comparisons have improved, little detailed analysis has been made.

Improved productivity is on the lips of all concerned whilst scant attention has been given to its wider measurement. The best approach would appear that of Cahen[300] relating to total productivity. It seems a pity that her ideas have not been universally adopted, or, if they have, are buried in the confidential files of the so-called planners.

SECTION 3

Methodology

"I must create a system or
be enslaved by another man's"

William BLAKE

Little comparative detailed analysis has been published on productivity in underground coal mining; and, any that has, has almost exclusively focused on labour productivity. The objective of the current research is to develop an integrated model of the important aspects of underground coal mining productivity. One of the major aims is to break away from the constraint of labour productivity, and hopefully place it in its true economic/technical perspective. In the building of the model, the best from earlier models are utilised, improved upon, and related more specifically to the underground coal mining industry.

Of previous reports and surveys, much good work had been spoilt by too much aggregation. Aggregations and comparisons have been made between widely different coal mining industries, with each industry being made up of various combinations of geology, methods of mine working, and types of coal produced. It is, therefore, thought vital to focus attention as much as possible on similar sectors of the coal mining industry.

3.1. Why Hard Coal?

The first decision must be to concentrate the model exclusively on hard coal and to exclude brown coal mining, as these two basic kinds of coal usually differ greatly in quality. The Economic Commission for Europe defines hard coal as having a gross calorific value of over 24 MJ (megajoules) per kilogramme, approximately 5,700 kcal/kg, on an ash free but moist basis, and brown coal with calorific values below this. Of course, within hard coal itself, there is a whole variety of types, including anthracite, steam, coking, etc. Generally, in Europe, hard coal is extracted from underground mines, whilst brown coal is found in higher strata and can often be produced by opencast methods. An international survey illustrating production differences was given by Collins[263].

Experience has shown that output in tons per unit of labour input is generally much higher in opencast than in underground coal mining, with an overall lower cost per ton. Consequently, research methods, which make a distinction between hard and brown coal, may lead to completely different results, both in physical and economic terms, than those in which all kinds of coal are treated as a single product. It is felt that clearer results can be obtained by exclusively studying hard coal, mined underground.

3.2. Why Europe?

In any study or research, strict parameters must be chosen. Earlier work was marred by making direct comparisons between the United Kingdom's and the United States' coal mining industries. It has been strongly considered in recent years that Europe should be the centre of thought for U.K. mining. Unlike America, the European industries are a more logical grouping to study, due to their geology, age, geographic position and methods of working. Also, much useful background statistical work has been produced by various European bodies.

It is considered that a single study just on one national industry, such as that of Cahen[300], might only reflect the paroquial nature and problems of that industry. In the United Kingdom, as in almost every country in Europe, there is a monopoly producer of coal dominating the industry. In West Germany, however, there are a few large non-nationalised producers with an oligopoly.

Because a pilot study was carried out with the National Coal Board statistics successfully, it was felt that the overall research could be adapted and used looking at Europe, both East and West. Obviously, it would have been far easier to have just concentrated on the National Coal Board or the Charbonnages de France, but one could have been caught in the trap of just using data provided solely for internal consumption with internal objectives in mind; also, management within each industry could possibly produce surveys of their own. Thus, a pan-European comparative study is a basic objective of this research.

The Coal Committee of the Economic Commission for Europe provides the best base to start this study, from both a physical and economic viewpoint. It maintains data in considerable detail on the East and West European coal industries. The only hard coal industry in Europe which does not report to that body to any significant degree is Spain, from which details have been sparse, at least until recently. Therefore, the research would embrace most of the European hard coal mining industries, excluding Spain (its output only reaching 11.9 million tonnes in 1977).

The Ukraine is concentrated upon, rather than the U.S.S.R. in total, as it represents the vast majority of the European/Russian production of underground hard coal, and also maintains separate data.

3.3. Why the Longwall Method of Mining?

Longwall underground techniques have traditionally been favoured in Britain and are widespread in Europe, China and the Soviet Union. Room and pillar methods predominate in North America, India, South Africa and Australia.

There has been considerable interest in the United States recently into longwall methods, but even in that so-called advanced technological society, there is very little longwall mining. Although longwall mining now dominates the hard coal underground scene, especially in Europe, there is still room and pillar working in certain areas. Therefore, one should spend a little time considering the basic differences in these underground mining methods.

3.3.1. LONGWALL MINING

In mechanised longwall mining, a power loader travels the length of the coal face, usually about 200 metres, cutting and extracting the coal to a depth of half to a metre at each pass. The coal is loaded on to an armoured face conveyor, discharged on to a belt conveyor system in the main roadway at the end of the face, and thence to the shaft bottom. Attached by double-acting rams to the face conveyor is a row of hydraulic powered supports, which push forward the conveyor, and then advance themselves behind the power loader as it passes along the face. The roof of the goaf, or void left behind the face after extraction of the coal, is allowed to collapse after supports are advanced.

In British practice, the power loader is a shearer with a rotating drum fitted with tungsten carbide picks which extract the coal. In the softer German seams, the coal is frequently extracted and loaded on to the conveyor by a simple plough traversing the face.

In the longwall advancing system, roadways are usually driven a little ahead of the face. Various types of machine are used for this purpose. The "roadheader" is a track-mounted machine with a traversing boom carrying a rotating drum fitted with picks. "Continuous miners" and "dintheaders" are rather similar machines carrying sets of parallel chains or drums each fitted with picks and working on the chain-saw principle. The "in-seam miner", used for extracting the coal in the advancing roadway, has a chain of buckets and picks rotating in a vertical place.

In the longwall retreating system, the complete panel, or area of coal to be extracted, is first blocked out by driving the roadways to the boundary where the coal face is opened out and advanced in the reverse direction, i.e. retreated towards the shaft (Figure 17).

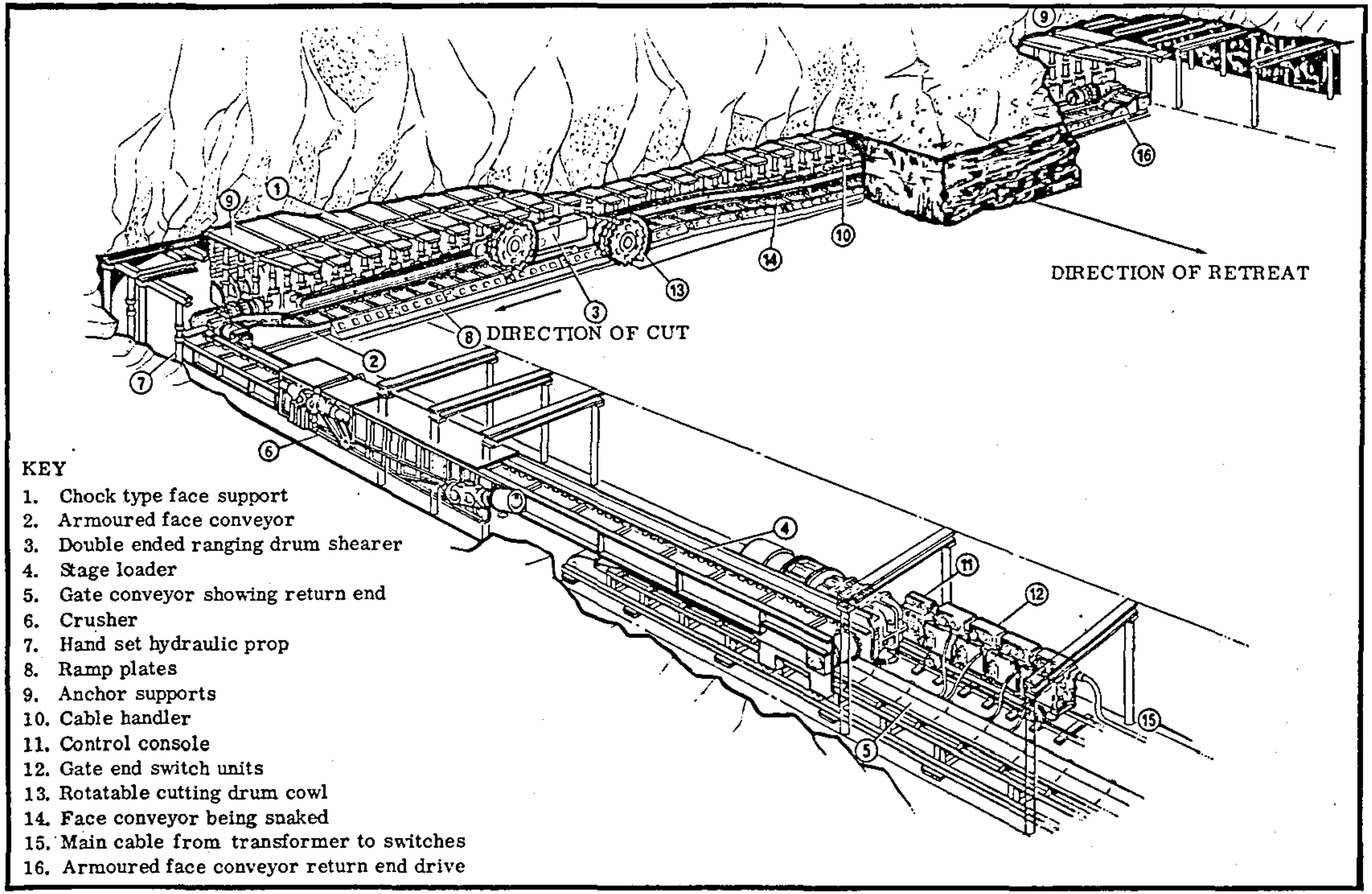


Fig. 17. Typical mechanised longwall retreat face layout
(Source: National Coal Board)

3.3.2. ROOM AND PILLAR MINING

In room and pillar (board and pillar, or pillar and stall) mining, coal is extracted from a network of intersecting parallel roadways, using continuous miners or shot-blasting methods. Rectangular blocks of coal, known as pillars, are left in situ between the roadways. The pillars perform a roof supporting function and hence much less mechanised roof support is needed than in the longwall system. On the other hand, more coal extraction and transportation machinery is required.

The system is clearly wasteful of coal reserves and, where practical, the pillars are robbed. This procedure is difficult and sometimes dangerous on account of the heavy roof pressures concentrated on the pillars, particularly at depth. Furthermore, if the pillars weaken and collapse, surface damage due to subsidence is unpredictable.

3.3.3. COMPARISON OF THE TWO METHODS

Longwall mining has the following advantages :-

(a) - it allows a high proportion of the coal in a seam to be extracted; usually at least 70% and often approaching 100%, unless the seam is so thick that much of the coal is inaccessible anyway;

(b) - the roof generally subsides in a gradual and regular manner as the props move forward. After such subsidence - indeed, in favourable conditions, during the subsidence - the surface will be safe. In seams not far below the surface, subsidence can be difficult to control; such seams may be better mined by open-cast methods;

(c) - longwall mining is generally appropriate for deep seams where roof pressures are so great that room and pillar mining involves leaving very large pillars intact;

(d) - though the initial setting up of standard longwall systems requires a large investment, typically £$\frac{3}{4}$M per face in 1976/77 in the United Kingdom and often much more overseas, operation requires less labour and lower maintenance costs than bord and pillar mining;

(e) - longwall collieries can often comply more readily with today's increasingly stringent safety requirements. This is because smaller areas of roof are exposed than in room and pillar, and because fewer cutting machines are required for comparable outputs.

For room and pillar methods, one can say that :-

(a) - provided the pillars can be extracted, reasonably high rates of recovery are feasible;

(b) - the initial capital outlay is generally less than in longwall mining;

(c) - the maximum workable seam thickness is rather greater than by longwall methods;

(d) - room and pillar is very suitable for the exploration of virgin areas of coal seams, but is limited to shallower seams because of roof pressure.

Thus, it can be seen that there are considerable differences in the mining methods, even more accentuated when one brings in investments and operating costs. Comparisons throughout Europe, therefore, would be more meaningful by concentrating exclusively on longwall coal mining, though it is appreciated there are some differences within that system.

3.4. The Framework

The area to be researched is thus chosen as underground longwall hard coal mining in Europe. One must now consider a logical framework for analysing the productive performance of the chosen area, both in physical and economic terms. The framework must progress to give the inter-relationships in producing an indicator of total productivity.

Before proceeding into details of the framework, further clarifications must be made. In talking of productivity related to longwall mining, the parameters are measured up to the end of the production process, that is when coal has been prepared and cleaned, ready for despatch from the mine in a saleable state acceptable to the market. As the productivity of the whole production system of longwall mining is being studied, all related inputs must be included not just at the longwall faces, and should embrace development work, underground transport, preparation plants, etc. Actual face performances are monitored within this system. Only by observing the total productive process can meaningful analysis be made, since high productivity at the face could be counter-balanced elsewhere.

The marketing process has been deliberately isolated for various reasons, although its importance is fully appreciated; it is considered to be a separate process. It might be old-fashioned, but the underlying tone of the research is production-orientated. In any study, especially an international one, the sphere of marketing adds a further dimension which could be completely segregated. Over the years, much confusion and false comparisons have been made through the neglect to keep these processes apart for analysation purposes, although they are obviously linked for the economic well-being of each individual industry.

Production and productivity must relate to the productive efficiency of the mine or mines. Marketing is dominated by such factors as the geographic location of the mine vis-à-vis its market affecting transport costs; the supply and demand position of coal which can be affected by, say, the declining steel industry; the pricing and marketing policy of the organisation; etc. Thus, although marketing is vital, any international comparison beyond the production process would be highly complex and subject to further research. Even within a country, such as the United Kingdom, pricing and marketing policies are often intricate. This could further be complicated by the problem in a country such as Poland, where there are two distinct markets with two very distinct sets of prices and policies for export and domestic consumption.

The research is mainly at the national level, supplemented with data at the level of the mine. On the physical side of the framework, one must decide where the starting point should be; the base would be the longwall coal face, as greater analysis could be obtained by looking at the industry and the colliery at the root. Also, both nationally and via the Economic Commission for Europe, considerable face data is available, even though it has to be standardised and adjusted.

After carrying out pilot studies, a physical framework is built, for analytical purposes, focusing on the longwall face and utilising the calculated expected pithead tonnages, a method used throughout Europe. This is considered better than using the weighed, or estimated run-of-mine, output measurements. These are not practised by all countries, and those that do often have their individual systems freely admitted to be approximations, such as in France where the weight of the dirt removed in preparation is added back to the net output.

Expected pithead tonnage (EPT) is basically derived for each longwall face as follows :-

$$\text{EPT} = \text{height extracted} \times \text{length of face} \times \text{advance} \times \text{density of extraction}$$

No measurement is meaningful without a time scale. Thus, if the advance per day is taken, the formula would then give the expected daily output per face in pithead tonnages. To obtain saleable tonnage or its equivalent, the pithead tonnages must be converted via a vend factor, where

$$\text{vend} = \left\{\frac{\text{saleable tonnage}}{\text{EPT}}\right\}$$

It must be borne in mind, however, that EPT is a calculated theoretical measure. Thus, a percentage vend of, say, 65% contains two distinct factors. Firstly, it is a reflection of the weight of saleable coal or its equivalent, obtained from the run-of-mine coal, after cleaning and preparation. Secondly, it contains a factor reflecting errors, if any, of forecasting or calculating these expected tonnages; these may be caused, for instance, if the seam is richer than anticipated, or if the basic assumption that the face is uniform in shape and size is not true. However, the larger the sample of faces, the more insignificant any errors become.

By adapting this approach, a basic model could be built up, starting at the face, and expanding to reflect various aggregates, such as the mine or the industry, as follows :-

$$\overline{DOF} = \bar{c} \cdot \bar{k} \cdot \bar{s} \cdot \bar{l} \cdot \bar{a}$$

Equation I

where : $\overline{DOF}$ = average daily output per longwall face in market tonnage

$\bar{c}$ = average vend (market tonnage/pithead tonnage)

$\bar{k}$ = weighted average density of extraction

$\bar{s}$ = weighted average of extracted seam thickness, including dirt bands, and allowing for operational losses

$\bar{l}$ = average length of longwall face, including stable holes

$\bar{a}$ = average advance of longwall face per working day

Obviously, to obtain any form of standardisation internationally, detailed definitions must be made (Appendix I). All values, in the survey, are metric.

Equation I is an expansion and sophistication of the EPT calculation. It introduces an average vend ($\bar{c}$), converting the pithead tonnages into market tonnages, these being the prepared coal as taken by the market (in the United Kingdom, it is the saleable tonnage). Also, average seam thickness is appropriately weighted for overall statistical accuracy.

Only revenue output is included, with development coal and lifted slurry excluded. Where possible, allowance is made for any loss due to expected spillage via the conveyor system. This minor adjustment is made on the weighted average seam thickness.

The weighted average density of the coal seam and dirt band extracted is derived :-

$$\bar{k} = \left\{ \bar{b}_{coal} \cdot \bar{w}_{coal} \right\} + \left\{ \bar{b}_{dirt} \cdot \bar{w}_{dirt} \right\}$$

where : $\bar{b}_{coal}$ and $\bar{b}_{dirt}$ = average proportion between coal and dirt thickness

$\bar{b}_{coal} + \bar{b}_{dirt}$ = 1

$\bar{w}_{coal}$ and $\bar{w}_{dirt}$ = average densities of coal and dirt

The density of the coal can vary due to its grade, with bituminous coal around 1.35 and anthracite 1.60 tons per cubic metre. The density of the dirt band depends considerably on its ash content. Thus, the figures for these various ingredients must be known or estimated; if the coal and dirt bands are ill-defined, a combined figure must be utilised.

The average daily output per face ($\overline{DOF}$) can thus be fairly accurately calculated. Pilot studies were carried out on over seventy faces throughout the Economic Commission for Europe area on longwall faces, both advancing and retreating, and it was found that $\overline{DOF}$ could be predicted to within an accuracy of ±2%.

The annual output from longwall faces in market tonnage can be shown as :-

$$O = \bar{d} \cdot \bar{n} \cdot \overline{DOF}$$

Equation II

where : O = output per annum from longwall faces in market tonnage

$\bar{d}$ = average number of days worked per longwall face during the year

$\bar{n}$ = average number of longwall faces per working day during the year

Thus, combining Equations I and II :-

$$O = \bar{d} \cdot \bar{n} \cdot \bar{c} \cdot \bar{k} \cdot \bar{s} \cdot \bar{l} \cdot \bar{a}$$

Equation III

For Equation III, annual national outputs from longwall faces are analysed via the Concentration Indices[301] published since 1960 by the Economic Commission for Europe; they are of course verified and supplemented by other national data. Tables are then built up, covering the period 1960 to 1976, for the following seven countries :-

Belgium
Czechoslovakia
France
Poland
Ukraine
United Kingdom
West Germany

1960 is chosen as the starting year for the research for several reasons. Firstly, it was the point in time when the availability of relatively cheap oil began to show marked effects, especially on Western European energy economies. Secondly, it was a fairly stable period economically, after the recovery from the Second World War. Thirdly, it was the dawn of mechanisation. And, lastly, it has been used as a base year in the statistics of the Economic Commission for Europe from which much of this information has been gleaned.

Visits were made to the various countries, to gain further data and clarify definitions. Equation III was a useful tool for validating statistics, as it is almost a tautology. If the calculated and actual did not agree within a reasonable discrepancy of not more than ±5%, errors in the data invariably were highlighted. In fact, the method was so successful in validating statistics that it has been approved by an international body.

The type of errors that were and are still encountered include :-

(a) - misprints in the data;

(b) - geographic areas not fully representative of the country's output, illustrated by the fact that Czechoslovakia in some years only reported the Ostrava/Karvina region, and Belgium, in recent years, only sometimes reported the Campine region;

(c) - profile differences; for instance, where strikes were not properly reflected in the data, or where national definitional changes were not clearly recorded;

(d) - major differences in definition. This is illustrated by the fact that the model showed that there

> was a discrepancy in the West German output figures. On fuller investigation, it was found that these were expressed in tvF which, translated, means "clean, valuable or pure coal". This is a theoretical output, not based on calorific value but is the estimated pure coal (making a dirt allowance) after cleaning. For example, if one ton is actually shipped, .95 tvF may be estimated.

After investigations were made, it was found that Equation Equation III was always in line with the corrected values.

It should be stressed that the Equation, unlike Gregory, Lock and Ormerod's[296] model, is not cross-sectional, looking at infinite detail on one specific day, but is based on trends allowing managers within the industry to check those trends. It also highlights the important physical factors enabling management to evaluate which are the main determinants in production, thus predicting future trends.

Although labour productivity is not considered by any means to be the be-all or end-all, it is considered that, as traditionally so much emphasis has been placed on it, a further equation (Equation IV) would be developed incorporating it, not so much for its own sake but to show its inter-relationships :-

$$\frac{O}{MY_u} = \overline{DOF} \cdot \frac{MS_u}{MY_u} \cdot \frac{1}{MS_u/dn}$$

Equation IV

where : $\frac{O}{MY_u}$ = average output per man-year for underground longwall workers during the year

$\frac{MS_u}{MY_u}$ = average manshifts per man-year for underground longwall workers

MS_u/dn = average underground manshifts per longwall face-day worked

Output per man-year is chosen because, as Harris[302] stated, it is perhaps one of the most under-rated labour statistics used. The measure has the advantage of depicting what is happening over a representative period of time, and smooths the effects of factors working both for and against increased labour productivity.

A major problem which has taken the Economic Commission for Europe thirteen years to resolve is : what is an underground worker? In their national statistics, the United Kingdom and Belgium include under-officials whilst the other five countries exclude them. The United Kingdom data embraces job training, but not contractors or manpower working on capital output, whilst in West Germany it is sometimes found that complete faces are worked by contractors with the output counted in analysis but not the shifts worked.

Although the Economic Commission for Europe has only just recently brought in a new definition of underground manpower, embracing all men except managers, scientific staff, and including contractors' men, it is considered that, as a trend from 1960 to 1976 is required, the old definitions should be used as it is impossible to achieve such a trend in any other way. Also, the returns under the new definitions have been sparse and often showing little difference to the old definition. Similar definitional problems arise : What is a working year? This is obviously affected by various factors such as holidays allowed; for example, in 1970, in West Germany, there was a change in the sick benefit scheme which encouraged absence to rise considerably, especially in the Ruhr. What is a manshift? It varies between countries; for instance, in most West European countries, overtime counts as two shifts or double time, but not so in Eastern Europe, and length of shifts slightly differ.

Thus, the tables derived from Equation IV are based on Appendix I. A 1960 base is used, and every effort has been made to prepare data that is comparable through time for any country, that is by adjusting for known changes in definitions. Where information is not directly related to longwall mining, it is corrected, after consultation with the industry, to include longwall activities only. This is achieved by obtaining further data, by apportionment, or by isolating longwall geographically as in the case of France.

The increase of mechanisation throughout Europe since 1960 has played a major role in the advancement of productivity. Equation III is then applied to mechanised faces exclusively, using the Economic Commission for Europe's definition that a mechanised face is a face on which a machine either loads prepared coal or cuts and loads coal simultaneously; coal felled in the stable holes of mechanised faces is included in mechanised output.

A further sophistication is added to the national level relating mechanised longwall output to an equation based rather on the machine than on the man :-

$$O_m = \bar{d}_m \cdot \bar{n}_m \cdot \overline{DOF}_m$$

Thus,

$$O_m = \bar{d}_m \cdot \bar{n}_m \cdot \frac{MAT}{McS} \cdot \frac{O_m}{MAT} \cdot \frac{McS}{dn_m}$$

Equation V

where : O_m = output per annum from mechanised longwall faces in market tonnage

$\bar{d}_m$ = average number of days worked per mechanised longwall face during the year

$\bar{n}_m$ = average number of mechanised longwall faces per working day during the year

$\overline{DOF}_m$ = average daily output per mechanised longwall face in market tonnage during the year

$\frac{MAT}{McS}$ = average machine available time in minutes per machine shift at mechanised longwall faces during the year

$\frac{O_m}{MAT}$ = average mechanised longwall output per minute of machine available time during the year

$\frac{McS}{dn_m}$ = average number of machine shifts per mechanised longwall face-day worked during the year

The data for this comes from official statistics, visits to the various countries and, in some instances, derivations of machine available time (MAT), the time in minutes a machine can be manned at the face.

The period in which a mechanised face is being operated by a single team is called a machine shift. In the United Kingdom, shifts are counted in whole units, even if only ten minutes are worked, whilst in Eastern Europe, they are counted in fractions. National definitions are used as statistical differences are insignificant.

One major problem to be resolved is the measurement of working time underground. In Belgium and France, it is measured from surface to surface; in Poland and West Germany, from the surface to returning to the cage for ascent; in the Ukraine, six hours at the face; in Czechoslovakia, it is from leaving the cage at the shaft bottom to the time of return to it; and, in the United Kingdom, "one winding" time is included. Also, in West Germany, when working in hot conditions, a break must be taken after six hours. Because of these differences, a standard definition of time spent underground is used : that is the time from entering the cage at the top of the shaft, to re-entering the cage at the bottom, after underground work. After much discussion, this appeared to reflect the lowest common denominator. On this basis, allowing for travelling, preparation and refreshment times, machine available time per machine shift is calculated. National data are directly used where available, or are derived. All statistics are compared and verified with the national figures to an accuracy of ±5%.

Thus, two sets of trends are developed for the period 1960 to 1976 for mechanised longwall output, based on Equations III and V.

3.5. The Total Productivity Approach

Practical measures, such as labour productivity, have their weakness in isolation. Total productivity measures, as used by Eilon, Gold & Soesan[73], Craig & Clark Harris[20] and Cahen[300], are considered to be a vast improvement, even though full of challenges and problems.

Gold's basic approach was highly complex and was adapted by Eilon into the r model, which was a return on total investment. Craig & Clark Harris[20] and Cahen[300] developed rather pedestrian total productivity measures which were basically output to all input factors, the former allowing for a profit factor.

Here, the Cahen approach is preferred, for she stopped at the point of production and did not introduce a marketing or profit element. In relating productivity in coal mining to the productive process, marketing aspects should be isolated. Thus, the ultimate total productivity measure should be :-

$$\frac{\text{longwall hard coal output}}{\text{total productive inputs}}$$

As the study focuses on hard coal, even though this is not completely homogeneous, output should be measured physically in metric tons, not in any economic value such as adjusted sales or added value. To allow for the fact that not all coal is equal, a further sophistication would be added later, converting the physical output into a hard coal equivalent or expressing it in megajoules or kilo-calories per ton.

Total input can only really be measured and aggregated with a financial base. The problems of inflation and exchange rates have to be overcome. Purchasing power parities are investigated thoroughly, but their inclusion would be a major piece of research in its own right.

To allow for the distortions of inflation and exchange rates, two decisions are made. Firstly, financial data are adjusted by indices of inflation based on 1960 = 100; and secondly, they are expressed in U.S. dollars, at a constant exchange rate, that being the rate in 1960. Price indices used are not just those of retail prices which suffer from their aggregation, but each input factor is deflated by the most appropriate indices. The U.S. dollar is chosen because it is possibly the most international of all currencies, and forms a neutral base. The effects of inflation and exchange rates are shown separately later. It is felt that the approach of Oakland[268] was the correct one, and the effects of these two financial diseases must be segregated.

Obviously, in a sophisticated industry such as longwall coal mining, there are a multitude of inputs. These comprise three major sectors : labour, capital and supplies/overheads.

The basis of physical outputs is fairly simple, that is from national data on longwall output obtained from each individual country or via the Concentration Indices. These are also reflected in far greater detail showing the major elements in Equation III and the tables derived thereof.

As regards inputs, a basic source of information is the series on Capital Formation & the Cost of Production[303] issued by the Economic Commission for Europe. However, the cost and investments are related to the whole industry and not broken down into longwall and other methods of working.

Thus, a considerable detailed approach is needed to isolate longwall inputs. Fortunately, in most countries, longwall production completely dominated underground hard coal mining over the period, and small adjustments to the inputs were made, after consultation with the various authorities. Where, as in the case of France, Czechoslovakia and Poland, the percentage of the longwall production was substantially lower, the figures had to be scrutinised even more thoroughly. Fortunately, as regards Poland and Czechoslovakia, visits to those countries enabled accurate figures to be obtained. As to France, the problem was slightly more involved as the French and their coalfields are highly individual, and it was decided, after consultation with Charbonnages de France, to segregate longwall mining geographically; in this way, the best available figures are ascertained, even though it must be admitted that a small degree of error is inevitable.

3.5.1. MANPOWER INPUT

The manpower input should reflect the gross manpower costs directly related to the production process. Gross figures are used because they are the actual cost to the employer. If net figures were to be applied, that is those based on take-home remuneration after tax and other deductions, this would not be a true reflection of the economic cost to the employer; also, the variety of tax systems and deductions would complicate the analysis.

The manpower input does not only represent wages and salaries, but includes also other labour costs. These involve holiday pay, supplementary benefits in case of injury, national insurance, pensions, as well as concessionary coal and other fringe benefits. Social charges are organised in different ways from country to country and are borne by the employee, the industry and the state in varying proportions. However, any standardisation of these can be the basis for an independent future study. A comprehensive survey is given by the Statistical Office of the European Communities[304] for the period 1960 to 1975 for the Community of the Nine.

In their manpower data, the majority of countries in the survey only incorporate inputs of those concerned with production. West Germany and France, however, generally embody all inputs whether direct or indirect. The difference between the direct/indirect concepts is brought out in the case of Belgium, where calculations are made on the basis of both principles showing approximately a 10% increase when indirect manpower is allowed for. Thus, the aim is to include only manpower inputs related to the production process, with the figures for West Germany and France adjusted after consultation.

It must be remembered that the trends start from 1960, and, as with currency and prices, social charges and other features affecting the manpower inputs must be held as at 1960. The actual manpower input in each year is derived as follows :-

$$MI = MY_{current} \cdot \frac{MI}{MY}_{1960}$$

where :

MI	=	manpower input for longwall output during the year
$MY_{current}$	=	man-years for longwall output during the current year
$\frac{MI}{MY}_{1960}$	=	average manpower input per man-year for longwall output, in 1960

This is a method recommended by Greenberg[82], Kendrick & Creamer[81] and utilised by Craig & Clark Harris[20] and Cahen[300]. One problem which has to be allowed for is the change in mix of manpower over the years. For instance, with the advent of mechanisation, the balance between men below and above ground has changed. Also, certain jobs in the current year might not have been occupied in the base-year; after consultation, estimations for these are made.

In this way, the manpower input, based on 1960, is built up to show the total gross manpower input, including social charges to each industry. That is the total productive manpower related to longwall mining, not just at longwall faces.

3.5.2. CAPITAL INPUT

Over the years, the greatest problem in all total factor and total productivity analyses has been the input of capital. This is even more complicated when making an international study.

There has been much talk, in recent times, on replacement cost accounting, as mentioned earlier via the Sandilands[83] and Morpeth[84] Reports. These have been watered down for practical purposes into the Hyde Guidelines[305] and, to date, the National Coal Board has failed to publish any form of current cost accounts. The National Economic Development Office[306] did produce some current cost statements or, to be more correct, adjustments for the National Coal Board's accounts; these were only admitted to be an approximation and only covered those assets which were not fully written off and have therefore been subject to a depreciation charge in the historic cost accounts.

Throughout the countries covered in the survey, the capital input is measured by some form of depreciation based on historic cost, a concept which evoques much controversy. Methods of depreciation vary between countries. In the United Kingdom, it is a government directive. In West Germany, it is more complex as the German industry may include other activities such as steel making, and depreciation is sometimes a vehicle to off-load expenses on to the coal sector for favourable tax advantages. In the three East European countries, depreciation is based on historic costs of assets which are revalued every few years, and, unlike Britain, it is a cash flow out of the enterprise; in face, plant and machinery may still be depreciated though they might already be fully written off because their expected working life is regularly re-assessed and often increased; depreciation may also include an element of repairs and maintenance.

Thus, with all these variations, the first priority in the study is to reconcile the various depreciation charges, especially those from Eastern Europe. A detailed analysis is made to ensure that only buildings, plant, etc. relevant to longwall mining, are included, isolating all others. Elements relating to repairs and maintenance are excluded where possible and transferred to the "supplies/overheads" category. In this way, the fairly substantial differences in reported depreciation by the industries are reconciled.

It is not practical to use the leasing technique illustrated by Craig & Clark Harris[20] or the tilted annuity method prescribed by Groves[307]. This is because these include allowances for interest charges and would only lead to unnecessary complications, especially at an international level, with the complexities of interest rates.

One would have dearly liked to have been able to produce an even more meaningful measure of capital input, based on economic and technological value to the industry rather than on financial depreciation, but there are too many discrepancies and too much equipment already completely written off. The measure of capital input that best and most practically reflects the situation is based on current costs; depreciation methods rooted on national practice are scrutinised and adjusted as much as possible; groups of assets are each deflated by a wholesale index, based on 1960, each index being lagged by the weighted average age of the assets. This is considered an improvement on the simpler method of just taking a single price index :-

$$Dep_{1960} = \frac{P}{Y\ B}$$

where : Dep_{1960} = depreciation (replacement in 1960 prices)

P = historic cost of assets

Y = weighted average of estimated lives of assets

B = current index (based on 1960 = 1.00) lagged by the weighted average age of assets

In this way, but obviously more intricately, capital inputs are calculated. A replacement element, in 1960 terms, is featured embracing only those assets not currently written off, and thus, to this extent, under-estimates the capital input. This method incorporates the best concepts of accounting thoughts on fixed assets, expressed via the Hyde Guidelines[305], especially applied at an international level.

3.5.3. SUPPLIES/OVERHEADS INPUT

Obviously, there are a variety of other inputs which could be broken down into infinite detail. However, the best practical approach is to place these into one category, which includes all other production inputs, other than labour or capital.

It comprises three major elements : supplied materials, energy and overheads. The first two are relatively straight-forward to reconcile whilst, to make the overheads compatible, all elements of taxes or interest are omitted unless relating to the production process. After scrutiny, these inputs are deflated by an appropriate weighted index, based on 1960 and built on various wholesale price indices.

3.5.4. TOTAL INPUT

In this way, the three major inputs of manpower, capital and supplies/overheads are derived and combined to show, for each year, the total input of productive resources, based on 1960 prices, for the underground longwall hard coal mining industries of the surveyed seven countries. The total input is then converted into

U.S. dollars, at the 1960 exchange rate.

3.6. The Total Productivity Model

A measure of total productivity from 1960 for the various countries has thus evolved, relating output in tons to total input in U.S. dollars at 1960 prices and exchange rates. However, this is rather a static approach à la Cahen, and it is hoped that a more detailed analysis can be obtained by showing the major factors making up this total productivity. Therefore, an integrated model, similar to the r model of Eilon, is built on interlinking ratios and illustrates the important elements of the total productivity of hard coal longwall mining.

The ratios comprise three sectors, incorporating underground manpower, longwall mechanisation and underground energy utilisation. Obviously, many more features can be included but, if the model is to be of any practical use, it should be as uncluttered as possible.

Hereinafter, the model would be referred to as the Total Productivity Model (Figure 18).

As one looks at the various features of the Total Productivity Model itself, it is important to have a brief review of each of the nine elements embodied within it.

$$\frac{O}{TI} = \frac{O}{MY_u} \cdot \frac{CS_m}{MI_m} \cdot \frac{MI_m}{MI} \cdot \frac{MI}{TI} \cdot \frac{O_m}{CAP_m} \cdot \frac{CAP_m}{CS_m} \cdot \frac{O}{O_m} \cdot \frac{MY_u}{kWh_u} \cdot \frac{kWh_u}{O}$$

where : O = output per annum from longwall faces in market tonnage

TI = total input for longwall output, during the year

MY_u = man-years underground for longwall output, during the year

CS_m = capital stock in longwall face mechanisation, during the year

MI_m = mechanised longwall face manpower input, during the year

MI = manpower input for longwall output, during the year

O_m = output per annum from mechanised longwall faces in market tonnage

CAP_m = capacity of mechanised longwall face system in market tonnage, during the year

kWh_u = electrical energy utilised underground in longwall output, in kilowatt-hours, during the year

All inputs are expressed in U.S. dollars, at 1960 prices and exchange rates
All physical measures are metric

Fig. 18. TOTAL PRODUCTIVITY MODEL
for Analysis and Synthesis of Total Productivity

3.6.1. THE NINE ELEMENTS

Output per annum from longwall faces in market tonnage (O)

This figure is obtained from national data or from the Economic Commission for Europe's Concentration Indices, verified and analysed utilising Equation III. It is for hard coal longwall underground production, prepared for the market, and measured in metric tons.

Total input for longwall output during the year (TI)

It is a combination of the three major inputs of manpower, capital and supplies/overheads. It is expressed in U.S. dollars, at 1960 prices and exchange rates.

Man-years underground for longwall output, during the year (MY_u)

These include the manpower engaged for the majority of their working time in underground longwall hard coal mining, excluding under-officials. National figures are verified, using Equation IV.

Capital stock in longwall face mechanisation during the year (CS_m)

This is the capital stock in longwall face mechanisation expressed in U.S. dollars at 1960 prices, exchange rates and technology. It incorporates all mechanised capital equipment used and being held for mechanised longwall face areas.

Mechanised longwall face manpower input, during the year (MI_m)

This is the manpower input embracing production workers directly at the mechanised longwall face area, excluding those employed in the gate roads or setting up equipment. It is expressed in U.S. dollars at 1960 prices and exchange rates.

Manpower input for longwall output, during the year (MI)

This is the total manpower input, relating to the whole production system of longwall mining, expressed in U.S. dollars at 1960 prices and exchange rates.

Output per annum from mechanised longwall faces in market tonnage (O_m)

This figure is obtained from national data or from the Economic Commission for Europe's Concentration Indices, verified and analysed utilising Equations III and V. It is for hard coal longwall underground production, prepared for the market from mechanised faces, and measured in metric tons.

Capacity of mechanised longwall face system in market tonnage, during the year (CAP_m)

This is the obtainable capacity of the mechanised longwall faces, based upon their productive ability and estimated on their physical details. It is measured in metric tons, prepared for the market.

Electrical energy utilised underground in longwall output, during the year (kWh_u)

This is the electrical energy utilised underground, excluding lighting and ventilation, either measured directly or apportioned by the national authorities, in kilowatt-hours.

The majority of the nine elements are self-explanatory, but three need further clarification on the methodology used, because of their complexity or controversial nature.

3.6.2. CAPITAL STOCK IN LONGWALL FACE MECHANISATION (CS_m)

A meaningful figure of capital stock of longwall equipment is considered essential in analysing total productivity. Gross capital stock that is excluding any depreciation allowances can, if carefully applied, as discussed by Griffin[308,309], give an indication of output potential. Attempts previously to show capital stock in coal mining have failed, as illustrated by Lomax[291], because of their aggregation or remoteness.

As the survey relates to longwall mining, a capital stock of plant and equipment can, for analytical purposes, be built up concentrating exclusively on mechanised faces. Thus, in this way, the very important aspect of the growth of mechanisation, over the period 1960 to 1976, can be studied. However, it is still considered that the mechanised longwall capital stock of plant and equipment should only be for face equipment, used or being held and exclude development equipment in the gate roads. This is not in any way minimising the importance of development work which is included in the overall input to the total productivity model, but the variety of equipment and methods in this area detract from both the gathering of the data and their analysis. This is illustrated by the National Coal Board Mining Department[310], showing the great variety throughout Europe in heading equipment, especially with regard to its cost and technical specification.

Another feature which has to be reconciled is the fact that, almost entirely in the countries within the survey, non-mechanised supports are a revenue rather than a capital item, and therefore excluded from the capital stock.

All financial details relating to prices and exchange rates have to be reduced to a 1960 base. In discussing plant and equipment, there is the added feature of technological progress, which in the past has been neglected. Therefore, technology is kept constant as at 1960, and variations in technology will be shown separately in the analysis.

With these assumptions, the mechanised longwall capital stock is built up, based on 1960, for each country. These are derived through personal visits and correspondence with equipment manufacturers and mining authorities in the various countries involved, supplemented by conference data, such as that from the National Coal Board[311]. Allowances must be made for the various features, over the period of the survey, affecting the stock and its mix, such as :-

(a) - the mechanised support percentage, including the mix of powered and shield supports;

(b) - the face lengths of mechanised supports;

(c) - the number of machines per face;

(d) - the back-up factor of equipment, i.e. in store, or being maintained, for mechanised longwall face usage; and

(e) - the mix within power loaders, such as the growth in shearers vis-à-vis ploughs in West Germany.

Thus, the capital stock in longwall face mechanisation (CS_m) is calculated for a year, as follows :-

$$CS_m = \left[\left\{ \bar{n}_m \cdot \bar{f} \right\} + \left\{ \bar{n}_{sup} \cdot \bar{l}_{sup} \cdot \bar{u} \right\} + j \right]$$

where : $\bar{n}_m$ = average number of mechanised longwall faces per working day during the year

$\bar{f}$ = average capital cost of equipment per mechanised longwall face, excluding mechanised supports, during the year

$\bar{n}_{sup}$ = average number of mechanised supported mechanised longwall faces per working day during the year

$\bar{l}_{sup}$ = average length of mechanised supported mechanised longwall faces during the year

$\bar{u}$ = average cost per unit length of mechanised supported mechanised longwall face during the year

j = back-up factor of mechanisation and mechanised supports during the year

All cost figures are expressed in U.S. dollars, based on 1960 prices, exchange rates and technological specification

Specification enhancement is paying over and above inflation for the technological improvement of equipment, and can be based on welfare, such as increased safety, increased production, or both. This could be illustrated by an example in the United Kingdom :-

An average face, in 1977, of 179 metres long with powered supports every 1.1 metres, has 162 supports, each costing £3,000; thus, the total cost of powered supports would be £486,000. The capital cost of the conventional face is therefore made up as follows :-

	£
Powered supports	486,000
Two power loaders	140,000
Stage loader and face end equipment with transformer	50,000
Armoured face conveyor	75,000
	£751,000

In 1960, a similar face is estimated to have cost £130,000 and, with inflation for mining plant and equipment, would in 1977 be £424,000. The missing £327,000 is due to specification enhancement over the years, at an annual rate of 6.2% compound. This is very close to the figure of 6% quoted by Dr. P.D. Binns, the National Coal

Board's Plant Controller, in private conversation.

Thus, in discussing capital cost of plant and equipment, consideration must be made for the important factor of specification enhancement. In building up the capital stock of mechanised longwall face equipment, technological specifications have been held constant at 1960 (or estimated as at that date) to allow for the enhancement factor to be analysed.

3.6.3. MECHANISED LONGWALL FACE MANPOWER INPUT (MI_m)

Although the Economic Commission for Europe[312] have produced an analysis of the number and types of shifts per 100 tons of coal produced underground, these highlighted many differences in approach and were not exclusively for longwall faces. Definitions of "what is a face worker?" have always been rather blurred. However, it is essential to have details of longwall mechanised face manpower for analytical purposes, especially in relation to the capital stock for those faces.

A standardised definition of "face worker" is thus necessary. It excludes under-officials, since this is the practice of most countries involved. On the Continent, men setting up the face equipment are counted as face workers; it is felt that the British practice of excluding these should be adopted, and including only men working on face production. Another interesting feature clouding the data, even within the United Kingdom, deals with the treatment of advancing and retreating faces. With advance faces, face workers are counted whether they are working on the face or in the heading, and development men are those involved in the main roads. With retreat faces, only those working directly on the face are counted as face workers, and those working in main roadways and headings are counted as development workers. This explains in many instances, apart from the fact that retreat faces are often better and newer, why output per manshift at the face for retreat work is higher, as only 15 to 20 men are counted on the face instead of, say, 30 with the advance face.

Thus, only men working on production in the face area itself are counted in the analysis. This seems logical as the capital stock of mechanised equipment is being measured similarly. As information published on face workers is either unclear or non-existent, figures for man-years worked on mechanised longwall faces during the year must be verified or derived as follows :-

$$MY_m = \frac{MS_m}{McS} \cdot dn_m \cdot \frac{McS}{dn_m} \cdot \frac{1}{MS_m/MY_m}$$

where : MY_m = man-years worked on mechanised longwall faces, during the year

$\frac{MS_m}{McS}$ = average manshifts on mechanised longwall faces per machine shift, giving the average number of men at anyone time, working at a mechanised longwall face

dn_m = number of mechanised longwall face-days worked, during the year

$\frac{McS}{dn_m}$ = average number of machine shifts per mechanised longwall face-day worked, during the year

MS_m/MY_m = average mechanised longwall face manshifts per man-year during the year

Therefore, the manpower input at the mechanised longwall faces can be calculated :-

$$MI_m = MY_m \text{ (current)} \cdot \left\{ \frac{MI_m}{MY_m} \right\}_{1960}$$

where : MI_m = mechanised longwall face manpower input, during the year

MY_m (current) = man-years worked on mechanised longwall faces, during the year

$\frac{MI_m}{MY_m}_{1960}$ = average manpower input per man-year at mechanised longwall faces, in 1960

The resultant figure is expressed in U.S. dollars, based on 1960 prices and exchange rates.

3.6.4. CAPACITY OF MECHANISED LONGWALL FACE SYSTEM IN MARKET TONNAGE (CAP_m)

As with reserves or resources, capacity might mean all things to all men. However, it is essential to the analysis of productive performance, and hence to the total productivity model, to have a well-defined measure of capacity.

Various measures of capacity were investigated and tried. For example, the United States Department of Labor[204] monitored capacity based on days worked, using 280 days as full capacity, which really ducked the issue as it was just a measure against standard days.

A way which was considered and attempted was to look at the bull or best week's production in a year, and to gross it up by the total weeks worked. The results were most revealing though not in the context of what was required, a measure of attainable capacity. It was found that, from 1946 to 1976, capacity, built up this way, showed the British mining industry to be working on average at an 85% level, excluding strike years. On further investigation, it was discovered that mines were working at a fairly strict norm.

Another method which was investigated, at least for the United Kingdom, was to measure capacity on the utilisation of electric motors within the industry, that is to compare installed horsepower with the actual kilowatt-hours used. By converting the horsepower into potential kilowatt-hours over a standard time period, an actual over potential could be developed. Here again, the results were not considered a practical measure of capacity.

It is, therefore, apparent that capacity should be based upon the mechanised longwall faces themselves as, for analytical purposes, it is matched up with the mechanised capital stock and manpower inputs to those faces. It is freely admitted that, by concentrating on aggregated face capacities, one is really only focusing on the basic mechanised capacity of each industry. Thus, assumption is made that the skill of men, shaft capacity, washery intake, haulages, etc. are sufficient. Therefore, if one concentrates on the capacity of mechanised longwall faces, then, as supported by Davies[313], it would have four basic ingredients :-

(a) - the area of the seam exposed;

(b) - the dirt and density of the seam;

(c) - the time available for mining the seam; and

(d) - the effectiveness of technology and organisation, monitored in mechanised longwall face advance per unit time

These are reflected in Equation III, and it can be seen that the relationships between the four are multiplicative. Thus,

$$\text{Capacity} \propto \text{area exposed} \times \text{dirt and density} \times \text{time worked} \times \text{effectiveness}$$

In any reasonable time span for planning, the area, dirt and density factors are fixed, making capacity proportional to the time worked and the effectiveness of technology and organisation.

It was decided, after experimentation, to base mechanised longwall face capacity on Equation V as it is related to mechanised working. On that basis, capacity of mechanised longwall faces (CAP_m) is the obtainable output per annum.

Thus,

$$CAP_m = Z . G . H . Q$$

where : Z = obtainable $\{dn_m\}$ number of mechanised longwall face-days worked during the year

G = obtainable $\left\{\frac{MAT}{McS}\right\}$ average machine available time in minutes per machine shift at mechanised longwall faces during the year

H = obtainable $\left\{\frac{O_m}{MAT}\right\}$ average mechanised longwall output per minute of machine available time during the year

Q = obtainable $\left\{\frac{McS}{dn_m}\right\}$ average number of machine shifts per mechanised longwall face-day worked during the year

There is some criticism of relating output to machine available time (MAT) in that more output could be produced from thicker coal seams worked over the same time period. However, this becomes insignificant when analysing a whole industry sample, but obviously figures should not be taken in isolation and must be related to the seam thickness.

An important point to remember with capacity, no matter how well defined the parameters are, is that the final assessment must be subjective. Capacity could be based upon ideal standards. It can also be based on obtainable standards, allowing for normal hazards. The latter is used in this survey, in consultation with the various authorities within each country, in order to obtain a capacity that would be realistic in its achievement.

Data is once again based on 1960. Every effort is made to make it comparable through time, by adjusting for known changes in definitions and by ensuring that the statistics are, as far as possible, on a comparable definitional basis between the seven countries.

3.7. Total Productivity Components

The total productivity model is built up of nine component ratios, reflecting what are considered to be the most important aspects of the longwall hard coal mining industry. These are selected for their relevance to management and for highlighting the most important factors relating to total productivity. Obviously, many others could be introduced into the model. After the most careful consideration and experimentation, the final model is produced to show, with inflation, exchange rates and technology held constant (to be analysed separately), the trends in these components and their effects on determining total productivity.

Safety is most reluctantly left behind for two major reasons. Firstly, the model is basically of a physical/economic nature and it is considered that safety, although vital, is more appropriately dealt with as a separate discussion; as Collinson[314] showed, it comes more within the area of risk analysis. Secondly, international statistics on safety, especially outside the

European Economic Community, are ill-defined and weak in detail.

These components are divided into three specific areas : manpower ratios; longwall mechanisation ratios; and energy ratios.

3.7.1. MANPOWER RATIOS

$\left\{\frac{O}{MY_u}\right\}$ <u>Output per man-year for underground longwall workers</u>

This ratio best reflects underground labour productivity related to man-years, as it is the most reliable figure achieved in European labour statistics.

$\left\{\frac{CS_m}{MI_m}\right\}$ <u>Capital stock in longwall face mechanisation to mechanised longwall face manpower input</u>

This ratio reflects the input of manpower working directly at the mechanised longwall faces, with the capital machinery and equipment at and held for those faces, at 1960 prices, exchange rates and technology, and expressed in U.S. dollars. In this way, the trends and effects of the proportion of manpower input to capital stock can be analysed.

$\left\{\frac{MI_m}{MI}\right\}$ <u>Mechanised longwall face manpower input to total manpower input</u>

This monitors the trends in manpower input at mechanised longwall faces, compared with the total production manpower input of the whole longwall mining industry. Both inputs are at 1960 prices and exchange rates, expressed in U.S. dollars.

$\left\{\frac{MI}{TI}\right\}$ <u>Manpower input as a proportion of total input</u>

The important proportion of labour to total input is mirrored by this ratio, holding prices and exchange rates constant at 1960, expressed in U.S. dollars.

3.7.2. LONGWALL MECHANISATION RATIOS

$\left\{\frac{O_m}{CAP_m}\right\}$ <u>Mechanised longwall face capacity utilisation</u>

This monitors the longwall mechanised output in relation to the capacity that could reasonably be expected to be achieved from the faces.

$\left\{\frac{CAP_m}{CS_m}\right\}$ <u>Mechanised longwall face capital stock efficiency</u>

This ratio matches up the capacity of the mechanised longwall faces with a capital stock of the equipment, directly used or being held for those faces. Thus, it is a measure of the efficiency of that capital stock with prices, exchange rates and technology held constant at 1960, expressed in U.S. dollars.

$\left\{\frac{O}{O_m}\right\}$ <u>Mechanised longwall output factor</u>

This is a simple measure of the total longwall output in relation to the mechanised longwall output.

3.7.3. ENERGY RATIOS

The concluding two ratios balance the model. The use of electrical energy underground, though not forming a major economic element, reflects the trends in the man/machine relationship.

$\left\{\frac{MY_u}{kWh_u}\right\}$ <u>Man-years underground to underground electrical energy, for longwall output</u>

This relates manpower to electrical energy, both working underground in longwall mining. It shows the physical relationship between man and machine.

$\left\{\frac{kWh_u}{O}\right\}$ <u>Electrical energy underground per ton</u>

This mirrors the input of underground electrical energy in physical terms per ton of all longwall output.

3.7.4. TOTAL PRODUCTIVITY

The combination of the nine component ratios results in the total productivity measure.

$\left\{\frac{O}{TI}\right\}$ Total productivity measure

This is the relationship between the output of longwall hard coal and the total productive inputs, expressed in U.S. dollars and held at 1960 prices and exchange rates.

3.8. The Quality of Output

So far, discussion has been made purely in output, measured in physical tons as accepted by the market. However, there are variations within hard coal itself, such as in calorific value, ash and moisture content. Sir Derek Ezra once made the comment that the National Coal Board was producing plenty of coal but the wrong type of coal. It is extremely difficult to quantify in any meaningful way the quality of coal produced. However, whilst still regarding tonnage as the present ultimate measurement, a further element should be added to give some indication of the quality of output.

The first and seemingly the most logical approach is to look at the calorific value of the output, the best measure being net calorific values after excluding the latent heat resulting from the vaporisation of the moisture content of the coal. Obviously, calorific value is not the only determinant in the quality of coal, though a major one; for instance, coking coal, which is a chemical feedstock, cannot be properly graded on calorific value.

After much consultation and with the help of Leonard Williams, Director General for Energy at the Commission of the European Communities, outputs are converted into the hard coal equivalent as used in the Community's coal statistics. The foundation for this is fully described in Energy Statistics[315], but is basically the conversion of any lower grade coal into hard coal equivalent, utilising the following expression :-

$$f = 1.39 - 0.0208\,(A + 0.88\,W)$$

where : f = conversion factor (fraction of a ton of standard hard coal)

A = ash content percentage

W = moisture content percentage

What this really means in practice is that all tonnages with an inert content between 20 to 67-76%, depending on the relative contents of ash and moisture, are converted to the standard hard coal, using a ready reckoner based on the expression. Those with an inert content of less than 20% are included ton for ton. Coal with inert contents in excess of the upper limits are considered to have no calorific value whatsoever and are not taken into account.

This expression was derived from research in West German power stations and, although it is used now throughout the Community, it has been adopted, in this study, for all the seven countries. It does, however, have the weakness that it is only based on the evidence from one country alone. This measure is probably the best available reflection of coal quality, though it still ducks the issue of the coking coal chemical feedstock.

3.9. Inter-Country Comparison

Applying the total productivity model, with all its elements, components and equations, trends are shown, over the period 1960 to 1976, for each country and between each country. The major effort is considered to be the trends within countries, supported by international comparisons, for, even though the definitions within the model have been as stringent as any yet attempted, inter-country comparisons must be guarded.

3.10. Application of the Model to the Individual Mine

Many collieries were initially investigated in the seven countries. Those adopted are those exclusively using longwall methods, fully mechanised, and substantially mechanised supported. Several mines were rejected as they were not longwall, and, in one case, not underground. Obviously, only a small sample of mines throughout the countries could be chosen. For comparative purposes, it is those that were considered to be amongst the most productive by their own industry in 1972. At least, in this way, one is making comparisons within a related sample.

Twenty-two mines are studied, many of which were personally visited, and all involved considerable correspondence for clarification of data. As much of the information is of a confidential nature, the actual names of the mines are not revealed, only their national identities. The sample comprises :-

Belgium	two mines
Czechoslovakia	three mines
France	two mines
Poland	three mines
Ukraine	four mines
United Kingdom	five mines
West Germany	three mines

The response of individual mines in submitting data was most encouraging. However, because of the difficulty in obtaining reliable earlier statistics, and because, for the analysis, all mines should be fully mechanised, the period 1972 to 1976 is taken. This obviously restricts some discussion on trends, but the comprehensive information obtained over the period more than compensates for this. The approach used at the national level is applied also to the twenty-two mines, with the total productivity model, all its elements, components and equations. Data is still based on 1960, though the analysis covers the period 1972/76, in order to allow for a fair comparison with the national figures.

One might ask : Why go to the bother and the headache of investigating individual mines after the relative success at the national level? There are several reasons in the cause of methodology and later analysis :-

(a) - To demonstrate the model at the level of the mine. Firstly, to show that it could work, and, secondly, to illustrate its possible practical usage for colliery management.

(b) - To analyse the differences, if any, between the mines and their national averages.

(c) - To show any assumptions and alterations to the model that might be needed for operation and analysis at the level of the mine.

(d) - To focus on a small sample at the mine level, where, throughout the period of investigation, there was full mechanisation.

It is found that the methodology needs few alterations at the level of the mine. More statistical care is required, especially in weighting averages, as each mine is a smaller sample of faces. The tonnage is not converted into hard coal equivalents for two reasons : firstly, the lack in certain areas of sufficient data; and, secondly, in many instances, the output of the mine is blended with that of other mines, thus not facilitating a meaningful analysis. Also, in some ~~industries~~ countries, collieries do not actually own certain equipment but hire it from a plant pool; for comparative purposes, figures are adjusted, where appropriate, to reflect the situation as if the mine actually owns the equipment.

3.11. Methodology - Conclusions

It should be appreciated that, in utilising a total productivity model covering the period 1960/76 for seven countries at the national level, and a period 1972/76 for twenty-two individual mines, it is impossible to record every detail required. This section shows the methodology utilised that has been evolved by taking the best from general models, and painstakingly applying them to the longwall coal mining industry of Europe.

No model or methodology is perfect, but it is considered that the methods used, based on the assumptions and estimations shown, can give a realistic analysis of the data obtained from the very many sources across Europe, East and West.

SECTION 4

The Analysis

"Count what is countable
Measure what is measurable
And what is not measurable
Make measurable"

Galilei GALILEO

Based on the equations and the total productivity model, each of the seven countries is analysed individually, for the period 1960 to 1976, to illustrate the various trends and factors affecting those trends. Throughout, the predicted annual outputs and daily outputs per face are within an accuracy of ±4% to actual. The total productivity model, being a self-checking device, has an accuracy of within ±.5%. A comparative study is then made between the countries' elements and components, as well as other factors affecting their total productivity.

Twenty-two individual mines are analysed similarly for the period 1972 to 1976. Comparison is also made with the national average of their own country.

All figures for the seven countries pertain to calendar years. However, the exception lies with the United Kingdom which involves a change as from April 1964 when the British figures relate to the fiscal year, e.g. April 1968 to March 1969, referred to, in this research, as 1968. For the change-over period of fifteen months, January 1963 to March 1964, figures are adjusted for comparative purposes.

4.1. United Kingdom

A policy of rationalisation and concentration was carried out during the period. The number of producing collieries was 698 in 1960, reduced to 238 by March 1977. The closed mines were considered uneconomic at the time. Thus, there was a rapid reduction in the size of the industry and the sterilisation of otherwise workable reserves.

Longwall output, as a proportion of total hard coal output, rose from 93.2% to 98.0%. Production from mechanised faces, as a percentage of total production from all longwall faces, rose from 45.0% to 98.6%. Production from faces with mechanised supports, as a percentage of total production from longwall faces, also rose from 7% to 97%. Thus, it can be seen that the United Kingdom's hard coal mining industry was predominantly longwall throughout the period, and, in the field of mechanised output and mechanised supports, it was always amongst the highest in percentage of mechanisation in Europe, East and West.

Appendix IIIa shows that the United Kingdom's annual longwall production fell from 174 to 106 million tons, a drop of 39.1%. This was because there was a reduction in the number of faces due to concentration and rationalisation from 3603 to 785, a drop of 78.2%. Weighted average seam thickness extracted was 1.42 metres in 1976, an increase of 16.4% on 1960, whilst the average face length was 176 metres, an increase of 28.5% on 1960. Thus, there has been a growth of 49.5% in the area being worked on the average longwall face. There was a slight reduction of 5% in the days worked per longwall face during the year, reaching 230 in 1976. Due primarily to increased mechanisation and concentration, average daily advance per face increased by 92%, reaching 1.92 metres

metres in 1976; however, it did peak at 2.04 metres in 1972, and tended to drop slowly since. Mainly due to the increased average area worked and the far larger increase in daily advance per face, daily output per face rose from 193 to 582 tons, an increase of 201.5%.

Appendix IIIb demonstrates that although daily output per face rose by 201.5%, output per man-year underground increased by only 47.8% - rising from 431 in 1960 to 637 tons in 1976. Even allowing for the strike years of 1971 and 1973, underground labour productivity declined since 1972, when it reached 698 tons. Manshifts per man-year underground actually decreased by 10.4% from 220 to 197; in effect, the average miner spent less time at work. Offsetting this, there has been a rise of 82.7% in the manshifts worked underground per face-day, indicating the increased intensity of work per face, and reaching 180 in 1976. This was primarily due to the reduction of 63.1% in the number of manshifts worked, 78.2% in the number of longwall faces worked, and, only minimally, 5.0% in the number of days worked per face.

The United Kingdom has one of the highest proportions of mechanised output to total longwall production in Europe. Appendix IIIc shows that the mechanised longwall hard coal output rose from 78.3 in 1960 to 104.5 million tons in 1976, a rise of 33.5%. It did, however, reach a peak of 145 million tons in the period 1965/67. During the period 1960 to 1976, there was a reduction of 24.7% in the number of mechanised longwall faces, from 973 to

733, reaching a peak of 1415 in 1964. There has been a rise of 53.5% in the daily advance per mechanised face, from 1.27 in 1960 to 1.95 metres in 1976, reaching a peak of 2.15 metres in 1969 and showing a steady decline since. The mechanised face area worked had increased; weighted average seam thickness extracted had risen steadily by 11.7% reaching 1.43 metres in 1976; and, there has been a 6% increase in the average face length, reaching 178 metres in 1976, actually being greater in the period 1964/66; thus, the average mechanised face area worked rose by 18.4%. Mainly due to the increased area worked and increased daily advance per face, daily output per face rose from 322 in 1960 to 599 tons in 1976, a rise of 86%; however, daily output per face had been at a plateau since 1969, with the exception of the post-strike year of 1974.

The performance of mechanised longwall faces can be further analysed (Appendix IIId). Machine available time per machine shift dropped by 10.9%, reaching 320 minutes in both 1975 and 1976. This reduction in machine available time has been fairly steady and was due to various factors. Faces have been getting further away from the shaft, and, although there has been a considerable investment in man-riding equipment, travelling time has increased; it is fair to say that it would have increased far more without this. Also, there have been changes in shift and break times.

Although machine shifts per mechanised face-day have increased from 1.5 to 2.0 in 1976, they actually peaked at 2.2 in 1968/69. Thus, between 1960 and 1968, there was an increase in daily machine available time of 39.7%, which has fallen to 18.9% in 1976. An important feature was the fact that mechanised output per machine available time has steadily risen from .617 tons per minute in 1960 to .968 in 1976, an increase of 56.9%. In fact, advance per minute of machine available time rose from .236 centimetres in 1960 to .305 in 1976, a rise of 29.2%. The heavy investment in face equipment has had an influence on the output and advance per machine available time. The reason for the larger increase of output compared with advance per machine available time was mainly due to the increase in the average area worked, as well as a slight increase in the vend/density of the extraction.

Appendix IIIe illustrates the total input per ton, measured in US dollars at 1960 prices and exchange rate. There has been a 17.6% increase from 11.74 to 13.81 US dollars per ton. The percentage manpower input to total input has dropped from 60.4% to 36.3%, and reflected that far fewer men were employed. Capital input has been relatively stable between 7.1% and 9.5%, whilst supplies/overheads, including energy, rose from 32.4% in 1960 to 54.6% in 1976.

All these background factors culminate in the total productivity model (Appendix IIIf), supported by the information in the nine elements (Appendix X), to cover the period 1960 to 1976.

Output per man-year underground (O/MY_u) increased by 47.8% from 431 to 637 tons. This was achieved by the fact that longwall output (O) dropped by 39.1% whilst man-years underground (MY_u) dropped even further by 58.8%.

Capital stock mechanised to manpower input at longwall mechanised faces (CS_m/MI_m) increased by 129.4%, reflecting the emphasis on capital vis-à-vis manpower for mechanised faces. CS_m actually rose by 146.5%, reaching 475 million dollars in 1976, whilst MI_m rose only 7.5% because of the reduction in mechanised faces. However, the percentage of MI_m to total manpower input (MI) increased by 149.9% because MI_m increased by 7.5% whilst MI dropped by 56.9%. MI_m/MI reached a peak in 1967 and steadily decreased with the number of mechanised faces. The proportion of manpower input to total input (MI/TI) dropped from .604 to .363 by 39.9%. This was due to the fact that MI decreased by 56.9% and TI by only 28.3%.

The utilisation of mechanised capacity (O_m/CAP_m) has shown a slight but steady increase, except for the strike years of 1971 and 1973, from 60.3% in 1960 reaching 62.1% in 1976. Mechanised longwall face capital stock efficiency (CAP_m/CS_m) actually dropped by 47.5%; this was because CAP_m increased by 29.5% and CS_m by 146.5%. CAP_m/CS_m reached a peak in 1963, before the large increase in mechanised capital stock. Mechanised longwall output factor (O/O_m) decreased steadily from 2.22 to 1.01, showing a reduction of 54.5%; this reflected that mechanised output rose from 45.0% to 98.6% of total longwall output.

In the field of electrical energy usage underground, man-years underground to underground electrical energy (MY_u/kWh_u) showed a steady decrease of 68.1% from 354 to 113 man-years per million kilowatt-hours (gigawatt-hours). Also, electrical energy underground per ton (kWh_u/O) showed a steady increase, from 6.56 to 13.89 kilowatt-hours per ton, a rise of 111.7% over the period. Both these energy components reflected the increased utilisation of machine power, replacing manpower.

The total productivity measure (O/TI) decreased by 15.0% from 85.18 to 72.41 kilogrammes per US dollar at 1960 prices and exchange rate. This was due to output dropping by 39.1% and total input by 28.3%. In fact, total productivity reached a peak in 1968 and steadily declined since. The main reason for this was that coal prices increased quite rapidly from 1970, thus facilitating an adverse effect on efficiency. Also, as mentioned by Siddall[175] on the importance of economies of scale, there has been a sharp decrease in total longwall output since 1968, especially in mechanised output.

Each component had its influence on the total productivity measure. However, there was a higher-order effect of +246.8%, being the combined effects of the components, and was mainly due to the large changes in CS_m/MI_m, MI_m/MI and kWh_u/O.

All economic values have been expressed in US dollars at 1960 prices and exchange rate. 1976 figures must be reconciled with those expressed in current prices and exchange rate for comparative purposes. The £, in the period 1960/76 (Appendix XI) stood worse against the dollar than any other currency considered, falling to 62% of its 1960 value.

The constant value figure of 475 million US dollars for CS_m in 1976 must be increased by 215% for inflation, plus 247% for technological enhancement, as well as allowing for the 62% value in exchange rate, giving a figure of 1655 million dollars (£954 million at the 1976 exchange rate). This was supported by Binns[316], who stated that, in 1976/77, the replacement cost of plant-pool equipment at current prices would be of the order of £1,000 million or more, incorporating certain other equipment not included in CS_m.

MI and MI_m were increased by the manpower inflation of 472% and, allowing for exchange rate, would be : MI from 531.4 to 1884.5 million dollars, and MI_m from 84.6 to 300.0 million dollars. TI should be raised by the weighted average inflation of 285.6%, allowing for exchange rate, from 1463.9 to 3500.0 million dollars.

The effects of inflation, technological enhancement and exchange rate can be clearly seen by their effect on the elements and components. If current figures were taken, from 1960 to 1976, CS_m, MI, MI_m and TI showed increases of 758.8%, 52.7%, 281.2% and 71.3% respectively. This compared with increases in CS_m of 146.5% and MI_m of 7.5%, and decreases in MI of 56.9% and TI of 28.3% at constant values. Therefore, the increases in CS_m/MI_m were almost unaltered. MI/TI, in 1976, was 53.8% in current values compared with 36.3% at constant values, whilst CAP_m/CS_m was .102 compared with .354 tons per US dollar, and O/TI would be 30.30 compared with 72.41 kilogrammes per US dollar.

The effects of the twin evils of inflation and exchange rate can thus be, in some instances, dramatic; however, they do cloud the underlying trends which are better expressed in constant figures.

4.2. West Germany

In many respects, the pattern of events in West Germany has not been dissimilar to that of the United Kingdom. In common with other Western European coal producing countries, the Federal Republic has greatly reduced its annual output of hard coal. In 1960, there were 146 producing collieries, reduced to 43 in 1976; however, the average daily output per mine has more than doubled to 8740 market tons. In the period 1960/76, the production of longwall workings, as a percentage of total production, remained almost constant at around 95%. Production from mechanised faces, as a percentage of total production from longwall faces, rose steadily from 39.5% to 98.4%. The production from faces with mechanised supports, as a percentage of total production from longwall faces, rose from 3.0% in 1960 to 85.8% in 1976.

As discussed earlier, West Germany expresses many of its figures in tvF or pure coal. These are converted to a market ton basis (Appendix IVg).

Appendix IVa shows that longwall output dropped by 35.3% at a fairly steady pace from 140.6 in 1960 to 91.0 million tons in 1976. As with the United Kingdom, the main influences were : An 81.9% reduction in the number of faces from 1660 to 300, coupled with a steady increase in daily advance per face of 125.2% reaching 2.68 metres in 1976. Combined with the increase in the daily advance per face was the fact that the weighted average seam thickness extracted increased by 34.6% to 1.83 metres, and the average face length increased by 32.7%, reaching the impressive length of 219 metres in 1976. Thus, the average area extracted increased by 78.6% during the period. Mainly due to the increases in average area worked and daily advance per face, the daily output per face rose from 322 to 1296 tons, a massive increase of 302.5%, though there was a 6.4% reduction in days worked, reaching 247 in 1976.

The large increase of daily output per face was accompanied by a 68.5% increase in output per man-year underground, rising from 479 to 807 tons reaching a peak of 839 in 1973 (Appendix IVb). Manshifts per man-year underground dropped by 14.2% from 226 to 194 in the period, reflecting the reduction in working days for the individual miner. Manshifts per face-day underground increased by 105.1% indicating the increased intensity of work per face and reached 311.5 in 1976, the major influences being the decreases of 67.2% in manshifts worked and 81.9% in the number of working faces.

Output from mechanised longwall faces (Appendix IVc) rose from 55.5 to 89.5 million tons, an increase of 61.3%, although reaching a peak of 105.9 million tons in 1965. There was a 25% reduction in the number of mechanised faces, reaching 285 in 1976, and again peaking in 1964/65. Daily advance per mechanised face increased steadily up to 1974 to 2.75 metres remaining constant to 1976, a rise of 68.7% on 1960. Daily output per mechanised face rose from 541 to 1340 tons, an increase of 147.7%; this was largely due to the increase in the average daily advance and also to the fact that the weighted average seam thickness extracted rose by 35.3% to 1.84 metres and the average face length by 7.8% to 221 metres, a 45.8% increase in the average area of extraction. However, the Germans, although achieving impressive figures, are extracting more dirt; this is reflected by the fact that the vend dropped from 71% to 63%.

Appendix IVd illustrates that machine available time per machine shift fell by 10.2% to 325 minutes, whilst machine shifts per face-day had increased by 17.4% to 2.7. Thus, daily machine available time rose by 5.4%. Output per machine available time has shown an impressive increase of 118.8%, reaching 1.455 tons a minute in 1976. This was mainly due to the steady increase in advance to .313 centimetres per minute, a rise of 59.7%, as well as that in average mechanised face area worked.

Appendix IVe illustrates the total input per ton in US dollars at 1960 prices and exchange rate, showing a 9.1% rise from 13.50 to 14.73 US dollars per ton. The manpower percentage dropped from 56.4% to 31.2%, reflecting the reduction in manpower. The capital input varied from 5.3% to 7.8%, whilst the supplies/overheads, including energy, increased from 38% to 62%.

All these background factors culminate in the total productivity model (Appendix IVf), supported by the information in the nine elements (Appendix X), to cover the period 1960 to 1976.

Output per man-year underground (O/MY_u) increased by 68.5%; this was due to the fact that output dropped by 35.3% but man-years dropped even further by 61.6%. CS_m/MI_m increased by 183.2% because CS_m rose by 176.4% but MI_m fell by 2.3%, the majority of the increase occurring in the recent seven years as face mechanisation, at the expense of manpower, got more capital intensive. MI dropped by 60.9% compared to the modest fall in MI_m; thus, the proportion of mechanised face manpower input to total manpower input (MI_m/MI) rose by 150.2% to 12.91%, reaching a peak in 1970 of 13.64% and slowly declining with the number of mechanised faces. The proportion of manpower input to total input (MI/TI) dropped from .564 to .312 due to MI dropping by 60.9% and TI by only 29.4%.

Mechanised capacity utilisation (O_m/CAP_m) was .662 in 1976, a rise of 9.1%, caused by the growth of 61.3% in O_m and 47.9% in CAP_m. The latter was again reflected in the fact that mechanised longwall face capital stock efficiency (CAP_m/CS_m) dropped by 46.5%, as CS_m rose by 176.4%, outstripping the capacity increase. CAP_m/CS_m was at a peak in 1963 but declined steadily since, with a heavy investment in face equipment. The mechanised longwall output factor (O/O_m) decreased by 59.7%, mirroring the fact that mechanised output itself rose from 39.5% to 98.4%.

Reviewing the utilisation of electrical energy underground, man-years underground to underground electrical energy (MY_u/kWh_u) decreased from 361 to 93 man-years per million kilowatt-hours (gigawatt-hours), a steady reduction of 74.2%. The 49.1% increase of total kilowatts utilised underground was also reflected in the fact that kilowatt-hours underground per ton (kWh_u/O) increased from 5.78 to 13.32, a rise of 130.4%. Both these components showed the intensity of use of electrical energy underground and the decline of human energy.

The total productivity measure (O/TI) dropped by 8.3%, from 74.07 to 67.89 kilogrammes per US dollar at 1960 prices and exchange rate, due to output (O) decreasing by 35.3% and TI by 29.4%. This measure peaked in 1970, just before the price of coal took a sharp rise, and also when mechanised output was at a relative peak allowing economies of scale.

The higher-order effect in the West German total productivity model was +324.6%. This was mainly due to the interaction of the three components with large percentage changes : CS_m/MI_m, MI_m/MI and kWh_u/O.

Reconciliation between the 1960 prices and exchange rate figures and the 1976 current figures was made for comparative purposes. In the period 1960/76, the Deutsch Mark increased its value vis-a-vis the dollar by 76.6% (Appendix XI). Taking the 1976 constant value for CS_m of 372.2 million dollars must be raised by 83.0% for inflation and 227.0% for technological enhancement; this, coupled with the rise due to exchange rate, gave a current value of 2695 million US dollars, a 2176.2% increase on 1960 at current values, compared with an increase of 176.4% at constant values. Similarly, MI and MI_m must be raised by 298.2% for manpower inflation, plus the exchange rate, giving respectively 2941.0 and 379.7 million US dollars. The increase at current prices and exchange rate in MI is 174.7% and MI_m 586.6% since 1960. Similarly, the total input (TI) in 1976 at constant figures was 1340.4 million US dollars, allowing for the 76.6% increase in value due to exchange rate and 134% in weighted inflation. This gave a current figure of 5539 million US dollars, an increase of 191.8% on 1960.

Taking current values and exchange rate, CS_m/MI_m in 1976 was 7.10, a 231.8% increase on 1960, compared with 183.2% with constant values. MI/TI in 1976 was 53.1% compared with 31.2% at constant values. CAP_m/CS_m in 1976 was .050 tons per US dollar compared with .413 at constant values, reflecting the large increase in CS_m.

The total productivity measure (O/TI) was 16.43 kilogrammes per dollar in current values in 1976, compared with 67.89 at constant values, illustrating the effect and the distortion caused by inflation and exchange rate.

4.3. France

In recent years, the French hard coal industry has been seriously run down. There was a drastic reduction in production, resulting from more than halving the output from the Northern coalfields, and from the closing of many small mines in the lesser coalfields throughout the country.

Longwall mining has been by no means the dominant method of working. Production from longwall workings as a percentage of total production was 71.0% in 1960 dropping to 64.3% in 1976. Production from mechanised faces, as a percentage of total production from longwall faces, rose from 44.9% to 87.8%. Thus, France began to mechanise relatively early, but never achieved the heights of some of her contemporaries. Production from faces with mechanised supports, as a percentage of total production from longwall faces, rose from 2.0% in 1960 to 62.4% in 1976.

Appendix Va shows longwall hard coal output dropped by 66.6% from 39.2 to 13.1 million tons. There has been a 16.1% decrease to 235 days worked with a consistent and steady drop of 85.0% in the number of faces, down to 105 in 1976. Daily advance per face has increased from 1.19 to 1.90 metres, an increase of 59.7%, although it did reach a peak of 1.96 metres in 1970/71. Daily output per face increased from 189 to 493 tons, an increase of 160.8%. This was partly due to the increase in daily advance per face, and also to the fact that the weighted average seam thickness extracted rose by 11.2% to 1.69 metres and the average face length by 51.0% from 96 to 145 metres; thus, the average area being mined per face rose by 67.9%.

Whilst daily output per face increased by 160.8%, Appendix Vb shows that output per man-year underground (O/MY_u) only increased by 27.0% reaching 537 tons in 1976, with a peak of 559 tons in 1970, and a low of 414 tons in 1963 due to a five-week strike. Manshifts per man-year underground dropped by 16.1% to 193 in 1976. Manshifts per face-day underground increased by 72.4% showing the increase in work intensity per face and reached 177.2 in 1976, due mainly to the decreases of 77.9% in manshifts worked, 85.0% in longwall faces worked, and 16.1% in days worked per face.

Appendix Vc illustrates that mechanised longwall output decreased from 17.6 to 11.5 million tons, a decrease of 34.7%, although it did reach a peak of 24.4 million tons in 1966 and declined since. The number of days worked dropped by 16.1% to 235 in 1976 and the number of mechanised faces dropped by 59.6% to 93. The daily advance per mechanised face rose by 32.9% to 1.90 metres in 1974 staying constant to 1976, although reaching a peak of 2.21 metres earlier in 1972. Daily output per mechanised face rose from 260 to 522 tons, an increase of 100.8% although it did reach 538 tons in 1972; this increase was partially due to the rise in daily advance per face, plus the fact that the weighted average seam thickness extracted increased by 19.1% to reach 1.62 metres in 1976, and the average face length rose by 23.4% in the same period reaching 153 metres, resulting in an increase in average mechanised face area being mined of 47.0%.

Appendix Vd shows that there has been an 11.4% decrease in machine available time per machine shift, reaching 303 minutes in 1976. Machine shifts per face-day increased from 2.0 in 1960 to 2.3 in 1976, although it had been higher between 1969 and 1973. Mechanised output per machine available time rose from .399 to .755 tons per minute, an increase of 89.2%. The advance per machine available time also rose by 30.0%, reaching .273 centimetres per minute in 1976, although it did reach a peak of .283 in 1971. The difference in the increase in advance per minute and output per minute was mainly due to the increase in the average face area being mined.

Appendix Ve shows that, at 1960 prices and exchange rate, the total input per ton increased from 14.90 to 18.02 US dollars, a rise of 20.9%. The manpower percentage input dropped from 58.4% to 45.8% reflecting the fall in manpower, although not as great as in other West European countries. Capital input dropped to 7.4% in 1976 after rising from 8.8% in 1960 to 9.9% in 1971; this reflected the lack of investment in the French mining industry in recent years. Supplies/overheads and energy increased from 32.8% to 46.8% indicating that, as many of them are fixed costs, they would rise per unit should output decrease.

All these background factors culminate in the total productivity model (Appendix Vf), supported by the information in the nine elements (Appendix X), to cover the period 1960 to 1976.

Output per man-year underground (O/MY_u) has increased by 27.0% reaching 537 tons. This was due to the fact that output (O) decreased by 66.6% and MY_u, even further, by 73.7%. CS_m/MI_m increased by 72.7% mainly in the more recent six years. However, both CS_m and MI_m dropped by 12.1% and 49.1% respectively. The overall increase of the component reflected the emphasis at the face, especially in later years, of capital vis-à-vis labour.

Mechanised longwall face manpower input to total manpower input (MI_m/MI) increased from 6.28% to 10.08%. However, it reached a peak of 12.15% in 1971, the decline from thence was due to the reduction in the number of mechanised faces.

Mechanised longwall face capacity utilisation (O_m/CAP_m) increased over the period fairly steadily, with an overall rise of 5.3% over 1960 reaching .592 in 1976. Mechanised longwall face capital stock efficiency (CAP_m/CS_m) decreased by 29.5% due to the fact that CAP_m fell by 38.0% and CS_m by 12.1%. Actually, CAP_m/CS_m reached a peak in the late sixties and declined since, due to the increase in CAP_m not matching that of CS_m. The mechanised longwall output factor (O/O_m) decreased by 48.9% mirroring the increase of mechanised output from 44.9% to 87.8%.

The energy ratios based on kilowatt-hours utilised underground showed that man-years underground to underground electrical energy (MY_u/kWh_u) decreased from 352 man-years per million kilowatt-hours (gigawatt-hours) in 1960 to 125 in 1976, a drop of 64.5%. Electrical energy underground per ton (kWh_u/O) increased by 121.8% from 6.71 to 14.88 kilowatts. Both these components revealed the increased intensity of mechanisation.

The total productivity measure (O/TI) dropped by 17.3% from 67.11 to 55.50 kilogrammes per US dollar at 1960 prices and exchange rate, due to the fact that output (O) dropped by 66.6% and TI by 59.6%, reaching a peak in 1965. The probable reasons for this were that, in 1965, France's mechanised and longwall outputs were also at their height underlying the economies of scale; and coal prices were relatively low and stable, encouraging higher efficiency. In the model, there was a higher-order effect of +140.1% due to the interaction of the various components, especially those with high percentage changes.

Reconciling the figures based on 1960 prices and exchange rate with those of their current counterparts demonstrated that the French Franc, during the period, dropped to 98.7% of its value with respect to the US dollar (Appendix XI). Thus, CS_m, which in 1976 was 55.9 million US dollars at constant values, must be inflated by an increase of 134.4%, plus 236.6% for technological enhancement and, allowing for the exchange rate difference, resulted in 259.9 million US dollars. Thus, in current terms, CS_m increased by 308.6% compared with a decrease of 12.1% at constant values. MI and MI_m need to be inflated by an increase of 337.2% to reflect manpower costs and, adjusted for the exchange rate, would be in current terms MI 466.5 million US dollars, an increase of 36.8% over 1960, and MI_m 47 million US dollars, an increase of 119.6%. Total input (TI), in constant terms of 236 million US dollars in 1976, must be increased by the weighted inflation of 216.9% and, allowing for the 98.7% exchange rate factor, reached 738.2 million US dollars, an increase of 26.4% over 1960 at current figures compared with a decrease of 59.6% at constant prices and exchange rate.

Using current figures in 1976, CS_m/MI_m was 5.53, an increase of 86.2% on 1960 compared with an increase of 72.7% in constant terms. CAP_m/CS_m gave a value of .075 tons per US dollar compared with .347 utilising constant figures, the reduction due to the large increase in CS_m. MI/TI was 63.2% compared with 58.4% in 1960. O/TI was 17.75 kilogrammes per US dollar compared with 55.50 in constant figures in 1976, a decrease of 73.5% on 1960.

4.4. Belgium

Similar to many other West European coal producing countries, Belgium was compelled, for what it considered economic reasons, to drastically reduce its coal production, possibly pruning it back too far. The Belgian hard coal mining industry has been almost exclusively longwall. Production from longwall working, as a percentage of total production, was 100% in 1960, falling slightly to 98% in 1976. In 1960, Belgium had 75 collieries which were reduced to 13 by 1976. Belgium started from a relatively high mechanised base. Production from mechanised faces, as a percentage of total production from longwall faces, was 47.3% in 1960 and had risen to 98.6% in 1976. Production from faces with mechanised supports, as a percentage of total production from longwall faces, rose from 1.5% in 1960 to 64.5% in 1976.

Longwall production fell from 22 million tons in 1960 by 68.2%, to the modest figure of 7 million tons in 1976. The major influences on this were the reduction in the number of faces from 460 to 48, a fall of 89.6%. With this concentration and increased mechanisation, daily advance per face rose by 50% to 1.65 metres in 1976, though this had been most rapid in the latter four years, from 1973 to 1976. Similarly, daily output per face rose from 181 to 585 tons, an increase of 223.2% with again the largest strides being made in the latter four years (Appendix VIa). The weighted average seam thickness increased by 25.2% to 1.59 metres and the average face length increased by 79.8% to 205 metres. Thus, the average face area being worked increased by a massive 125.1%. Therefore, the rise in the daily output per face was more greatly influenced by the increase in the average area worked than by that in daily advance per face.

Appendix VIb matches this large increase in daily output per face with a modest increase of 43% to 409 tons in 1976 in output per man-year underground; indeed, in the period 1973/76, there was a decline in underground labour productivity. Manshifts per man-year underground, which throughout the period were the lowest in Europe, fell by 10.5% to 170 in 1976, and strongly contributed to the low underground labour productivity measured in output per man-year. Manshifts underground per face-day has increased by 102.2% to 243.1, indicating the growth in work intensity per face, mainly due to the reductions of 80.1% in manshifts worked and 89.6% in faces worked and 6.8% in days worked per face.

Appendix VIc shows that longwall mechanised output fell by 33.6% from 10.4 million tons in 1960 to 6.9 in 1976, reaching a peak of 16 million tons in 1964. The number of mechanised faces fell by 63.5% from 126 to 46, although again reaching a peak of 182 in 1964. Daily advance per mechanised face increased steadily by 36% reaching 1.70 metres in 1976. Mechanised daily output per face rose from 320 in 1960 to 600 tons in 1976, an increase of 87.5%; this was partly attributable to the increase in daily advance per face, and was also caused by the 16.1% increase in weighted average seam thickness and the 23.8% increase in average face length, reaching 1.59 and 208 metres respectively in 1976. Thus, the average area being worked per mechanised face increased by 43.7%.

Mechanised output can be further analysed via Appendix VId, which shows that machine available time per machine shift dropped over the period by 11.1% to

321 minutes in 1976. Machine shifts per mechanised face-day rose from 1.8 to 2.2; thus, daily machine available time also rose by 8.7%. Mechanised output per machine available time increased by 79.4% from .481 to .863 tons per minute, with a 25.5% rise in advance per minute of machine available time to .241 centimetres. The difference in the increase in advance and output per minute was primarily due to the increase in the average mechanised face area being mined.

Appendix VIe illustrates the total input per ton at 1960 prices and exchange rate, rising from 16.04 in 1960 to 20.20 US dollars in 1976, a rise of 25.9%, mainly due to the decline of output. Supplies/overheads, containing a fixed cost dimension, increased from 41.1% to 62.3% of the total unit input. The manpower percentage dropped from 53.3% to 32.1% due to the decline in manpower employed. Capital input, throughout the period, was in the region of 6%.

All these background factors culminate in the total productivity model (Appendix VIf), supported by the information in the nine elements (Appendix X), to cover the period 1960 to 1976.

Output per man-year underground (O/MY_u) increased by 43.0% due to the fact that output (O) dropped by 68.2% and man-years underground (MY_u) by 77.8%. Capital stock in face mechanisation to manpower input at longwall mechanised faces (CS_m/MI_m) increased by 216.9% due mainly to the reduction in MI_m of 64.8%, resulting from the drop in the number of mechanised faces. This component reflected the increase in capital at the mechanised face at the expense of manpower. However, the percentage of mechanised longwall face manpower input to total manpower input (MI_m/MI) rose by 45.6%, reaching 11.23% in 1976. It had peaked to 15.51% in 1970, but fell away due to the reduction in the number of mechanised faces. The proportion of manpower input to total input (MI/TI) fell from 53.3% to 32.1% with the rapid drop in manpower.

Mechanised longwall face capacity utilisation (O_m/CAP_m) increased by a modest 2.5% over 1960 reaching .570 in 1976, taking into account that there was a vast cut-back and only few relatively favourable faces were being utilised. Mechanised longwall face capital stock efficiency (CAP_m/CS_m) dropped by 41.8%, mainly due to the reduction of 35.3% in CAP_m. The mechanised longwall output factor (O/O_m) decreased by 52.1%, reflecting the fact that mechanised output rose from 47.3% to 98.6% of total longwall production during the period.

Concerning the utilisation of electrical energy underground, man-years underground to underground electrical energy (MY_u/kWh_u) fell from 395 to 160 man-years per million kilowatt-hours (gigawatt-hours), a steady decline of 59.5%. Underground electrical energy per ton (kWh_u/O) conversely increased from 8.86 to 15.29 kilowatt-hours per ton, a rise of 72.6%. Both these components mirror the increase in underground mechanisation and the decline in manpower.

The total productivity measure (O/TI) fell by

20.6% from 62.34 to 49.50 kilogrammes per US dollar at 1960 prices and exchange rate, reaching a peak in 1965, during a period of relatively high output and stable coal prices. In the total productivity model, there was a higher-order effect of +208.0% due to the interaction of the various components especially those with high percentage changes.

From 1960 to 1976, the value of the Belgian Franc increased against the US dollar by 38.1% (Appendix XI). CS_m, which in 1976 at constant values was 40.1 million US dollars, must be increased by 79.3% for inflation and 235.5% for technological enhancement. This, coupled with the increase in exchange rate, resulted in the current value of 229.7 million US dollars in 1976, an increase of 538.1% over 1960. MI and MI_m, which in 1976 were at constant values of 45.4 and 5.1 million US dollars respectively, must be inflated by an increase of 439.1% to reflect manpower costs and of 38.1% for the exchange rate. This resulted in current figures of 338 million US dollars for MI and 38 for MI_m, with increased of 79.7% and 162.1% respectively on 1960. Total input (TI) must be raised from its constant value of 141.4 million US dollars by the weighted inflation increase of 191.2%, as well as by the exchange rate difference, to give a current value of 568.6 million US dollars, a 61.1% increase on 1960.

Thus, at current values, CS_m/MI_m in 1976 was 6.04, an increase of 143.5% over 1960, and MI/TI was 59.4% compared with 53.3% in 1960. CAP_m/CS_m was only .053 tons per US dollar at current values, a decline of 89.8% on

1960, due to the large increase in CS_m. O/TI was 12.31 kilogrammes per US dollar compared with 49.50 at constant values, down by 80.3% on 1960.

4.5. Poland

From an early stage after the war, Poland made it clear that it would concentrate its energy policy on coal production. Because of this, the higher oil prices affected Poland to a far lesser degree than many other countries, especially in the West, which had placed heavy emphasis on imported oil. The performance of the Polish hard coal mining industry has, since the war and specifically since 1960, been most impressive. When one considers that in all West European industries there has been a sharp decline in production, longwall output in Poland actually increased by 151.4% from 1960 to 1976. This was partly because production from longwall working, as a percentage of total production, rose from 60.0% to 87.5%; however, taking that into account, the overall rise in longwall production in Poland was still outstanding throughout Europe.

Actually, Poland started with relatively little mechanisation. Production from mechanised faces, as a percentage of total production from longwall faces, was only 28.2% in 1960 rising to 86.3% in 1976. Even though production from faces with mechanised supports, as a percentage of total production from longwall faces, rose from 2.0% to 49.6%, Poland has always lagged behind Western Europe in this sphere.

Appendix VIIa gives an analysis of the large increase of 151.4% of longwall output, steadily rising to 156.9 million tons in 1976. This was caused by the fact that, due to deliberate planning, the gradual drop in the number of longwall faces, of 22.9% from 850 in 1960 to 655 in 1976, was far less than that experienced in the West. Daily advance per face increased steadily from 1.24 to 1.80 metres, a rise of 45.2% with the introduction of mechanisation. Daily output per face rose at a fairly even pace from 245 to 794 tons in 1976, an impressive rise of 224.1%. Weighted average seam thickness increased from 1.69 to 2.24 metres, a lift of 32.5%, and average face length rose from 91 to 148 metres, a rise of 62.6%, though these lengths are shorter than those of Western Europe. Due to these factors, the average area being worked per face rose by 115.6% which, coupled with the increase in daily advance per face, mainly resulted in the rise of daily output per face.

It can be seen from Appendix VIIb that the increase in daily output per face was matched by a 67.1% increase in output per man-year underground, rising from 486 to 812 tons. This was accompanied by the fact that manshifts per man-year underground dropped by 5.5% to 259 in 1976, a small respite in the miners' attendance per year. However, throughout the period, manshifts per man-year worked in Poland were amongst the highest in Europe. Also, manshifts underground per face-day have risen steadily by 83.4% to 253.3, caused mainly by the 42.2% increase in manshifts worked and the 22.9% drop in faces being worked. Poland was the only country in the survey to show an increase in total manshifts worked over the period.

Poland's record on mechanised output was most impressive. However, it must be borne in mind that it started from a relatively low threshold. Appendix VIIc shows that longwall mechanised output rose steadily from 17.6 million tons in 1960 to 135.4 million tons in 1976, a massive rise of 669.3%. Unlike the West, there actually was an increase in mechanised longwall faces at a fairly steady pace from 180 to 518, a rise of 187.8%.

There was an increase in daily output per mechanised face of 164.6% from 325 to 860 tons. Daily advance per mechanised face rose from 1.23 metres in 1960 to 2.00 in 1975/76, a rise of 62.6%. The large increase in daily output per mechanised face was caused by that in the daily advance per mechanised face, plus the fact that the weighted average seam thickness rose by 29.4% from 1.70 to 2.20 metres and average face length rose by 32.2% from 118 to 156 metres. Thus, the average area worked per face rose, over the period, by 71.1%. In general, weighted average seam thickness was up and average face length was down on Western Europe.

Mechanised face performance can be further analysed via Appendix VIId. Machine available time per machine shift had fallen by 7.3% since 1960 to 315 minutes in 1976; however, there has been an increase in machine shifts per face-day rising to 2.7 in 1974/76. In this way, daily machine available time rose by 13.7%. There has been a consistent growth in mechanised output per machine available time from .422 to 1.011 tons per minute, a rise of 139.6%. There was also a 43.3% rise in advance per minute of machine available time from .164 to .235 centimetres. The difference in these percentage rises was primarily due to the the increase in the average mechanised face area worked.

Appendix VIIe shows that the total input per ton has increased from 11.55 to 13.79 US dollars at 1960 prices and exchange rate, a rise of 19.4%. The percentage proportion of manpower input declined from 44.2% to 28.7%. Although total manpower input increased by 95.0%, it was outstripped by the other inputs. The capital input dropped slightly from 9% to 8%; this reflected the increase in output and should not hide the fact that Poland invested quite heavily. Supplies/overheads showed a modest rise from 46.9% to 63.2%, due mainly to the increase in material supplies and maintenance.

The total productivity model (Appendix VIIf) summarises the situation, supported by the information in the nine elements (Appendix X), to cover the period 1960 to 1976.

Output per man-year underground (O/MY_u) rose by 67.1% to 812 tons in 1976; this was caused by the fact that output (O) rose by 151.4% and MY_u by 50.5%. CS_m/MI_m increased by 32.9% reaching 3.88 in 1976 caused by the large rises of 502.1% and 353.3% in CS_m and MI_m respectively. This did also show that, although Polish mechanised faces had become more capital intensive, they were still substantially labour intensive.

Mechanised longwall face manpower input to total manpower input (MI_m/MI) rose by 132% on 1960, although it did reach a relative plateau between 1968 and 1976 when it was 12.04%, mainly due to the fairly steady number of mechanised faces. Mechanised longwall face capacity utilisation (O_m/CAP_m) increased steadily by 11.1% over 1960 reaching .743 in 1975/76. There was a relatively small increase of 15% in mechanised longwall face capital stock efficiency (CAP_m/CS_m) reaching .628 per US dollar in 1976, though peaking at .802 in 1966 before the heavier investment in mechanised supports. The reason for this modest increase was due to the fact that CAP_m and CS_m kept pace with each other, which appeared to be deliberate planning. The mechanised longwall output factor (O/O_m) decreased by 67.7%, illustrating the fact that mechanised output rose from 28.2% to 86.3% during the period.

The two components reflecting electrical energy usage underground showed the effect of increased mechanisation. MY_u/kWh_u fell from 380 man-years per million kilowatt-hours (gigawatt-hours) in 1960 to 106 in 1976, a drop of 72.1%, whilst kWh_u/O rose from 5.42 to 11.62 kilowatt-hours per ton, an increase of 114.4%.

The total productivity measure (O/TI) fell by 16.2% from 86.58 to 72.52 kilogrammes per US dollar at 1960 prices and exchange rate, due to output (O) increasing by 151.4% and total input (TI) by 200.2%. However, it did reach a peak in 1969 and fell away slightly since. This was mainly caused by the increased coal prices encouraging relatively lower efficiency. The higher-order effect in the total productivity model, due to the interaction of the components, was +213.8%. This was caused mainly by MI_m/MI and kWh_u/O being the components with the highest percentage changes.

From 1960 to 1976, the value of the Zloty increased against the US dollar at the official exchange rate by 20.6% (Appendix XI). Although East European countries are most reluctant to talk of inflation, careful research can reveal meaningful figures. CS_m, which in 1976 was 290.2 million US dollars at 1960 prices and exchange rate, must be increased by 32% for inflation, plus 348% for technological enhancement; this, coupled with the increase in currency value, gave a figure of 1680 million US dollars in 1976 at current values, a 3385.5% increase on 1960 compared with a 302.1% increase at constant values. MI and MI_m, which were respectively 621.0 and 74.8 million US dollars in constant terms in 1976, must be inflated by an increase of 162.1% for manpower inflation, and, with the exchange rate difference, resulted in 1962.9 and 236.4 million US dollars at current values respectively; these showed increased of 516.3% and 1332.7% on 1960.

Total input (TI) must be raised by the weighted inflation increase at 90.3% and exchange rate difference in order to bring the 1976 constant value of 2163.6 up to 4966.0 million US dollars at current values, a rise of 589.0% on 1960. Using current values, CS_m/MI_m was 7.11 in

1976, an uplift of 143.5% on 1960, reflecting the increased costs and specification for face equipment. MI/TI was 39.5%, compared with 44.2% in 1960. CAP_m/CS_m was .109 tons per US dollar at current values in 1976, compared with .628 at constant values, reflecting the increase in prices and technological enhancement in CS_m. The total productivity measure (O/TI) was 31.59 kilogrammes per US dollar at current values, a fall of 63.5% on 1960, compared with 72.52 at constant values.

4.6. Czechoslovakia

Czechoslovakia shares the Silesian Coal Basin with Poland. Unfortunately, only 10% is within its boundaries, forming the Ostrava-Karvina coalfields which are geologically poorer than the rest of the Basin lying to the north in Poland. 90% of Czechoslovakia's hard coal resources are to be found in this region, and mainly because of this, the progress of the Czech hard coal mining industry has only been modest, compared with that of Poland.

Since 1960, longwall working has been the major form of production, declining to 88% in 1976. Production from mechanised faces, as a percentage of total production from longwall faces, rose from 34.1% to 89.6% during the period. Similarly, production from faces with mechanised supports, as a percentage of total production from longwall faces, rose from 2.0% to 51.7%, much lower than in Western Europe.

Appendix VIIIa shows that longwall production fell by 5.7%, marginally dropping from 26.4 to 24.9 million tons.

The major factors influencing this output trend was the decrease from 503 to 190 in the number of faces, a fall of 62.2%. Daily advance per face rose from 1.20 to 1.96 metres, an uplift of 63.3%. Substantially due to mechanisation, daily output per face rose from 195 to 476 tons, an increase of 144.1%. Weighted average seam thickness rose from 1.18 to 1.65 metres, an increase of 39.8%, whilst average face length also rose by 15.7% from 102 to 118 metres, far below West European lengths. There was, therefore, a 61.8% increase in average area worked per face, which, coupled with that in daily advance per face, was mainly responsible for the growth in the daily output per face.

Appendix VIIIb shows that the increase in daily output per face was matched by an increase in output per man-year underground of 65%, from 388 in 1960 to 640 tons in 1976. There was a slight decrease of 5.9% in manshifts per man-year worked underground, reaching 223 in 1973 to 1976. It should be noted that the individual miner in Czechoslovakia was expected to attend far less than in the Ukraine and Poland. Manshifts underground per face-day rose by 39.3% from 119.1 to 165.9, reflecting increased work intensity per face, mainly attributable to the reductions of 46.2% in manshifts worked and the 62.2% in the number of faces worked.

Mechanised output in Czechoslovakia (Appendix VIIIc) rose by 147.8% from 9.0 to 22.3 million tons, remaining fairly stable since 1965. There was a modest 15% increase in the number of mechanised faces from 133 in 1960 to 153 in 1976, although actually reaching a peak in 1964/65. Daily advance per mechanised face increased from 1.22 to 2.05 metres, a rise of 68%, remaining fairly stable during 1974/76. This plateauing effect also occurred in mechanised daily output per face, rising from 245 to 529 tons, an uplift of 115.9%. There was also a 35.5% rise in area worked per mechanised face, due to increases of 26.5% in the weighted average seam thickness to 1.72 metres, and 7.1% for the average face length to 120 metres; the latter reached a peak of 128 metres in 1970, still well below West European figures. The combination of the increases in average face area worked and daily advance per face was primarily responsible for the growth in mechanised daily output per face.

Mechanised output can be further analysed via Appendix VIIId. Machine available time per machine shift had steadily declined to 345 minutes in 1976, a 7.3% drop on 1960 still remaining the highest in Europe. However, there has been an increase in machine shifts per face-day from 2.0 to 2.5, resulting in an overall increase in daily machine available time of 15.9%. Mechanised output per machine available time has increased steadily from .338 to .645 tons per minute, a rise of 90.8%. Advance per machine available time rose by 45.1% from .164 to .238 centimetres per minute; the difference between the two increases was substantially caused by the growth in the average mechanised face area worked.

Appendix VIIIe illustrates that the total input per ton rose from 13.05 to 15.62 US dollars at 1960 prices and exchange rate, a growth of 19.7%. The manpower percentage input dropped from 45.0% to 28.1% due to the reduction in manpower. The percentage capital input also rose from 10.9% to 13.3%, reflecting increased capital expenditure related to a fairly constant output. The supplies/overheads percentage showed a modest increase from 44.1% to 58.6% of the total input, mainly due to the increase in materials supplied.

All these background factors culminate in the total productivity model (Appendix VIIIf), supported by the information in the nine elements (Appendix X), to cover the period 1960 to 1976.

Output per man-year underground (O/MY_u) rose by 65.0% caused by a drop in output (O) of 5.7% and in MY_u of 42.8%. Capital stock in longwall face mechanisation to mechanised longwall face manpower input (CS_m/MI_m) increased by only 23.1% to 4.05 in 1976, indicating that faces were still substantially labour intensive. This was caused by CS_m increasing by 100.9%, although it remained fairly stable since 1970, whilst MI_m increased by 62.3%, though falling since 1966, due to the reduction in the number of mechanised faces. This is also reflected in the fact that, although MI_m/MI rose from 6.83% in 1960 to 15.80% in 1976, it peaked at 1970 and thence declined.

Mechanised longwall face capacity utilisation (O_m/CAP_m) rose from 68.2% in 1960 to 73.8% in 1975/76.

The mechanised longwall face capital stock efficiency (CAP_m/CS_m) rose by 14.0% to .432 tons per US dollar in 1976, reaching a peak in 1968 before the heavier investment in mechanisation. The mechanised longwall output component (O/O_m) decreased by 61.8%, reflecting the increase in mechanised output from 34.1% to 89.6%.

With reference to electrical energy usage underground, MY_u/kWh_u fell by 69.3% from 414 to 127 man-years per million kilowatt-hours (gigawatt-hours), whilst kWh_u/O increased by 98.5% from 6.21 to 12.33 kilowatt-hours per ton, reflecting the increase in mechanisation to the relative decline in manpower.

The total productivity measure (O/TI) dropped by 16.4% from 76.63 to 64.03 kilogrammes per US dollar at 1960 prices and exchange rate, due to output (O) falling by 5.7% and total input (TI) rising by 12.9%. However, it reached a peak in 1969/70, coinciding with that of longwall output. In the total productivity model, the higher-order effect, caused by the interaction of the components, was +187.8%, mainly due to MI_m/MI and kWh_u/O, those with the highest percentage changes.

The Czechoslovakian Koruna appreciated by 25.3% against the US dollar in the period 1960/76 (Appendix XI). The 1976 constant figure of CS_m was 69.9 million US dollars. This must be lifted by 15% for inflation, plus 316% for technological enhancement, and, allowing for exchange rate, rising to 377.5 million US dollars at current values in 1976, an increase of 984.8% on 1960. MI and MI_m, which were at constant values of 109.2 and 17.2 million US dollars respectively in 1976, must be raised by the manpower inflation of 162.2% and the exchange rate, reaching 358.8 million US dollars for MI and 56.5 for MI_m, at current values in 1976. Total input, which was 388.9 million US dollars in 1976 at constant values, must be increased by 25.3% for the exchange rate, as well as by the weighted average inflation increase of 82.6%. This resulted in a 1976 figure of 890 million US dollars at current values, a rise of 158.3% on 1960.

Using the current values, CS_m/MI_m showed an increase of 103.1% on 1960, whilst the proportion of manpower input to total input (MI/TI) was 40.3% in 1976 compared with 45.0% in 1960. CAP_m/CS_m, affected considerably by the current values of capital stock, showed a current figure of .080 tons per US dollar in 1976 compared with .432 at constant values, a decrease of 78.9% on 1960. O/TI in 1976 was 27.98 kilogrammes per US dollar in current values, a 63.5% drop on 1960, compared with 64.03 at constant values in 1976.

4.7. Ukraine

On the Continent of Europe, the Ukraine is the largest producer of longwall hard coal, and has been a slight enigma with detailed information being sparse until recently. Actually, longwall working has always been dominant in the Ukraine, claiming 89% of total underground production in 1960, rising to 100% in 1970/76. The industry had become increasingly mechanised, with production from mechanised faces, as a percentage of total production from longwall faces, rising from 29.9% in 1960 to 98.8% in 1976, a figure higher than both its East European partners. As regards mechanised supports, production from faces with mechanised supports, as a percentage of total production from longwall faces, rose from 3% in 1960 to 40% in 1976.

Appendix IXa shows that there has been a 25.9% increase in longwall production in the Ukraine, rising steadily from 137.0 to 172.5 million tons, though remaining fairly constant since 1971. The main factors affecting this performance have been the drop in the number of faces from 2110 to 1438, a fall of 31.8%. Daily advance per face increased over the period from 1.30 to 1.48 metres, a modest rise of 13.8%. Daily output per face rose from 192 to 402 tons, an increase of 109.4%. There was also an increase of 75.2% in the average area worked per face; this was caused by the fact that there was an 18.9% increase in weighted average seam thickness to 1.13 metres, much thinner than that of any other country in this survey, and an increase in average face length from 110 to 162 metres, a rise of 47.3%. The increase in average area worked, coupled with that of daily advance per face, was substantially responsible for the increase in daily output per face. Also, although there has been a 4.7% drop in the average days worked per face to 305 in 1976, it was, throughout the period, the highest in Europe.

Appendix IXb illustrates that output per man-year underground rose by only 38.3% from 405 in 1960 to 560 tons in 1976, and has more or less stood still since 1973. This modest rise, compared with that of the daily output per face, was due to the fact that manshifts per man-year underground fell from 270 to 229, a decrease of 15.2% reflecting the reduction in individual labour toil. Manshifts underground per face-day increased by 28.4% to 164.4; this was mainly due to the reductions of 22.7% in manshifts worked, of 31.8% in faces worked, and of 4.7% in days worked per face.

Mechanised longwall output in the Ukraine (Appendix IXc) rose rapidly over the period from 41.0 in 1960 to 170.4 million tons in 1976, a rise of 315.6%, though remained relatively constant since 1971. The main factors affecting this has been the increase from 595 to 1352 mechanised faces, a rise of 127.2% although in fact the number of faces reached a peak in 1970 and gradually declined since. Daily advance per mechanised face rose by 13.8% to 1.48 metres in 1976, although it has been virtually constant since 1972. Daily output per mechanised face rose from 212 to 410 tons, an increase of 93.4%, with little increase in the period 1974/76. Also, there was a 64.8% increase in the area worked per mechanised face. This was due to increases of 18.0% in weighted average seam thickness to 1.18 metres and 39.7% in average face length to 162 metres. The increase in average area worked, coupled with that of daily advance per face, was mainly responsible for the increase in daily output per mechanised face.

Mechanised output can be further studied utilising Appendix IXd. There has been a 6.2% reduction in machine available time per machine shift reaching 319 minutes in 1976, as well as a slight increase in machine shifts per face-day to 2.7 during the 1970s. Mechanised output per minute of machine available time was fairly low, rising from .244 to .480 tons, a rise of 96.7%. The increase in advance per machine available time was a modest 17.0% from .147 to .172 centimetres a minute. The major influence on the increase in output per daily machine available time has been the growth in average area worked.

Total input per ton at 1960 prices and exchange rate (Appendix IXe) increased from 11.79 to 15.73 US dollars per ton, a rise of 33.4%. The manpower percentage of the input fell from 52.0% to 40.7%, reflecting that, despite investment, the industry is still relatively labour intensive. The capital percentage input rose slightly from 15.8% to 17.2% showing the increase in investment. Supplies/overheads modestly grew from 32.2% in 1960 to 42.1% in 1976, mainly due to increased material supplies.

The total productivity model (Appendix IXf) summarises the position, supported by the information in the nine elements (Appendix X), to cover the period 1960 to 1976.

Output per man-year underground (O/MY_u) rose by 38.3% due to output (O) rising by 25.9% and MY_u falling by 8.8%. CS_m/MI_m showed a relatively small increase of 20% reaching 3.06 in 1976; in later years, despite investment in mechanisation, the industry was still fairly labour intensive at the mechanised faces. This was further reflected in the fact that MI_m/MI had steadily increased to 19.2% in 1976, a rise of 159.8% on 1960. The proportion of manpower input to total input (MI/TI) dropped from .520 to .407, a fall of 21.7%.

Mechanised longwall face capital stock efficiency (CAP_m/CS_m) dropped by 9.1% during the period reaching .331 in 1976, although it did peak in 1967 and thence declined. This was mainly because CS_m slightly outstripped CAP_m, although, due to planning, they kept a fairly even pace. Mechanised longwall face capacity utilisation (O_m/CAP_m) increased from 71.3% in 1960 to reach 79.2% in 1976. Mechanised longwall output factor (O/O_m) decreased by 69.8% reflecting the increase in mechanised longwall output from 29.9% to 98.8% during the period.

The trends in electrical energy usage underground, measured in kilowatt-hours, reflected the increase in mechanisation. MY_u/kWh_u declined from 407 to 139 man-years per million kilowatt-hours (gigawatt-hours), a drop of 65.9%, whilst kWh_u/O increased by 111.4% from 6.06 to 12.81 kilowatt-hours per ton.

The total productivity measure (O/TI) fell by 25.1%, from 84.82 to 63.57 kilogrammes per US dollar at 1960 prices and exchange, during the period, steadily declining since 1960/61 and indicating the independence and the relative inefficiency of the industry. The higher-order effect of +199.2% of the total productivity model was due mainly to the interaction of those components with the largest percentage changes, such as MI_m/MI and kWh_u/O.

The Rouble appreciated against the US dollar, from 1960 to 1976, by 20.6% (Appendix XI). Taking the 1976 CS_m figure of 649.4 US dollars at constant values, this must be increased by 10% for inflation, plus 330% for technological enhancement, coupled with exchange rate increase, giving a figure of 3446 million US dollars in current figures, a 2079.6% rise on 1960. Similarly, MI and MI_m, which in 1976 at constant values were 1104.3 and 212.0 million US dollars respectively, must be increased by 95.9% for manpower inflation, and exchange rate increase of 20.6%, to give figures of 2609.0 and 500.9 million US dollars in current terms. The increases for MI and MI_m were 210.6% and 706.6% respectively on 1960.

The total input must be raised by the exchange rate factor, plus the weighted average inflation increase of 70.4%, raising the 1976 constant value of 2713.4 to 5576.1 million US dollars in current terms, a 245.2% increase on 1960. Taking current figures, CS_m/MI_m in 1976 was 6.88, a 169.8% increase on 1960, compared with 20% in constant terms. MI/TI in current terms was 46.8% compared with 52.0% in 1960. The large increase in CS_m reduced CAP_m/CS_m in 1976 from .331 tons per US dollar, in constant terms, to .062 in current terms, an 83.0% decrease on 1960. O/TI, in current terms in 1976, was 30.94 kilogrammes per US dollar, a decrease of 63.5% on 1960. This compared with 63.57 kilogrammes per US dollar in constant terms, a decrease of 25.1% on 1960.

4.8. Comparative Study

In 1732, Dr. Thomas Fuller wrote : "Nothing is good or bad but by comparison". However true it may be that no ratio or figure can be taken in complete isolation, international comparisons must be guarded, despite the fact that rigorous definitions and the best available information are used throughout this study. Within these constraints, certain comparisons can be made in the various trends, and factors affecting those trends, in European longwall hard coal mining during the period 1960 to 1976.

It should be pointed out that one is discussing two different leagues within the seven countries. The United Kingdom, West Germany, Poland and the Ukraine have been, throughout the period, substantial producers of longwall hard coal. France and Czechoslovakia have had outputs of a much smaller dimension, whilst Belgium in recent years has almost relegated into the oblivion into which Holland's coal industry went.

Comparison is made between the industries in Europe, each backed by the differing commitments of government and work force.

4.8.1. LONGWALL OUTPUT AND LABOUR PRODUCTIVITY

In Western Europe, especially in France and Belgium, there has been a considerable cut-back in longwall production, due to economic factors, accompanied by the reduction in the number of longwall faces worked. However, in the

East European trio, only Czechoslovakia, with comparatively smaller decreases in output and number of longwall faces, has revealed a similar pattern. Longwall output in the Ukraine rose by 25.9% and in Poland by 151.4%, mainly due to planned policy, though there were still modest reductions in the number of longwall faces.

With the mechanisation programme, mechanised longwall output rose in all countries, except in France and Belgium, though considerably higher in Eastern Europe. This is especially true of the Ukraine and Poland, with increases of 315.6% and 669.3% respectively. However, although the Eastern block countries did start in 1960 from a much lower mechanisation threshold, their improvement has been most impressive, specifically in Poland. During the period 1960 to 1976, the number of mechanised faces in the West European countries, although rising initially, actually declined, whilst the pattern differed in the East European countries. In Poland, there was a 187.8% increase in the number of mechanised faces, a 127.2% in the Ukraine, and a modest 15.0% in Czechoslovakia.

In every country, output per man-year underground increased (Appendix XIIa). In the West European countries, this was due to man-years underground falling greater than output. To a lesser degree, this also happened in Czechoslovakia. In the Ukraine, output increased whilst there was a slight decrease in man-year underground. Poland, however, was in the unique position that labour productivity increased due to the fact that both output and man-year underground rose, but the former at a greater pace.

In all countries, there has been a substantial rise in the daily output per face from all longwall faces, ranging from 109.4% in the Ukraine to the impressive 302.5% in West Germany (Appendix XIIIa). This has principally been a direct result of two factors : firstly, increased mechanisation, causing increase in daily advance per face; and, secondly, increased average face area worked which, in France, Belgium, Poland and Ukraine, had a greater influence than the rise in the daily advance per face. However, the vend and density of extraction had minimal effect on the increase in the daily output per face.

The increase in daily output per face was not met by a similar increase in output per man-year underground. This was due, in all countries, to the reduction in man-shifts per man-year underground of various degrees, reflecting a relaxation in the time commitment per man over the year (Appendix XIIIb). This reduction was greater than that in the average annual number of days worked per face, except for France, where it was equal. Total manshifts underground have fallen, except for Poland, and total face-days have declined even further, primarily due to the reduction in the number of longwall faces. Therefore, manshifts underground per face-day substantially rose illustrating the increased intensity of work per face (Appendix XIIIc).

4.8.2. MECHANISATION

All countries have invested heavily in longwall face mechanisation, with a greater emphasis on mechanised supports in Western Europe. In all cases, mechanised daily output per face rose, ranging from 86.0% in the United Kingdom to 164.6% in Poland (Appendix XIIId). This was mainly due to two factors : firstly, the increase in the average mechanised face area worked, having a greater influence in France, Belgium, Poland and Ukraine; and, secondly, the increase in daily advance per mechanised face, with France and United Kingdom reaching a peak in 1972 and 1969 respectively and thence declining. In all countries, production from mechanised faces, as a percentage of the total production from longwall faces, rose, reflected in the decline of the mechanised longwall output factor (Appendix XIIb).

In all instances, machine available time per machine shift dropped over the period. This was caused by the fact that faces were getting further away from the shaft, shift lengths were falling, and investment in underground transport was not fully compensating for these. Except for the Ukraine, daily machine available time rose because of the increase in machine shifts worked per face-day.

Appendices XIIIe and XIIIf show that the advance per minute and output per minute of machine available time steadily increased over the period. The main reason for the higher increase in mechanised output, compared with advance per minute of machine available time was the increase in average face area worked. West Germany in 1976 had the highest advance per minute of .313 centimetres as well as output per minute of 1.455 tons.

In every country, electrical energy used underground per ton, excluding lighting and ventilation, increased considerably (Appendix XIIc). Conversely, there was a substantial decline in man-years underground to underground electrical energy, showing the change of emphasis from manpower to electrical power (Appendix XIId).

Capital stock in longwall face mechanisation to mechanised longwall face manpower input increased, especially in the more recent years, with heavier investment in mechanisation, including supports (Appendix XIIe). Mechanised longwall face manpower input to total manpower input also increased, but, in Western Europe and Czechoslovakia, it tended to gradually decrease in the later years due to the fall in the number of mechanised faces (Appendix XIIf).

There was a relatively modest increase in mechanised longwall face capacity utilisation (Appendix XIIg), considering the vast investments in mechanisation and the increase in average mechanised face areas worked. Also, the East European countries were working at a lower capacity, marginally above that of Western Europe, than they would publicly admit. In all countries, except Poland and Czechoslovakia because of their controlled planning, mechanised longwall face capital stock efficiency fell due to the increase in capacity being outstripped by the capital stock (Appendix XIIh). However, in France and Belgium, it was caused by the relative decline of the two elements.

4.8.3. THE INGREDIENTS OF TOTAL INPUT

In all countries, there was a reduction in the proportion of manpower input to total input (Appendix XIIi). In Poland and Ukraine, the manpower proportion fell, although the total manpower input actually rose but was outstripped by the other inputs.

Capital input to total input showed small increases or remained stable, except for France where it decreased. Supplies/overheads input to total input increased in all cases. These changes in proportions indicate the decline in manpower employed with the exception of Poland and Ukraine, and the increase in the use of materials, energy and overheads. This is particularly true in declining industries, such as France and Belgium, where overheads must be more thickly spread over the lower output; also, in Eastern Europe, considerable supplies were needed at the non-mechanised supported faces.

4.8.4. TOTAL PRODUCTIVITY

To give any international comparative analysis, total productivity must be in constant terms and exchange rates, isolating inflation and international currency variations.

The total productivity models of each country and Appendix XIIj show individual performances in the period 1960 to 1976. In every instance, there was a decrease in the total productivity measure, ranging from 25.1% in the Ukraine to 8.3% in West Germany; with the exception of the Ukraine, it increased to a peak and thence declined. These peaks were invariably during periods of relatively high output, especially mechanised output, thus reaping the economies of scale. They were all in the period 1965 to 1970, with relatively low and stable coal prices, encouraging efficiency, except for Ukraine which started from a high in 1960/61, and thence declined due to the comparative inefficiency of its industry.

4.8.5. CURRENT VALUES

No-one really needs to be told of the economic ills of inflation and exchange rates. Appendix XI illustrates that the £ has performed worse than any other in the exchange rate stakes. Inflation has reared its head throughout Europe, East and West, though the former more reluctantly admit it. In all instances, manpower inflation has been far greater than any other; in constant values, manpower input to total input fell considerably, but remaining fairly stable in current values. Thus, as shown by Cahen[300], the rewards of high coal prices and total productivity have been mainly reaped by the reduced work force still employed.

All countries paid more, over the period, for technological enhancement for mechanised face equipment than for inflation. The increases, due to technological enhancement, were of a similar magnitude throughout Western Europe. However, they were more pronounced in Eastern

Europe, as mechanisation started from a lower threshold; also, to some extent, this enhancement had to be imported.

4.8.6. THE QUALITY OF COAL

Throughout the survey, output is measured in market tons. However, if the outputs of the seven countries are converted into hard coal equivalents, as decribed in Section 3, it can be seen that the hard coal equivalent conversion factors dropped slightly over the period 1960 to 1976 (Appendix XIV).

The hard coal equivalent values per ton were lower in Poland and Ukraine, due to the fact that their markets accept, or are obliged to accept, less cleaned and prepared coal, and that, in the cold winters, much of the preparation equipment is inoperable. The slightly higher fall of 2.6% of the hard coal equivalent per ton in the United Kingdom is partly caused by power stations accepting lower grade coal. The West German measures for hard coal equivalent per ton, which were the highest in Europe, correlate closely with the figures for tvF or pure coal (Appendix IVg).

4.9. The Individual Mine

Twenty-two mines, representative of the seven countries, are analysed utilising the total productivity model and equations, for the period 1972 to 1976. These mines are considered by their individual authorities to be those achieving high overall labour productivity in 1972. Each production unit is termed a mine because of its managerial structure, but, in some cases and especially in

Poland, it is a mining complex. For political reasons, the very best mines are not always revealed, and, indeed, some are barely up to the claimed standard.

The analysis shows (Appendix XV) that the accuracy of the prediction of annual mine and daily face outputs, and of the total productivity measure, is similar to that attained at the national level. However, statistical care must be taken with such a small number of faces per colliery sample.

The mines differ in many aspects : The number of seams worked varied from 1 to 12. In 1972, the smallest workable reserves of coal were as low as 5.5 million tons whilst the richest were as great as 366, with most collieries ranging from 50 to 100 million tons. The oldest colliery opened in 1850 whilst the newest in 1967. The number of shafts in operation ranged from 1 to 8, with the number of coal winding shafts and levels from 1 to 4. Of the production levels, 47% did not exceed 500 metres in depth, and 10% were in the region of 800 to 1000 metres in 1972. One could obviously itemise in greater detail characteristic differences, but this is not the aim of the exercise. In fact, it is to demonstrate the applicability of the analytical process to the mine.

Comparison is made between the mines and their national average for the components of the total productivity model and for the key physical factors (Figure 19). All economic values are based on 1960 prices and exchange rates to allow meaningful analysis. As each colliery was

Mine	$\frac{O}{TI}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$	$\overline{DOF}_m$	$\frac{O_m}{MAT}$	$\frac{a_m}{MAT}$	$\bar{l}_m$	$\bar{s}_m$	$\bar{a}_m$
UK1	/	/	/	/	X	/	X	/	X	X	/	/	/	/	X	/
UK2	/	/	/	/	X	/	/	/	X	X	/	/	/	/	/	/
UK3	/	/	/	/	X	/	/	/	X	X	/	/	/	/	/	/
UK4	/	/	/	/	X	X	/	/	/	X	/	/	X	/	/	X
UK5	/	/	/	X	X	/	/	/	X	X	/	/	X	/	/	/
WG1	/	/	/	X	X	/	/	/	X	X	/	/	/	/	/	/
WG2	/	/	/	X	/	/	/	/	X	/	/	/	/	/	/	/
WG3	/	/	/	/	X	/	X	/	X	X	/	/	/	/	X	/
FR1	/	/	/	X	X	/	/	/	X	X	/	/	/	/	/	/
FR2	/	/	/	X	X	/	/	/	X	X	/	/	/	X	/	/
BEL1	X	X	/	/	/	X	X	/	X	/	X	X	X	X	X	X
BEL2	/	/	/	X	X	/	X	/	X	/	/	/	/	/	/	/
POL1	/	/	/	/	X	/	X	/	X	/	/	/	/	/	X	/
POL2	/	/	/	/	X	/	X	/	X	/	X	X	X	/	X	X
POL3	X	X	/	/	X	/	X	/	/	X	X	X	X	X	/	X
CZ1	/	/	/	X	X	X	/	/	X	X	/	/	/	/	/	/
CZ2	/	/	/	X	/	/	/	/	X	X	/	/	/	/	/	/
CZ3	/	/	/	X	X	/	/	/	X	/	/	/	/	X	/	/
UKR1	/	/	/	X	X	/	X	/	X	X	/	/	/	/	/	/
UKR2	/	/	/	X	X	/	/	/	X	X	/	/	/	X	/	/
UKR3	/	/	/	/	X	/	X	/	X	X	/	/	/	/	/	/
UKR4	/	/	/	X	X	X	/	/	X	X	/	/	/	/	/	/

/ = greater than national average for the period 1972/76, or major part thereof
X = smaller than national average for the period 1972/76, or major part thereof

Based on Appendix XV
See Appendix II for notation

Fig. 19. Individual Mines, compared to their national average

fully mechanised during the period, the mechanisation factor (O/O_m) was, in each case, unity.

In 20 mines, labour productivity, measured in output per man-year underground, was greater, and, in some cases, only marginally greater, than the national average. In every case, capital stock in longwall face mechanisation to mechanised longwall face manpower input was also greater; this was mainly due to the fact that the mines were fully mechanised, with all West European and just over 50% of faces in East European Mines being mechanised supported. In 19 mines, the proportion of manpower input to total input was below the national average, emphasizing the use of capital vis-à-vis labour. This is also reflected in the fact that, in 20 mines, man-years underground to underground electrical energy utilised was also below. However, electrical energy used underground per ton was lower in only 16 mines, due to the variety and utilisation of equipment installed in each mine.

In 18 cases, mechanised longwall face capacity utilisation was greater, and surprisingly in most cases only marginally greater, than the national average. Mechanised longwall face capital stock efficiency showed no clear trends vis-a-vis the national average, and in only a few cases was it much above. Mechanised longwall face manpower input to total manpower input was lower than the national average for 12 mines; this was due mainly to varying face manning efficiency, and to the fact that, in several mines, considerable longwall development work was carried out affecting the proportion of the inputs.

In the period 1972 to 1976, in every instance, except in West Germany, the total productivity measure was at its highest in 1972, and thence declined. In 20 mines, the total productivity measure was up, or impressively up, on the national average.

There was a clear relationship between total productivity and labour productivity measured in output per man-year underground. Although there was modest kinship over the whole sample, there was a perfect positive correlation, within each country, between the two measures, except in the Ukraine where the Spearman's rank correlation was +.80. These results were very similar to those of Cahen[300], when analysing the nine coalfields of France in 1958. Except for the United Kingdom and Ukraine, there was a perfect positive correlation, within each country, between labour productivity, total productivity and the size of annual colliery output. In other words, the mines with the highest output usually had the highest labour and total productivity.

Of the key physical measures, in 19 mines, daily output per mechanised face and output per machine available time were above the national average, whilst advance per machine available time was also above for 17 of them. Average mechanised face length was greater than the national average in 17 mines, weighted average seam thickness in 17, and daily advance per mechanised face in 18. However, only in 12 mines were these three measurements all greater than the national average.

4.10. The Analysis - Conclusions

The analysis shows the accuracy and many of the analytical potentials of the total productivity model approach. It can be applied to any level of longwall mining activity, provided statistical care is taken and clear data is available, based on rigorous definitions. For comparative purposes over time, constant terms must be used to indicate underlying trends. Inflation, technological enhancement and exchange rates must be isolated and their effects demonstrated separately.

SECTION 5

In Conclusion

"The mining engineer in management
needs to improve his decision making
role when presented by an ever widening
choice of technical opportunities"

Robert DUNN

5.1. The Total Productivity Model

The inadequacies of productivity measurement, based on one single input such as labour, have been freely admitted in recent years, especially as the production process became more involved. As Fenske[2] stated, a partial measure of productivity, such as output per manshift, can only give meaningful control if all factors, except the one being studied, are held constant. Several writers, particularly Eilon, Gold & Soesan[73] and Craig & Clark Harris[20], have correctly emphasized that any indicator of productivity should be integrated to reveal all the elements that are considered of managerial importance to the overall performance of the enterprise.

By relying solely on labour productivity measurements, it is very difficult to comprehend all the factors affecting production and their inter-relationships. It cannot even answer the problem pronounced by Wearly[168] of whether the yardstick of productivity should be high labour productivity or low unit cost. Siddall[175] was quite correct : the term productivity is all too commonly used in a narrow sense, related to labour productivity. He rightly stated that productivity must be considered as the relationship between output and input in all its forms, particularly as nearly all factors are either directly or indirectly under management control.

Thus, the need for a more comprehensive approach to productivity measurement is required, above all in such a highly complex industry as longwall hard coal mining.

However, attempts to break away from the narrow approach of labour productivity, or at least those published, have been minimal; this is surprising, particularly after the work of Cahen[300] in the French coal mining industry, as far back as 1961. The underground hard coal mining industry is, each year, becoming more complex from both a management and a technological viewpoint, and requires the management tools for proper control and decision making as emphasized by Dunn[317].

As illustrated by Teague & Eilon[15], a productivity model must reflect those management objectives considered most important to monitor and control, as well as to reveal their inter-dependencies. The total productivity model, developed in the research, combines the best of earlier work and is applied to the hard coal longwall mining industry. Elements and components, considered to be vital to the industry and supported by the various equations built upon physical data, are monitored. It is not claimed that the model is a panacea for the running of longwall mines. What it does achieve is to integrate the major factors considered to affect the physical and economic performance of the industry, reflected in the component ratios of manpower, longwall mechanisation and energy. It also demonstrates the potential of such an approach in management control.

The model can be used at any level of longwall mining, and its potential is demonstrated both nationally and for the individual mine. One major problem to overcome in the research was the availability of reliable data, which was a considerable task to gather and verify, and in which there were two types of error.

Firstly, there was the involuntary or human error which was due mainly to lack of uniform definitions. This was surmounted by many visits throughout Europe, applying definitions of a clear but rigid nature.

Secondly, there was the type of error which one could almost call deliberate. In areas of information of several countries, figures were purposefully distorted; or, over the period, definitions were altered to confuse interpretation of trends. For example, such as in Poland, figures for labour productivity were rounded up for political or national-pride reasons; they were sometimes 30% higher than those calculated on total output, divided by total manshifts or total man-years. In Ukraine, where careful investigation had to be made to obtain marketable hard coal figures, the Russians specialised in usually revealing output in run-of-mine coal, often including brown coal. The West Germans expressed many of their figures related to output in three different ways : in market tons, in hard coal equivalents, but, most often, in tvF, which is a theoretical measure based on pure coal. In the United Kingdom, data had to be scrutinised to obtain continuity, and, in recent years, as pointed out by the Colliery Guardian[318], costs and revenues relating to opencast have been combined with those of underground mining.

The importance of the reconciliation of data in the research cannot be over-stressed. The physically-based equations particularly are highly successful as self-checking devices. Indeed, they have been approved by an international agency.

One might ask : Why is the research on an international/European basis? The reason is that no industry is more international than coal mining, and the concentration of the expertise of longwall mining has always been prevalent in Europe. To look at just the United Kingdom would be rather paroquial, but by viewing the trends and recent history of other industries, useful comparative information is ascertained.

The model's greatest attribute is that it enables management to view trends. It does not look cross-sectionally in depth at one particular instant of time, as did Gregory, Lock & Ormerod[296], but allows trends to be analysed, as well as factors affecting those trends.

If one is dealing in trends over time and at an international level, it is vital, for analytical purposes, to hold certain economic factors constant, showing their effects separately. Thus, economic figures in the model are given in 1960 prices and exchange rates, utilising the US dollar as the base. Technological specification is also held at a 1960 base with regards to face equipment. Technological enhancement, the paying over-and-above inflation for technological improvements in the equipment is separately analysed. The underlying trend must be in constant terms to allow a meaningful analysis, as supported by Craig &

Clark Harris[20] and Oakland[268].

5.2. Observations

The research covers the period 1960 to 1976 for seven hard coal producing countries in Europe. This was an era of exceptional change, reflected in the trends and features of the analysis. The starting point is 1960, when the availability of relatively cheap oil began to show its marked effect, especially on West European energy economies, and, continuing as far up-to-date as possible. Internationally, there was the energy crisis in the early 1970s, and, technologically, there has been the advent of mechanisation. 1960 is also a good base as it was a fairly stable period economically across Europe, after the recovery from the Second World War. The study and analysis look at two horizons : longwall mining in general and mechanised longwall mining.

Although the study is based on rigorous definitions and reconciled data, observations must be guarded due to the variations in approaches and social structures across Europe. However, certain trends are abundantly clear.

In Western Europe, there has been a substantial reduction in longwall hard coal mining, accompanied by a similar decline in the number of longwall faces worked. However, in Eastern Europe, there was a modest reduction in the number of faces, whilst longwall output increased in both Ukraine and Poland, more so in the latter.

Over the period, output per man-year underground increased; in the West European countries, it peaked in the early 1970s, and then declined, causing much concern in the industries. Underground manpower was deliberately reduced, except in Poland. There was also a fall in man-shifts per man-year reflecting the reduction in the time commitment per underground miner over the years. Conversely, manshifts underground per face-day actually increased, illustrating the fact that, although there were fewer men and fewer faces and, to some extent, fewer days worked, those faces were being utilised at a greater intensity.

Daily output per face increased primarily for two reasons : firstly, the introduction of mechanisation and better working methods, raising the daily advance per face; and, secondly, average face areas being worked gradually increased.

As regards vend, it should be noted that, especially in Belgium and West Germany, a considerable part of the production was dirt. Some of the figures for vend may appear slightly higher than those expressed in conversation by mining engineers, as they were based on expected pithead tonnages. If these were compared, where possible, with those raised and weighed, the latter would contain some extra 10% or so of weight comprising roof and floor extracted, as well as ripping dirt. In the East European countries, specifically in Poland and Ukraine, the vend was relatively high as, in many instances, coal was accepted by the market in a less prepared and cleaned state than in the West. This is again reflected in the fact that the values for hard coal equivalent per ton were lower in these countries. Thus, although their outputs were in marketable coal, it was of a somewhat lower quality.

One of the greatest features of the period has been the increase and sophistication of face mechanisation, from a mild application in the early 1960s to a revolution in later years. Each country progressed at a different rate, and made differing emphases. However, the results are clear.

Across Europe, there was a definite change, from manpower to machine power. Electrical energy per ton used underground, excluding lighting and ventilation, considerably increased with more powerful machinery. Conversely, there was a sharp drop in man-years underground to underground electrical energy.

In all the countries of the study, daily output and daily advance per mechanised face increased substantially. Average mechanised face areas also increased, thus aiding the productive task. Machine available time, when man and machine come together per machine shift, fell, but was more than compensated, except in the Ukraine, by increases in daily machine shifts worked, raising daily machine available time.

Figure 20 shows that there was a rise in the effectiveness of technology and organisation, measured in advance per machine available time, ranging from 59.7% in West Germany to 17.0% in the Ukraine. There was an

	Effectiveness (advance per minute)	Output per Minute	Average Area Worked
	%	%	%
United Kingdom	29.2	56.9	18.4
West Germany	59.7	118.8	45.8
France	30.0	89.2	47.0
Belgium	25.5	79.4	43.7
Poland	43.3	139.6	71.1
Czechoslovakia	45.1	90.8	35.5
Ukraine	17.0	96.7	64.8

Fig. 20. The relationship between increases in effectiveness, output per minute and average area worked at longwall mechanised faces, from 1960 to 1976

increase in the average area being worked per mechanised face ranging from 71.1% in Poland to 18.4% in the United Kingdom. The interaction of effectiveness and area, combined with small changes in vend and density, achieved the large increases in output per minute of machine available time. In Poland and Ukraine particularly, the increase in average area worked had a greater effect on the output per minute, than did effectiveness.

Although each country has invested heavily in face mechanisation, there has been a variety in the mix of equipment used throughout Europe. Figure 21 shows that, in 1976, in West Germany, France and Belgium, due to their softer seams, hard roofs and floors, as well as mining traditions, mechanised output by ploughs predominated, whilst, for the other four countries, it was more by shearers. However, throughout the period 1960 to 1976, in all countries, there has been some trend towards shearers.

	Ploughs	Shearers	Other
	%	%	%
United Kingdom	2.2	80.3	17.5
West Germany	67.5	30.7	1.8
France	62.0	38.0	-
Belgium	86.0	14.0	-
Poland	9.0	91.0	-
Czechoslovakia	7.0	82.0	11.0
Ukraine	5.0	95.0	-

Fig. 21. Percentage breakdown of mechanised longwall output by machine type, 1976

Combining international data in 1975/76, it was found, as supported by Hartley[319], that machine available time could be broken down into three more or less equal parts : one third machine running time, one third operational and ancillary time, and one third lost time due to face delays (Figure 22).

	Face Conveyor	Power Loading Machine	Coal Clearance System	Other
	%	%	%	%
United Kingdom	18.3	22.5	25.0	34.2
West Germany	22.0	8.0	24.0	46.0
France	20.4	33.6	6.2	39.8
Belgium	4.3	40.7	7.6	47.4
Poland	19.0	22.0	25.0	34.0
Czechoslovakia	21.0	19.0	24.0	36.0

Fig. 22. Percentage breakdown of mechanised face delays, 1975/76

It is true that some of the definitions are not perfectly consistent, but problems are international, and the majority of delays are due to face conveyors, power loading machinery, and coal clearance systems. There is a degree of interaction between the major causes. For example, overloading by the machine frequently causes face conveyor breakdowns; similarly, peak outloading from the face coupled with ripping dirt causes blockages, overloading and delays in the coal clearance system.

The figures indicate that, if possible, the problems have yet to be solved, taking into account the fact that nowhere in Europe was machine running time much above one third of machine available time, remaining a relatively static proportion since 1960. This also reflects that no matter how productive a face is, machine and transport reliability, as well as coal clearance, are vital.

Face delays have fallen slightly in the United Kingdom with the introduction of the new incentive schemes, as shown in Production and Productivity Bulletin[320]. This was due mainly to self-motivated, better work arrangements from the underground miners; only time will tell if there is any permanence to this.

As would be expected, within longwall itself, there have been changes in methods of working. This can be clearly seen with retreat mining. In the United Kingdom, there has been a small increase in retreat working from 1967 to 1976, with the number of faces rising from 37 to 103. At the same time, according to Weber[321], retreat mining in West Germany declined in the period 1968 to 1975, from 24% to 18% of longwall production, mainly because of increasingly strict mining regulations. In Ukraine, Poland and Czechoslovakia, retreat mining has been principally used. Thus, in all countries, some variation could have been caused due to the advancing versus retreating changes. However, this is considered to be minimal for two reasons : firstly, in most cases, there was only a small variation in emphasis; and, secondly, over a period of time, if one treated advancing and retreating from a similar statistical base with regards to development work, then the claimed advantages of retreat against advance would be modest. In fact, in West Germany, there has been a massive increase in daily output per face, accompanied by the slight decline in the proportion of retreat working.

The measure of capacity and its utilisation have always been somewhat of an enigma in the field of underground coal mining, an extractive industry. In fact, it has been claimed, in more than one instance, that it is a near impossibility. This, however, cannot be taken seriously or the art of mechod study and operational research would die. As carried out in this survey, measures of capacity can be achieved, utilising obtainable face standards. It is true that there is no perfect answer to capacity, but it would be completely incorrect to ignore it. Thus, the measure of longwall mechanised face capacity is taken as the obtainable aggregate capacity for those faces. On these assumptions, there has been only a modest increase in mechanised longwall face capacity utilisation, especially when one considers the investment in increased mechanisation and technology and the fact that faces are being worked with larger areas. In all countries, mechanised longwall face capital stock efficiency fell, except in Poland and Czechoslovakia. This illustrates that the increases in mechanised longwall capital stock at constant figures outmatched the obtainable capacity it could achieve.

Bryan[221] talks of mechanisation, the dream that became a reality. However, jubilation over the achievements of mechanisation must be tempered with some economic caution. In all cases, capital stock in longwall face mechanisation related to the mechanised longwall face manpower input rose, especially in recent years, indicating the increased capital intensity of mechanisation.

	Effectiveness (advance per minute)	CS_m per metre of face length	
		in constant terms	with technological enhancement
	%	%	%
United Kingdom	29.2	208.8	662.9
West Germany	59.7	241.3	674.8
France	30.0	76.5	317.5
Belgium	25.5	146.3	480.2
Poland	43.3	58.1	450.1
Czechoslovakia	45.1	62.8	195.0
Ukraine	17.0	29.2	136.4

Fig. 23. The percentage increases in effectiveness, capital stock of mechanised longwall equipment per metre of face length in constant terms at 1960 prices and exchange rates, and with technological enhancement, for the period 1960 to 1976

Figure 23 shows the increases in effectiveness in technology and organisation, measured in advance per minute of machine available time, with mechanised longwall capital stock held or used per metre of face length. It can be clearly seen that nowhere in Europe, East or West, has an industry been achieving anything but a meagre return on the investment in technology. Ignoring inflation and exchange rate changes, but including technological enhancement, investment in capital stock of mechanised longwall equipment per metre of face length has risen dramatically in relation to the small increases in effectiveness. It is true to say, however, that the larger extracted seam thickness generated capital expenditure especially in mechanised supports. Also, part of the technological enhancement was attributable to safety and welfare rather than to production. If there had been no investment in face technology, effectiveness would have not stood still, but would have declined. Thus, the measures of increases in effectiveness may slightly under-estimate the situation. However, when one considers that not only has there been the considerable increases in capital stock per metre of face length, but the cost of researching, developing, installing and maintaining such equipment, one must have great doubts on the economic advantages of increased sophistication. The question posed by Siddall[222] must ring out true; he stated "solutions through technology - when?"

The research found little correlation between labour productivity measured in output per man-year underground and total productivity over time. Except for the Ukraine, total productivity reached a high in the period 1965/70 in an era of high output enabling economies of scale, as well as of low and stable coal prices which encouraged relative efficiency, before declining.

All underground coal mining industries throughout Europe, East and West, were to some extent subsidised, either directly or in some subtle manner by their own State.

	United Kingdom	West Germany	France	Belgium
	%	%	%	%
1960	97.5	94.8	83.9	92.4
1961	98.2	90.7	79.7	83.1
1962	100.4	91.6	78.3	84.3
1963	100.2	95.1	72.6	86.5
1964	99.4	93.6	77.2	81.9
1965	98.3	91.4	71.5	77.6
1966	99.4	90.8	69.3	71.1
1967	99.3	93.2	64.7	62.9
1968	97.5	95.5	58.2	61.2
1969	94.4	93.7	59.1	60.1
1970	97.0	91.4	70.5	63.0
1971	80.3	95.5	74.9	65.8
1972	87.8	92.6	65.2	56.1
1973	84.2	89.0	60.1	48.0
1974	82.3	88.9	74.7	59.6
1975	93.9	91.9	74.4	67.0
1976	91.0	94.3	70.0	62.2

Fig. 24. Coverage of costs in the underground coal industry (revenue per ton of coal as a percentage of total production costs)

Figure 24 illustrates the fact that, in the period 1960 to 1976, for the four coal mining countries of Western Europe, the revenue did not cover the total production costs except for 1962 and 1963 in the United Kingdom. Detailed figures are difficult to obtain from Eastern Europe, but, in private conversation, it was revealed that their pattern was close to break-even.

The survey is based on economic values held at 1960 prices and exchange rates. In all countries, manpower costs have inflated more than other inputs. This can be demonstrated by the fact that, in constant terms, manpower input to total input declined, but remained relatively stable in current terms. Thus, the economic benefits have been gathered mainly by the declining work force.

The United Kingdom has suffered far worse from inflation than any of the other countries, but this was partly compensated in international competitive terms by the decline in exchange rate. In West Germany, inflation was lower, but the strength of the Deutsch Mark made the German industry internationally less competitive. The East European countries managed better on both accounts (Figure 25).

	(A) Inflation	(B) Exchange Rate	(A) x (B) Combined
United Kingdom	385.6	62.0	239.1
West Germany	234.0	176.6	413.2
France	316.9	98.7	312.8
Belgium	291.2	138.1	402.1
Poland	190.3	120.6	229.5
Czechoslovakia	182.6	125.3	228.8
Ukraine	170.4	120.6	205.5

Fig. 25. Indices of weighted inflation and exchange rates, 1976 (1960 = 100)

These combined effects are clearly illustrated in Figure 26. The 1976 total productivity measures, in current terms, were only a fraction of those in constant terms, reduced by the combined inflation and exchange rate index. West Germany and Belgium actually were the most affected, and the United Kingdom and East European countries the least.

	(A) Current Terms	(B) Constant Terms	(A)/(B)
United Kingdom	30.30	72.41	41.8%
West Germany	16.43	67.89	24.2%
France	17.75	55.50	32.0%
Belgium	12.31	49.50	24.9%
Poland	31.59	72.52	43.6%
Czechoslovakia	27.98	64.03	43.7%
Ukraine	30.94	63.57	48.7%

Fig. 26. Total productivity measures in kilogrammes per US dollar in current terms at 1976, and constant terms at 1960 prices and exchange rates, as well as their percentage relationship

It can be seen from Appendix XIIj, looking at total productivity measures in constant terms, that the United Kingdom was probably the most efficient producer of coal in Europe. In ten of the sixteen years, it had the highest measure, and was supreme in the period 1962/69. From Figure 26, the effects of inflation and exchange rates on constant figures can be observed to affect the competitive position internationally of each industry. There was some change in the order of rank of competitiveness, although the industry with the highest total productivity factor, in constant and current terms in 1976, was Poland. The Spearman's rank correlation for the seven countries in 1976, between constant and current terms, was +.643, indicating the effect of the changing order of rank of these factors in the different countries.

As regards safety and its relation to productivity, no conclusive evidence has yet been published to clearly link the two. According to Corwine[322], increased attention to safety through the rigorous enforcement of mandatory safety standards in the United States have been accompanied by loss of productivity. Although international comparisons on safety are extremely difficult due to measurement and definitions, it is fair to say that there has been a downward trend in accident rates across Europe. Safety is not considered part of the model, even though it is a vital question. This is because the model is basically of a physical/economic nature, and safety control is a separate and major issue linked to risk analysis. Accidents themselves cost money, through loss of production directly or through low morale. Safety is uppermost in the minds of all who sensibly pursue mining, but its economic effects are still a matter of conjuncture, though there has been increased investment in the safety facet of technological enhancement.

The analysis, utilising the individual mines, showed the applicability of the use of the model at that level. In many instances, the so-called better mines were only marginally superior or more utilised than their national average. The mines with the largest output often showed the highest labour and total productivity, illustrating the importance of scale.

5.3. Future Work

The potential of such a model is demonstrated as a tool available for management control. The trends, since 1960, showed clear patterns where, although some of the facts are common mining knowledge, they are presented in an integrated form in order to analyse their interdependencies. Thus, recent history can be studied and hence forecasts can be built for planning purposes.

In an era of high investment and sophisticated technology, mining objectives should concentrate on total productivity, with its components and elements. Complex situations require more comprehensive approaches to seek the underlying trends and to answer such questions, as posed by Bradley[323], as to why European coal technology is up but production down.

Research is itself like longwall coal mining, an extractive industry. Thus, although the foundation is laid, the situation is continually changing, and new ideas, concepts and resources are always required.

Research can only lead the way. The challenges and the potential of broader avenues to productivity are most exciting. These include three specific spheres of future work :-

(a) practical application of the total productivity model;
(b) informational areas of study; and
(c) functional research.

5.3.1. PRACTICAL APPLICATION

Although the research is practical in nature, a further dimension would be added by its application, in whole or in part, to particular collieries or areas continuously over a period of time. Objectives would be set and monitored in total productivity terms, that is fully integrating physical and economic targets. In this way, in collaboration with managers at all levels, the model and its concepts can be observed and commented upon. A full test survey can thus be carried out to monitor the improved information that would arise to management and its reaction to it. Views on the applicability of the broader approach could then be ascertained from all levels of management. Initially, because of the availability of information and the relevant ease of installation, it is possible that only the physical parameters could be observed.

For instance, on the purely physical side of control, the concept of analysing performance of longwall faces, either individually or aggregated, based on face area available and time spent on those faces can illustrate to management the interaction of these factors of basic capacity. This is supported by Simpson & Davies[324].

Also, daily output and daily advance per face are most useful measures of colliery performance. They can, however, be improved upon by expressing output and advance in relationship to the machine available time in minutes, both related to the face areas worked. Moreover, basic manpower productivity could be expressed in output per man-hour, rather than per manshift, on a standardised measurement of underground work - as now being experimented by the Coal Committee of the Economic Commission for Europe[325]. This latter measure would iron out discrepancies caused by variations over time and between areas or countries in the measurement and definition of shifts worked.

The potential of the total productivity model as a whole is exposed. It can provide further dimensions for the decision making role, as demanded by Dunn[317]. For instance, it can monitor the performance, both physically and economically, of two types of machinery, of advance versus retreat working, and of wide-web working. In all these cases, the inter-dependencies can be fully appreciated, especially as, at present, the countries in the survey achieve only a poor return on their investment in longwall face technology.

In the research, much attention of the component ratios focus on mechanised faces. However, the total productivity model can be adapted and applied to other mining functions away from the face.

5.3.2. INFORMATIONAL AREAS OF STUDY

This area of study is to develop an even more relevant and meaningful informational input to the model.

Although there have been great strides in the last two decades in the standardisation of international information, and although the Coal Committee of the Economic Commission for Europe is slowly but surely achieving this, considerable work is still required to facilitate meaningful international comparisons.

During the survey, most of the analysis considers output in a relatively homogeneous measurement of marketable tonnage, supplemented by showing the hard coal equivalent per ton. Although this measure is adopted by the European Economic Community, other qualitative measurements of the output of coal should be studied further in order to produce more relevant measures of output.

The economic ills of inflation are isolated in the research, as well as the effects of technological enhancement on face equipment. Much attention is given to the reporting of accounting data on the replacement of fixed assets. However, the technological aspects have hitherto been avoided, and the role of technological enhancement must be separately analysed. A region of additional study would be the application of these concepts to replaceable assets other than face equipment.

At present, exchange rates are the only practical vehicle to reflect, though not perfectly, international economic changes. An improvement could well be the usage of purchasing power parities, the relationship between various countries of a basket of certain goods; however, this is still at an early stage. In the not too distant future, international research could well be based on such data.

A comparative analysis of the subsidies of the mining industries across Europe is needed, as there is some distortion due to the fact that each industry is in some way financially supported by the State. Also, social subsidies affect manpower costs by the differing distribution between employee, industry and State, in social expenditure.

There are often considerable errors in forecasting, especially at the level of the mine, on such basic measurements as expected pithead tonnage. Thus, information would be greatly improved by research into the forecasting practices, and then continually relating the outcome with the forecast.

5.3.3. FUNCTIONAL RESEARCH

This research is deliberately production-orientated. However, other functions related to coal mining can also be studied utilising the total productivity concepts.

The marketing and pricing province is of extreme importance, although considered to be a separate process. Marketing can be usefully be defined as the process in a society by which the demand for economic goods and services is anticipated or enlarged, and satisfied through the conception, provision, physical distribution and exchange of such goods and services. Success would depend on the skill with which the management is able to give satisfaction and obtain the appropriate net profit. It is linked to production for the economic well-being of the individual industry, as it is the revenue generator whilst production is only a cost incurring process. Therefore, further work is required to adapt and apply the total productivity concepts to measure the marketing system.

A major area of future work must be the economic study of the safety function and its relationship to all aspects of productivity, including total productivity. Although mine safety is on everyone's lips, the economic data including costs, in many instances, is most unsatisfactory and often lost in general overheads. Research ought to be carried out into safety and welfare investment, including the technological enhancement aspects. Also, this should be allied to costs, both direct and indirect, of accidents to achieve a cost-benefit and risk-related analysis. Work is required in the standardisation and recording of safety costs. This could lead to the analysis of preventative and actual costs to determine a minimum cost for a given accident level.

Due to the Mines Safety & Health Commission of the European Economic Community, international definitions have been made more comparable. However, it is found that there are greater discrepancies in safety data than in any other, especially between East and West Europe. A reconciliation of definitions and data in safety would prove a valuable contribution to international discussions on the subject.

5.4. The Perspective

Coal, as the most abundant fossil fuel, has a major role to play in European energy economies. Sir Derek Ezra[326] stated that its future depends on exploration, investment, technological research and conservation. It is hoped that this research adds a further dimension : that of management control and planning, based upon a total productivity approach.

Longwall hard coal mining will remain the life-blood of the collieries of the future in Europe. Its productivity, measured in a total fashion, can make a contribution to an industry with a proud past and most certainly a proud future.

Basic Definitions

Average Daily Advance - the aggregate measured advance on faces worked per aggregate face-days worked during the year

Average Face Length - the aggregate face lengths to the number of faces worked during the year

Average Vend - the proportion of market tonnage of coal available after normal processing, to the expected pithead tonnage

Colliery or Mine - the smallest production unit operating under the general responsibility of a manager and statistically self-reporting

Daily Machine Available Time - the average time in minutes per day that men can work at a mechanised face

Daily Output per Face - the aggregate output from longwall faces in market tonnage per aggregate face-days worked during the year

Face-Days - the aggregate number of days on which coal is loaded at each face

Hard Coal - coal of gross calorific value of over 24 MJ (megajoules) per kilogramme ($\simeq$5700 kcal/kg) on an ash-free but moist basis

Longwall Face - a face worked by conventional longwall methods

Machine Available Time per Machine Shift - the time in minutes per machine shift, i.e. the time from entering the cage at the top of the shaft to re-entering it at the bottom, less travelling, preparation and refreshment times

Machine Shift - the period in which a mechanised face is manned by a single team of men ready to operate the face

Manshift - the normal period of attendance at a mine of one worker in one working day, overtime being expressed 'pro rata' in terms of normal shifts

Man-Years Underground - the average annual number of workers engaged most of their working time in underground longwall work, excluding under-officials

Market Tonnage - the output of coal, cleaned and prepared as accepted by the market

Mechanised Face - a face on which a machine either loads prepared coal or cuts and loads simultaneously. Coal felled in the stable holes of mechanised faces is included in mechanised output

Mechanised Supported Faces - longwall faces with mechanised self-advancing, power-operated supports, for roof control

Output - production of longwall hard coal in market tonnage excluding development coal and lifted slurry

Pithead Tonnage - the output of raw coal produced at a colliery

Seam Thickness - the height of seam thickness extracted, including any dirt bands within this height

Underground Worker - a worker engaged most of the working time in underground work related to longwall production, excluding under-officials

Main Notation

$\bar{a}$	average advance of longwall face in metres per working day
$\bar{a}_m$	average advance of mechanised longwall face in metres per working day
$\frac{a_m}{MAT}$	average mechanised advance in centimetres per minute of machine available time, during the year
$\bar{c}$	average vend (market tonnage/pithead tonnage)
$\bar{c}_m$	average vend for mechanised output (market tonnage/pithead tonnage)
CAP_m	capacity of mechanised longwall face system in market tonnage during the year in million tons
$\frac{CAP_m}{CS_m}$	mechanised longwall face capital stock efficiency during the year, in tons per US dollar at 1960 prices and exchange rates
CS_m	capital stock in longwall face mechanisation during the year, in million US dollars at 1960 prices and exchange rates
$\frac{CS_m}{MI_m}$	capital stock in longwall face mechanisation to mechanised longwall face manpower input, during the year
$\bar{d}$	average number of days worked per longwall face during the year
$\bar{d}_m$	average number of days worked per mechanised longwall face during the year
$\overline{DOF}$	average daily output per longwall face in market tonnage
$\overline{DOF}_m$	average daily output per mechanised longwall face in market tonnage
$\bar{k}$	weighted average density of extraction in pithead tons per cubic metre
$\bar{k}_m$	weighted average density of extraction from mechanised longwall faces in pithead tons per cubic metre
kWh_u	electrical energy utilised underground in longwall output, in million kilowatt-hours (gigawatt-hours) during the year

$\frac{kWh_u}{O}$	electrical energy utilised underground per market ton, in kilowatt-hours, during the year
$\bar{l}$	average length of longwall face in metres, including stable holes
$\bar{l}_m$	average length of mechanised longwall face in metres, including stable holes
$\frac{MAT}{McS}$	average machine available time in minutes per machine shift at mechanised longwall faces, during the year
$\frac{McS}{dn_m}$	average number of machine shifts per mechanised longwall face-day worked, during the year
MI	manpower input for longwall output, during the year, in million US dollars at 1960 prices and exchange rates
$\frac{MI}{TI}$	manpower input as a proportion of total input, during the year
MI_m	mechanised longwall face manpower input, during the year, in million US dollars at 1960 prices and exchange rates
$\frac{MI_m}{MI}$	mechanised longwall face manpower input as a percentage of total manpower input, during the year
MS_u/dn	average underground manshifts per longwall face-day worked, during the year
$\frac{MS_u}{MY_u}$	average manshifts per man-year for underground longwall workers
MY_u	man-years underground in thousands for longwall output
$\frac{MY_u}{kWh_u}$	man-years underground to underground electrical energy, in million kilowatt-hours (gigawatt-hours) for longwall output
$\bar{n}$	average number of longwall faces per working day, during the year
$\bar{n}_m$	average number of mechanised longwall faces per working day, during the year
O	output per annum from longwall faces in market tonnage, in million tons
$\frac{O}{MY_u}$	average output per man-year for underground longwall workers in market tons

$\frac{O}{O_m}$	mechanised longwall output factor per annum
$\frac{O}{TI}$	total productivity measure during the year, in kilogrammes per US dollar at 1960 prices and exchange rates
O_m	output per annum from mechanised longwall faces in market tonnage, in million tons
$\frac{O_m}{CAP_m}$	mechanised longwall face capacity utilisation, during the year
$\frac{O_m}{MAT}$	average mechanised longwall output in market tons per minute of machine available time, during the year
$\bar{s}$	weighted average of extracted seam thickness in metres, including dirt bands and allowing for operational losses
$\bar{s}_m$	weighted average of extracted seam thickness of mechanised longwall faces in metres, including dirt bands and allowing for operational losses
TI	total input for longwall output, during the year, in million US dollars at 1960 prices and exchange rates
$\frac{TI}{O}$	total input per market ton, expressed in US dollars at 1960 prices and exchange rates

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APPENDIX IIIa

Total longwall output in million tons and Daily output per face in tons

	O_A	O_P	$\bar{d}$	$\bar{n}$	$\bar{c}$	$\bar{k}$	$\bar{s}$	$\bar{l}$	$\bar{a}$	$\overline{DOF}_P$	$\overline{DOF}_A$
1960	174.0	174.9	242	3603	.80	1.50	1.22	137	1.00	201	193
1961	170.0	162.9	241	3022	.80	1.50	1.22	143	1.11	232	224
1962	177.3	175.7	242	2733	.80	1.50	1.23	150	1.20	266	256
1963	178.8	177.5	240	2473	.80	1.50	1.26	157	1.26	299	288
1964	175.6	176.3	239	2241	.81	1.49	1.26	164	1.32	329	318
1965	166.3	171.9	238	2070	.81	1.49	1.27	165	1.38	349	335
1966	157.2	157.5	237	1674	.81	1.49	1.27	166	1.56	397	386
1967	155.4	157.8	239	1526	.81	1.49	1.27	166	1.70	433	417
1968	150.8	155.9	239	1297	.81	1.49	1.30	167	1.92	503	492
1969	137.8	141.3	234	1098	.81	1.49	1.34	170	2.00	550	538
1970	131.4	134.2	234	1027	.81	1.49	1.34	171	2.02	559	547
1971	108.1	107.8	193	997	.82	1.48	1.35	171	2.00	560	550
1972	125.7	129.1	238	948	.82	1.48	1.36	170	2.04	572	556
1973	96.1	97.0	196	865	.82	1.48	1.37	172	2.00	572	558
1974	113.6	114.3	237	824	.83	1.47	1.40	173	1.98	585	593
1975	111.7	111.1	232	818	.83	1.47	1.40	174	1.97	585	583
1976	106.0	105.7	230	785	.83	1.47	1.42	176	1.92	585	582

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

UNITED KINGDOM

Output per man-year underground
in tons

	$\frac{O}{MY_u}$	$\overline{DOF}$	$\frac{MS_u}{MY_u}$	MS_u/dn
1960	431	193	220	98.5
1961	445	224	218	109.7
1962	491	256	218	113.7
1963	514	288	217	121.6
1964	533	318	215	128.3
1965	528	335	212	134.5
1966	548	386	212	149.3
1967	580	417	212	152.4
1968	627	492	214	167.9
1969	680	538	215	170.1
1970	691	547	213	168.6
1971	598	550	181	166.5
1972	698	556	207	164.9
1973	565	558	182	179.7
1974	691	593	207	177.6
1975	662	583	201	177.0
1976	637	582	197	180.0

Based on Equation IV
See Appendix II for notation

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APPENDIX IIIc

Mechanised longwall output in million tons
and
Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1960	78.3	77.6	242	973	.81	1.49	1.28	168	1.27	330	322
1961	91.8	94.7	241	1147	.81	1.49	1.28	168	1.32	343	332
1962	117.0	116.8	242	1255	.81	1.49	1.30	169	1.45	384	386
1963	133.2	134.6	240	1345	.81	1.49	1.31	177	1.49	417	419
1964	142.2	141.6	238	1415	.81	1.49	1.29	180	1.50	420	428
1965	145.3	144.6	238	1389	.81	1.49	1.29	179	1.57	437	430
1966	145.4	144.5	237	1357	.81	1.49	1.30	179	1.60	449	444
1967	145.3	144.3	239	1340	.81	1.49	1.30	166	1.73	451	468
1968	143.1	141.1	239	1100	.81	1.49	1.32	166	2.03	537	547
1969	132.3	133.4	234	957	.81	1.49	1.35	170	2.15	595	592
1970	127.3	127.6	234	908	.81	1.49	1.36	171	2.14	601	594
1971	104.9	103.2	193	879	.82	1.48	1.37	171	2.14	608	604
1972	122.3	121.7	238	860	.82	1.48	1.37	172	2.08	595	594
1973	94.3	95.1	196	804	.82	1.48	1.40	175	2.03	604	589
1974	111.6	110.4	237	763	.83	1.47	1.40	176	2.03	610	620
1975	109.8	108.6	232	769	.83	1.47	1.41	176	2.01	609	606
1976	104.5	102.1	230	733	.83	1.47	1.43	178	1.95	606	599

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

UNITED KINGDOM

Mechanised longwall output in million tons
and
mechanised advance in centimetres
related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1960	78.3	242	973	359	.617	1.5	.236
1961	91.8	241	1147	354	.586	1.6	.233
1962	117.0	242	1255	354	.640	1.7	.241
1963	133.2	240	1345	352	.651	1.8	.235
1964	142.2	238	1415	350	.635	1.9	.226
1965	145.3	238	1389	348	.631	2.0	.226
1966	145.4	237	1357	346	.653	2.0	.231
1967	145.3	239	1340	344	.628	2.1	.239
1968	143.1	239	1100	342	.723	2.2	.270
1969	132.3	234	957	338	.794	2.2	.289
1970	127.3	234	908	329	.867	2.1	.310
1971	104.9	193	879	327	.900	2.1	.312
1972	122.3	238	860	327	.870	2.1	.303
1973	94.3	196	804	327	.915	2.0	.310
1974	111.6	237	763	326	.946	2.0	.311
1975	109.8	232	769	320	.962	2.0	.314
1976	104.5	230	733	320	.968	2.0	.305

Based on Equations V and III
See Appendix II for notation

UNITED KINGDOM

Total input per ton
in US dollars at 1960 prices and exchange rate,
and its percentage breakdown

	TI/O	Manpower	Capital	Supplies/ Overheads
		%	%	%
1960	11.74	60.4	7.2	32.4
1961	11.68	58.7	7.4	33.9
1962	11.15	56.8	8.8	34.4
1963	10.78	55.3	8.3	36.4
1964	10.50	54.9	8.8	36.3
1965	10.48	53.7	7.8	38.5
1966	10.76	51.0	7.8	41.2
1967	10.33	50.4	7.6	42.0
1968	10.02	47.5	8.4	44.1
1969	10.25	45.9	8.7	45.4
1970	10.59	43.9	8.7	47.4
1971	12.90	42.1	9.3	48.6
1972	11.06	41.0	9.5	49.5
1973	14.15	39.4	7.1	53.5
1974	12.71	36.3	9.3	54.4
1975	13.11	36.1	9.0	54.9
1976	13.81	36.3	9.1	54.6

UNITED KINGDOM

APPENDIX IIIf

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1960	85.18	85.12	431	2.45	6.37	.604	.603	.674	2.22	354	6.56
1961	85.61	85.20	445	2.22	8.54	.587	.605	.685	1.85	340	6.60
1962	89.68	89.32	491	2.20	11.03	.568	.605	.710	1.51	301	6.76
1963	92.76	92.60	514	2.17	12.75	.553	.607	.744	1.34	287	6.78
1964	95.24	94.68	533	2.28	14.40	.549	.609	.702	1.23	272	6.89
1965	95.42	95.08	528	2.46	15.57	.537	.611	.663	1.14	244	7.77
1966	92.93	92.68	548	2.77	17.06	.510	.611	.583	1.08	223	8.18
1967	96.80	97.08	580	3.31	18.66	.504	.613	.475	1.07	204	8.46
1968	99.80	99.51	627	3.51	18.40	.475	.615	.502	1.05	186	8.58
1969	97.56	97.25	680	3.80	17.83	.459	.616	.488	1.04	158	9.31
1970	94.43	94.15	691	3.96	17.85	.439	.617	.478	1.03	146	9.90
1971	77.52	77.25	598	4.69	17.67	.421	.525	.411	1.03	136	12.25
1972	90.42	90.74	698	4.89	17.47	.410	.618	.406	1.03	136	10.56
1973	70.67	70.43	565	5.38	16.23	.394	.512	.393	1.02	120	14.71
1974	78.67	78.96	691	5.38	16.37	.363	.618	.392	1.02	116	12.47
1975	76.28	76.55	662	5.65	15.81	.361	.621	.374	1.02	116	13.05
1976	72.41	72.10	637	5.62	15.92	.363	.621	.354	1.01	113	13.89

Based on Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

APPENDIX IVa

WEST GERMANY

Total longwall output in million tons
and
Daily output per face in tons

	O_A	O_P	$\bar{d}$	$\bar{n}$	$\bar{c}$	$\bar{k}$	$\bar{s}$	$\bar{l}$	$\bar{a}$	$\overline{DOF}_P$	$\overline{DOF}_A$
1960	140.6	140.0	264	1660	.70	1.71	1.36	165	1.19	320	322
1961	140.9	139.2	263	1435	.70	1.71	1.36	173	1.31	369	368
1962	139.7	141.3	262	1327	.70	1.71	1.41	172	1.40	406	398
1963	140.8	141.5	264	1205	.70	1.71	1.44	172	1.50	445	439
1964	140.9	141.2	264	1136	.70	1.71	1.48	182	1.46	471	466
1965	134.0	134.0	262	1082	.69	1.72	1.48	183	1.47	472	486
1966	125.0	121.7	255	848	.69	1.72	1.58	183	1.64	563	543
1967	111.0	109.7	239	727	.69	1.72	1.60	190	1.75	631	616
1968	111.3	111.0	251	642	.69	1.72	1.60	190	1.91	689	707
1969	110.1	111.2	253	560	.68	1.73	1.63	195	2.10	785	815
1970	110.2	113.7	254	506	.68	1.73	1.65	199	2.29	885	912
1971	110.9	110.6	253	457	.67	1.75	1.66	210	2.34	956	966
1972	103.3	101.2	245	410	.66	1.77	1.70	215	2.36	1008	1046
1973	98.5	97.4	249	342	.65	1.79	1.78	215	2.57	1144	1158
1974	95.9	97.1	248	328	.64	1.81	1.80	216	2.65	1193	1231
1975	93.8	93.7	248	313	.63	1.83	1.82	217	2.65	1207	1250
1976	91.0	91.8	247	300	.63	1.83	1.83	219	2.68	1238	1296

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

WEST GERMANY

Output per man-year underground
in tons

	$\frac{O}{MY_u}$	$\overline{DOF}$	$\frac{MS_u}{MY_u}$	MS_u/dn
1960	479	322	226	151.9
1961	515	368	226	161.5
1962	555	398	224	160.6
1963	596	439	226	166.5
1964	618	466	227	171.2
1965	626	486	219	170.0
1966	656	543	212	175.5
1967	688	616	202	180.9
1968	778	707	209	189.9
1969	811	815	211	212.0
1970	808	912	205	231.4
1971	808	966	201	240.3
1972	807	1046	190	246.3
1973	839	1158	194	267.8
1974	838	1231	200	293.8
1975	808	1250	199	307.9
1976	807	1296	194	311.5

Based on Equation IV
See Appendix II for notation

WEST GERMANY

APPENDIX IVc

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1960	55.5	55.0	264	380	.71	1.70	1.36	205	1.63	548	541
1961	70.0	70.2	263	475	.71	1.70	1.36	210	1.63	562	580
1962	83.8	86.6	262	566	.71	1.70	1.44	205	1.64	584	602
1963	94.6	92.6	264	582	.70	1.71	1.46	209	1.65	603	615
1964	104.8	106.4	264	675	.70	1.71	1.48	203	1.66	597	606
1965	105.9	106.6	262	648	.69	1.72	1.49	204	1.74	628	626
1966	101.9	100.4	255	558	.69	1.72	1.60	202	1.84	706	691
1967	93.2	91.5	242	505	.69	1.72	1.62	205	1.90	749	747
1968	97.5	96.5	251	460	.69	1.72	1.62	208	2.09	836	829
1969	99.4	98.6	253	425	.68	1.73	1.65	210	2.25	917	931
1970	101.9	102.9	254	410	.68	1.73	1.66	210	2.41	988	1029
1971	103.2	104.2	253	398	.67	1.75	1.69	214	2.44	1035	1081
1972	98.7	97.5	245	372	.66	1.77	1.71	216	2.48	1070	1109
1973	94.8	96.8	249	315	.65	1.79	1.78	220	2.71	1235	1276
1974	92.9	94.9	248	300	.64	1.81	1.82	220	2.75	1275	1330
1975	91.8	92.3	248	296	.63	1.83	1.82	218	2.75	1258	1265
1976	89.5	90.4	246	285	.63	1.83	1.84	221	2.75	1289	1340

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

WEST GERMANY

Mechanised longwall output in million tons
and
mechanised advance in centimetres
related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1960	55.5	264	380	362	.665	2.3	.196
1961	70.0	263	475	362	.673	2.3	.196
1962	83.8	262	566	360	.682	2.3	.198
1963	94.6	264	582	359	.746	2.3	.200
1964	104.8	264	675	357	.716	2.3	.202
1965	105.9	262	648	355	.732	2.4	.204
1966	101.9	255	558	353	.811	2.5	.209
1967	93.2	242	505	352	.833	2.6	.208
1968	97.5	251	460	350	.923	2.6	.230
1969	99.4	253	425	347	1.025	2.6	.249
1970	101.9	254	410	342	1.060	2.7	.261
1971	103.2	253	398	338	1.123	2.7	.267
1972	98.7	245	372	335	1.197	2.7	.274
1973	94.8	249	315	332	1.348	2.7	.309
1974	92.9	248	300	330	1.401	2.7	.309
1975	91.8	248	296	327	1.416	2.7	.311
1976	89.5	246	285	325	1.455	2.7	.313

Based on Equations V and III
See Appendix II for notation

WEST GERMANY

Total input per ton
in US dollars at 1960 prices and exchange rate,
and its percentage breakdown

	TI/O	Manpower	Capital	Supplies/ Overheads
		%	%	%
1960	13.50	56.4	5.6	38.0
1961	13.05	55.0	5.3	39.7
1962	12.46	54.3	5.6	40.1
1963	12.36	51.3	6.0	42.7
1964	12.24	49.8	6.0	44.2
1965	12.73	48.1	6.3	45.6
1966	12.42	48.3	6.7	45.0
1967	12.27	47.4	7.3	45.3
1968	11.22	46.1	7.4	46.5
1969	10.70	45.9	6.5	47.6
1970	10.53	45.2	6.5	48.3
1971	10.77	43.8	5.6	50.6
1972	11.35	41.5	5.9	52.6
1973	11.28	40.1	7.7	52.2
1974	12.68	35.1	7.8	57.1
1975	14.35	32.0	6.9	61.1
1976	14.73	31.2	6.8	62.0

WEST GERMANY

APPENDIX IVf

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1960	74.07	73.80	479	2.14	5.16	.564	.607	.772	2.53	361	5.78
1961	76.63	76.53	515	2.13	6.84	.550	.616	.772	2.01	325	5.97
1962	80.26	80.24	555	2.14	8.78	.543	.619	.762	1.67	293	6.14
1963	80.91	80.96	596	2.22	9.54	.513	.625	.802	1.49	270	6.20
1964	81.70	81.37	618	2.19	11.13	.498	.629	.796	1.34	253	6.39
1965	78.56	78.67	626	2.14	12.07	.481	.632	.791	1.27	226	7.05
1966	80.52	80.44	656	2.24	12.08	.483	.638	.785	1.23	205	7.43
1967	81.50	81.55	688	2.44	12.75	.474	.613	.760	1.19	184	7.88
1968	89.11	89.34	778	2.62	13.01	.461	.645	.774	1.14	164	7.83
1969	93.46	93.45	811	2.74	13.32	.459	.648	.777	1.11	149	8.26
1970	95.00	95.18	808	3.22	13.64	.452	.651	.681	1.08	138	8.98
1971	92.86	92.43	808	3.69	13.42	.438	.654	.609	1.07	130	9.52
1972	88.10	88.55	807	4.21	13.56	.415	.646	.550	1.05	121	10.26
1973	88.65	88.68	839	4.93	12.76	.401	.658	.515	1.04	113	10.52
1974	78.87	78.64	838	5.83	12.28	.351	.659	.461	1.03	102	11.70
1975	69.69	69.78	808	5.88	12.23	.320	.661	.448	1.02	99	12.55
1976	67.89	68.05	807	6.06	12.91	.312	.662	.413	1.02	93	13.32

Based on Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

WEST GERMANY

tvF as a fraction of a market ton

1960	.962
1961	.962
1962	.959
1963	.959
1964	.959
1965	.958
1966	.958
1967	.959
1968	.956
1969	.954
1970	.951
1971	.946
1972	.943
1973	.938
1974	.935
1975	.931
1976	.931

Based on References 327 and 328

FRANCE

APPENDIX Va

Total longwall output in million tons and Daily output per face in tons

	O_A	O_P	$\bar{d}$	$\bar{n}$	$\bar{c}$	$\bar{k}$	$\bar{s}$	$\bar{l}$	$\bar{a}$	$\overline{DOF}_P$	$\overline{DOF}_A$
1960	39.2	37.8	280	702	.63	1.76	1.52	96	1.19	192	189
1961	37.2	37.9	277	669	.63	1.76	1.53	95	1.27	205	198
1962	37.2	38.1	280	642	.63	1.76	1.49	101	1.27	212	209
1963	32.6	33.0	256	549	.63	1.76	1.51	107	1.31	235	229
1964	32.2	33.4	278	488	.63	1.76	1.51	115	1.28	246	242
1965	34.4	34.2	274	488	.63	1.76	1.52	115	1.32	256	254
1966	33.8	33.7	274	430	.63	1.76	1.52	118	1.44	286	282
1967	31.7	31.5	260	385	.63	1.76	1.54	119	1.55	315	306
1968	27.3	26.9	247	328	.63	1.76	1.54	120	1.62	332	329
1969	29.6	30.4	255	295	.63	1.76	1.57	129	1.80	404	415
1970	27.8	28.1	251	250	.62	1.77	1.65	126	1.96	447	433
1971	22.0	22.0	243	204	.62	1.77	1.65	125	1.96	444	435
1972	20.2	19.5	239	188	.62	1.77	1.63	125	1.94	434	439
1973	16.8	16.6	238	157	.62	1.77	1.64	135	1.83	445	448
1974	15.0	14.8	230	145	.62	1.77	1.64	135	1.83	445	450
1975	13.8	13.6	234	126	.62	1.77	1.68	135	1.85	460	457
1976	13.1	12.6	235	105	.62	1.77	1.69	145	1.90	511	493

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

FRANCE

Output per man-year underground in tons

	$\frac{O}{MY_u}$	$\overline{DOF}$	$\frac{MS_u}{MY_u}$	MS_u/dn
1960	423	189	230	102.8
1961	434	198	230	104.9
1962	444	209	231	108.7
1963	414	229	209	115.6
1964	427	242	229	129.8
1965	472	254	229	123.2
1966	483	282	229	133.7
1967	500	306	222	135.9
1968	493	329	210	140.1
1969	542	415	214	163.9
1970	559	433	211	163.4
1971	547	435	204	162.2
1972	539	439	200	162.9
1973	530	448	193	163.1
1974	525	450	187	160.3
1975	528	457	191	165.3
1976	537	493	193	177.2

Based on Equation IV
See Appendix II for notation

FRANCE

APPENDIX Vc

Mechanised longwall output in million tons
and
Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1960	17.6	17.4	280	230	.64	1.75	1.36	124	1.43	270	260
1961	18.4	18.6	277	241	.64	1.75	1.38	124	1.45	278	267
1962	20.8	20.8	280	250	.64	1.75	1.38	131	1.47	298	297
1963	19.6	19.9	256	244	.63	1.76	1.38	139	1.50	319	313
1964	21.2	21.7	278	244	.63	1.76	1.46	139	1.42	319	309
1965	23.3	23.1	274	253	.63	1.76	1.47	143	1.43	333	325
1966	24.4	25.0	274	241	.63	1.76	1.44	148	1.60	378	368
1967	23.9	24.7	260	238	.63	1.76	1.44	148	1.69	399	388
1968	20.6	21.0	247	200	.63	1.76	1.44	149	1.79	426	423
1969	22.3	22.1	255	176	.63	1.76	1.47	149	2.03	493	504
1970	24.5	24.7	251	188	.62	1.77	1.50	152	2.09	523	512
1971	19.4	19.4	243	156	.62	1.77	1.50	145	2.15	513	520
1972	17.8	17.3	239	133	.62	1.77	1.55	145	2.21	545	538
1973	14.9	14.6	238	122	.62	1.77	1.55	145	2.04	503	520
1974	13.2	13.0	230	120	.62	1.77	1.57	144	1.90	471	478
1975	12.1	11.9	234	105	.62	1.77	1.60	145	1.90	484	468
1976	11.5	11.3	235	93	.62	1.77	1.62	153	1.90	517	522

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

FRANCE

Mechanised longwall output in million tons and mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1960	17.6	280	230	342	.399	2.0	.210
1961	18.4	277	241	340	.405	2.0	.213
1962	20.8	280	250	337	.441	2.0	.218
1963	19.6	256	244	336	.467	2.0	.223
1964	21.2	278	244	336	.465	2.0	.211
1965	23.3	274	253	332	.482	2.1	.205
1966	24.4	274	241	329	.510	2.2	.221
1967	23.9	260	238	327	.513	2.3	.225
1968	20.6	247	200	325	.558	2.3	.239
1969	22.3	255	176	322	.643	2.4	.263
1970	24.5	251	188	320	.676	2.4	.272
1971	19.4	243	156	316	.675	2.4	.283
1972	17.8	239	133	314	.713	2.5	.281
1973	14.9	238	122	309	.692	2.4	.275
1974	13.2	230	120	305	.682	2.3	.271
1975	12.1	234	105	303	.707	2.3	.273
1976	11.5	235	93	303	.755	2.3	.273

Based on Equations V and III
See Appendix II for notation

APPENDIX Ve

FRANCE

Total input per ton
in US dollars at 1960 prices and exchange rate,
and its percentage breakdown

	$\frac{TI}{O}$	Manpower	Capital	Supplies/ Overheads
		%	%	%
1960	14.90	58.4	8.8	32.8
1961	15.23	58.9	9.0	32.1
1962	14.86	59.3	9.1	31.6
1963	14.47	59.2	9.2	31.6
1964	13.48	58.5	9.7	31.8
1965	13.25	58.4	9.4	32.2
1966	13.29	58.0	9.3	32.7
1967	13.67	57.2	9.1	33.7
1968	13.90	56.4	9.8	33.8
1969	13.47	55.2	9.8	35.0
1970	13.81	54.9	9.7	35.4
1971	13.82	54.4	9.9	35.7
1972	14.53	52.9	9.0	38.1
1973	15.96	51.6	8.5	39.9
1974	16.90	49.5	7.5	43.0
1975	17.91	46.7	7.4	45.9
1976	18.02	45.8	7.4	46.8

FRANCE

APPENDIX Vf

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1960	67.11	67.10	423	2.97	6.28	.584	.562	.492	2.23	352	6.71
1961	65.65	65.56	434	2.96	6.72	.589	.565	.491	2.02	332	6.93
1962	67.29	67.22	444	2.94	7.16	.593	.568	.530	1.79	322	6.99
1963	69.11	68.78	414	2.81	8.77	.592	.547	.520	1.66	312	7.73
1964	74.19	74.06	427	2.93	9.13	.585	.537	.580	1.52	299	7.83
1965	75.47	75.03	472	2.89	9.16	.584	.571	.579	1.48	264	7.96
1966	75.24	75.10	483	2.68	10.40	.580	.576	.584	1.38	253	8.19
1967	73.15	73.21	500	2.74	10.85	.572	.570	.568	1.33	228	8.77
1968	71.93	71.82	493	2.75	11.08	.564	.546	.577	1.33	215	9.41
1969	74.24	74.55	542	2.73	11.00	.552	.579	.583	1.33	196	9.43
1970	72.41	71.96	559	3.03	11.61	.549	.581	.569	1.13	183	9.75
1971	72.36	72.02	547	3.46	12.15	.544	.580	.480	1.13	172	10.64
1972	68.82	68.73	539	3.94	11.46	.529	.588	.432	1.13	170	10.94
1973	62.66	62.77	530	4.46	11.06	.516	.589	.371	1.13	156	12.08
1974	59.17	59.33	525	4.62	10.89	.495	.578	.361	1.14	141	13.53
1975	55.82	55.74	528	5.03	10.14	.467	.590	.348	1.14	134	14.13
1976	55.50	55.40	537	5.13	10.08	.458	.592	.347	1.14	125	14.88

Based on Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

BELGIUM

APPENDIX VIa

Total longwall output in million tons
and
Daily output per face in tons

	O_A	O_P	$\bar{d}$	$\bar{n}$	$\bar{c}$	$\bar{k}$	$\bar{s}$	$\bar{l}$	$\bar{a}$	$\overline{DOF}_P$	$\overline{DOF}_A$
1960	22.0	21.1	264	460	.59	1.85	1.27	114	1.10	174	181
1961	21.5	20.9	260	444	.59	1.85	1.28	118	1.10	181	187
1962	21.2	21.0	257	419	.59	1.85	1.40	118	1.08	195	190
1963	21.2	20.4	250	419	.59	1.85	1.40	124	1.03	195	188
1964	21.2	20.4	256	400	.59	1.85	1.40	124	1.05	199	197
1965	19.6	19.6	240	388	.59	1.85	1.40	130	1.06	211	209
1966	17.3	17.4	237	329	.58	1.86	1.40	134	1.10	223	219
1967	16.3	16.4	243	272	.58	1.86	1.42	137	1.18	248	258
1968	14.7	14.8	243	230	.58	1.86	1.42	147	1.18	266	274
1969	13.0	12.6	235	182	.58	1.86	1.45	155	1.22	296	308
1970	11.2	10.9	226	151	.58	1.86	1.47	158	1.28	321	332
1971	10.8	10.5	239	129	.58	1.86	1.50	162	1.30	341	350
1972	10.3	10.0	241	115	.58	1.86	1.52	166	1.32	359	366
1973	8.6	8.4	240	89	.58	1.86	1.52	171	1.40	393	400
1974	7.9	7.8	240	75	.58	1.86	1.55	175	1.48	433	430
1975	7.2	7.0	241	53	.58	1.86	1.58	200	1.62	552	545
1976	7.0	6.8	246	48	.58	1.86	1.59	205	1.65	580	585

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

BELGIUM

Output per man-year underground
in tons

	$\frac{O}{MY_u}$	$\overline{DOF}$	$\frac{MS_u}{MY_u}$	MS_u/dn'
1960	286	181	190	120.2
1961	328	187	200	114.0
1962	358	190	201	106.7
1963	360	188	202	105.5
1964	362	197	202	109.9
1965	360	209	202	117.3
1966	373	219	193	113.3
1967	409	258	193	121.7
1968	420	274	190	124.0
1969	428	308	184	132.4
1970	441	332	175	131.7
1971	456	350	180	138.2
1972	458	366	183	146.2
1973	439	400	180	164.0
1974	432	430	177	176.2
1975	400	545	173	235.7
1976	409	585	170	243.1

Based on Equation IV
See Appendix II for notation

BELGIUM

APPENDIX VIc

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{i}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1960	10.4	10.6	264	126	.60	1.84	1.37	168	1.25	318	320
1961	12.9	13.1	260	152	.60	1.84	1.37	169	1.30	332	327
1962	14.0	14.4	257	160	.59	1.85	1.40	170	1.35	351	353
1963	15.9	15.8	250	180	.59	1.85	1.40	169	1.36	351	341
1964	16.0	16.0	256	182	.59	1.85	1.40	164	1.37	343	340
1965	14.9	14.8	240	174	.59	1.85	1.40	166	1.40	355	352
1966	13.3	13.6	237	155	.58	1.86	1.43	168	1.43	371	360
1967	12.6	12.7	243	133	.58	1.86	1.41	172	1.50	392	401
1968	11.3	11.6	243	120	.58	1.86	1.40	177	1.49	398	408
1969	10.0	9.8	235	96	.58	1.86	1.47	181	1.52	436	447
1970	9.1	8.9	226	85	.58	1.86	1.48	188	1.54	462	483
1971	9.2	9.0	239	80	.58	1.86	1.49	190	1.55	473	485
1972	8.9	9.1	241	76	.58	1.86	1.52	190	1.59	495	486
1973	7.3	7.3	240	60	.58	1.86	1.52	194	1.60	509	499
1974	7.2	7.2	240	56	.58	1.86	1.55	199	1.62	539	534
1975	7.0	6.8	241	50	.58	1.86	1.58	202	1.65	568	550
1976	6.9	6.9	246	46	.58	1.86	1.59	208	1.70	606	600

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

BELGIUM

Mechanised longwall output in million tons and mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1960	10.4	264	126	361	.481	1.8	.192
1961	12.9	260	152	358	.506	1.8	.202
1962	14.0	257	160	353	.508	1.9	.201
1963	15.9	250	180	349	.533	1.9	.205
1964	16.0	256	182	345	.524	1.9	.209
1965	14.9	240	174	343	.547	1.9	.215
1966	13.3	237	155	340	.532	2.0	.210
1967	12.6	243	133	337	.551	2.1	.212
1968	11.3	243	120	335	.551	2.1	.212
1969	10.0	235	96	333	.633	2.1	.217
1970	9.1	226	85	331	.681	2.1	.222
1971	9.2	239	80	330	.694	2.1	.224
1972	8.9	241	76	327	.675	2.2	.221
1973	7.3	240	60	326	.707	2.2	.223
1974	7.2	240	56	324	.752	2.2	.227
1975	7.0	241	50	322	.820	2.2	.233
1976	6.9	246	46	321	.863	2.2	.241

Based on Equations V and III
See Appendix II for notation

BELGIUM

Total input per ton in US dollars at 1960 prices and exchange rate, and its percentage breakdown

	$\frac{TI}{O}$	Manpower	Capital	Supplies/ Overheads
		%	%	%
1960	16.04	53.3	5.6	41.1
1961	15.88	51.5	5.6	42.9
1962	15.56	51.4	5.8	42.8
1963	15.15	51.4	5.8	42.8
1964	14.92	51.6	6.3	42.1
1965	14.16	49.6	6.0	44.4
1966	14.56	47.3	5.8	46.9
1967	14.52	45.9	5.9	48.2
1968	15.01	45.5	6.1	48.4
1969	14.23	43.4	6.2	50.4
1970	14.63	38.9	6.6	54.5
1971	15.58	37.6	5.8	56.6
1972	15.92	37.2	6.8	56.0
1973	16.82	37.5	6.3	56.2
1974	17.31	36.6	6.1	57.3
1975	20.21	32.8	5.3	61.9
1976	20.20	32.1	5.6	62.3

BELGIUM

APPENDIX VIf

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1960	62.34	62.11	286	2.48	7.71	.533	.556	.519	2.11	395	8.86
1961	62.97	63.13	328	2.70	9.38	.515	.557	.521	1.67	341	8.93
1962	65.17	64.92	358	2.77	10.44	.514	.553	.516	1.51	316	8.96
1963	66.00	65.69	360	2.81	11.81	.514	.559	.518	1.33	310	8.96
1964	67.02	66.65	362	3.03	11.18	.516	.555	.521	1.32	308	8.96
1965	70.63	70.53	360	3.10	12.71	.496	.562	.489	1.31	305	9.13
1966	68.69	68.51	373	3.18	13.68	.473	.540	.475	1.30	274	9.77
1967	68.86	69.13	409	3.10	14.50	.459	.565	.456	1.29	237	10.31
1968	66.64	66.65	420	3.06	14.44	.455	.565	.451	1.30	232	10.27
1969	70.27	70.39	428	3.54	14.32	.434	.566	.435	1.30	225	10.38
1970	68.33	68.24	441	4.23	15.51	.389	.539	.403	1.23	205	11.07
1971	64.17	63.90	456	4.82	15.16	.376	.568	.350	1.17	191	11.48
1972	62.80	62.99	458	6.42	12.29	.372	.567	.326	1.16	186	11.75
1973	59.47	59.55	439	6.94	11.80	.375	.567	.290	1.18	183	12.44
1974	57.79	58.05	432	7.67	11.60	.366	.567	.285	1.10	173	13.42
1975	49.48	49.48	400	7.74	11.32	.328	.568	.294	1.03	170	14.72
1976	49.50	49.29	409	7.86	11.23	.321	.570	.302	1.01	160	15.29

Based on Figure 18
See Appendix II for notation

Suffic A = actual
P = predicted

APPENDIX VIIa

POLAND

Total longwall output in million tons and Daily output per face in tons

	O_A	O_P	$\bar{d}$	$\bar{n}$	$\bar{c}$	$\bar{k}$	$\bar{s}$	$\bar{l}$	$\bar{a}$	$\overline{DOF}_P$	$\overline{DOF}_A$
1960	62.4	63.1	310	850	.79	1.59	1.69	91	1.24	239	245
1961	66.1	66.8	310	832	.79	1.59	1.76	93	1.26	259	258
1962	69.4	70.7	310	824	.79	1.59	1.76	97	1.29	277	283
1963	74.6	76.0	310	793	.80	1.58	1.80	103	1.32	309	317
1964	81.0	82.4	310	775	.80	1.58	1.83	109	1.36	343	351
1965	85.0	87.8	310	758	.80	1.58	1.85	115	1.39	374	383
1966	92.7	90.3	310	755	.80	1.58	1.85	117	1.41	386	399
1967	95.4	95.9	310	727	.80	1.58	1.87	125	1.44	425	431
1968	101.5	99.4	310	722	.80	1.58	1.87	127	1.48	444	460
1969	106.7	106.7	309	722	.80	1.58	1.90	131	1.52	478	482
1970	113.4	113.1	309	724	.80	1.58	1.92	137	1.52	505	503
1971	122.2	116.8	309	724	.82	1.56	1.96	137	1.52	522	520
1972	123.5	124.4	309	725	.82	1.56	2.00	140	1.55	555	562
1973	132.9	131.4	307	722	.83	1.55	2.00	144	1.60	593	617
1974	140.9	138.3	305	720	.83	1.55	2.00	144	1.70	630	617
1975	151.0	148.3	305	692	.83	1.55	2.15	146	1.74	703	713
1976	156.9	154.2	305	655	.84	1.54	2.24	148	1.80	772	794

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

POLAND

Output per man-year underground in tons

	$\frac{O}{MY_u}$	$\overline{DOF}$	$\frac{MS_u}{MY_u}$	MS_u/dn
1960	486	245	274	138.1
1961	496	258	275	143.0
1962	522	283	273	148.0
1963	541	317	275	161.1
1964	564	351	274	170.5
1965	569	383	269	181.1
1966	584	399	269	183.8
1967	603	431	266	190.1
1968	634	460	262	190.1
1969	653	482	262	193.4
1970	671	503	262	196.4
1971	692	520	261	196.1
1972	704	562	256	204.3
1973	736	617	259	217.1
1974	761	617	259	210.0
1975	784	713	262	238.3
1976	812	794	259	253.3

Based on Equation IV
See Appendix II for notation

APPENDIX VIIc

POLAND

Mechanised longwall output in million tons
and
Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1960	17.6	17.4	310	180	.80	1.58	1.70	118	1.23	312	325
1961	19.8	19.9	310	192	.80	1.58	1.70	120	1.30	335	350
1962	23.1	22.1	311	200	.80	1.58	1.71	122	1.35	356	369
1963	29.8	29.8	310	248	.80	1.58	1.71	128	1.40	387	398
1964	38.8	38.0	310	286	.80	1.58	1.72	134	1.47	428	441
1965	46.7	45.9	310	315	.80	1.58	1.70	141	1.55	470	478
1966	58.0	57.9	310	368	.80	1.58	1.70	144	1.64	507	508
1967	66.5	68.1	310	413	.80	1.58	1.70	150	1.65	532	520
1968	71.0	72.5	310	440	.80	1.58	1.70	150	1.65	532	513
1969	77.3	79.1	309	440	.80	1.58	1.89	145	1.68	582	606
1970	85.0	84.6	309	436	.80	1.58	2.04	145	1.68	628	631
1971	95.2	93.0	309	452	.82	1.56	2.05	146	1.74	666	638
1972	96.5	97.6	309	450	.82	1.56	2.10	146	1.79	702	691
1973	106.0	108.8	307	448	.82	1.56	2.10	155	1.90	791	763
1974	118.4	121.4	305	485	.83	1.55	2.10	155	1.96	821	798
1975	127.6	132.1	304	509	.83	1.55	2.14	155	2.00	853	820
1976	135.4	139.8	304	518	.84	1.54	2.20	156	2.00	888	860

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

POLAND

Mechanised longwall output in million tons and mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1960	17.6	310	180	340	.422	2.2	.164
1961	19.8	310	192	337	.449	2.2	.175
1962	23.1	311	200	334	.505	2.2	.184
1963	29.8	310	248	333	.506	2.3	.183
1964	38.8	310	286	330	.552	2.4	.186
1965	46.7	310	315	329	.606	2.4	.196
1966	58.0	310	368	327	.622	2.5	.201
1967	66.5	310	413	327	.635	2.5	.202
1968	71.0	310	440	325	.641	2.5	.203
1969	77.3	309	440	325	.700	2.5	.207
1970	85.0	309	436	322	.784	2.5	.209
1971	95.2	309	452	321	.817	2.6	.208
1972	96.5	309	450	319	.837	2.6	.220
1973	106.0	307	448	319	.929	2.6	.229
1974	118.4	305	485	317	.935	2.7	.229
1975	127.6	304	509	317	.963	2.7	.234
1976	135.4	304	518	315	1.011	2.7	.235

Based on Equations V and III
See Appendix II for notation

POLAND

Total input per ton
in US dollars at 1960 prices and exchange rate,
and its percentage breakdown

	TI/O	Manpower	Capital	Supplies/ Overheads
		%	%	%
1960	11.55	44.2	8.9	46.9
1961	11.52	43.0	9.0	48.0
1962	11.51	41.7	9.0	49.3
1963	11.51	40.2	9.0	50.8
1964	11.60	40.7	8.8	50.5
1965	11.84	41.6	8.7	49.7
1966	11.83	40.6	8.9	50.3
1967	11.69	39.9	8.9	51.2
1968	11.52	39.2	9.0	51.8
1969	11.47	38.7	9.0	52.3
1970	11.49	38.1	9.0	52.9
1971	12.33	35.1	8.0	56.9
1972	12.30	34.6	8.6	56.8
1973	12.94	32.0	8.2	59.8
1974	13.26	30.5	8.3	61.2
1975	13.19	30.3	8.3	61.4
1976	13.79	28.7	8.1	63.2

POLAND

APPENDIX VIIf

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1960	86.58	86.70	486	2.92	5.19	.442	.669	.546	3.55	380	5.42
1961	86.80	86.73	496	2.93	5.34	.430	.671	.576	3.34	357	5.64
1962	86.88	86.59	522	2.82	5.66	.417	.675	.643	3.00	319	6.00
1963	86.89	86.46	541	2.79	6.95	.402	.685	.649	2.50	298	6.19
1964	86.21	86.20	564	2.58	7.84	.407	.697	.720	2.09	277	6.39
1965	84.46	84.26	569	2.44	8.46	.416	.700	.771	1.82	266	6.60
1966	84.53	84.52	584	2.32	9.94	.406	.703	.802	1.60	240	7.14
1967	85.54	85.55	603	2.29	11.62	.399	.722	.779	1.43	226	7.35
1968	86.80	86.82	634	2.42	11.91	.392	.724	.741	1.43	209	7.56
1969	87.22	86.93	653	2.37	12.04	.387	.727	.785	1.38	197	7.77
1970	87.03	86.56	671	2.76	11.68	.381	.725	.732	1.33	178	8.36
1971	81.10	80.75	692	3.03	11.85	.351	.729	.687	1.28	157	9.20
1972	81.30	81.00	704	3.17	11.88	.346	.731	.667	1.28	148	9.56
1973	77.28	76.77	736	3.32	11.85	.320	.734	.666	1.25	131	10.35
1974	75.42	75.39	761	3.61	12.00	.305	.739	.649	1.19	119	11.04
1975	75.81	75.42	784	3.76	12.05	.303	.743	.628	1.18	113	11.26
1976	72.52	72.58	812	3.88	12.04	.287	.743	.628	1.16	106	11.62

Based on Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

CZECHOSLOVAKIA

APPENDIX VIIIa

Total longwall output in million tons
and
Daily output per face in tons

	O_A	O_P	$\bar{d}$	$\bar{n}$	$\bar{c}$	$\bar{k}$	$\bar{s}$	$\bar{l}$	$\bar{a}$	$\overline{DOF}_P$	$\overline{DOF}_A$
1960	26.4	26.1	269	503	.79	1.69	1.18	102	1.20	193	195
1961	27.5	27.3	269	499	.79	1.69	1.20	106	1.20	204	210
1962	28.0	27.3	269	499	.79	1.69	1.20	106	1.20	204	210
1963	28.2	27.4	268	503	.79	1.69	1.15	106	1.25	203	208
1964	28.0	27.8	265	492	.77	1.71	1.15	105	1.34	213	215
1965	27.7	27.4	262	444	.77	1.71	1.15	109	1.43	236	242
1966	26.9	27.6	262	404	.77	1.71	1.17	113	1.50	261	267
1967	26.1	26.2	262	330	.77	1.71	1.24	116	1.60	303	314
1968	26.0	26.5	260	310	.77	1.71	1.29	118	1.64	329	339
1969	27.2	27.3	260	298	.77	1.71	1.38	122	1.59	352	361
1970	27.2	27.5	260	288	.77	1.71	1.41	122	1.62	367	377
1971	25.7	25.6	260	257	.77	1.71	1.42	122	1.68	383	387
1972	25.6	25.2	260	232	.77	1.71	1.42	123	1.82	418	423
1973	24.8	24.7	262	207	.75	1.73	1.61	118	1.85	456	439
1974	24.8	25.1	262	196	.75	1.73	1.63	118	1.96	489	475
1975	24.8	24.4	262	192	.74	1.74	1.65	116	1.97	485	482
1976	24.9	24.5	262	190	.74	1.74	1.65	118	1.96	491	476

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

CZECHOSLOVAKIA

Output per man-year underground
in tons

	$\frac{O}{MY_u}$	$\overline{DOF}$	$\frac{MS_u}{MY_u}$	MS_u/dn
1960	388	195	237	119.1
1961	404	210	238	123.7
1962	412	210	237	120.8
1963	403	208	238	122.8
1964	400	215	240	129.0
1965	401	242	231	139.4
1966	434	267	231	142.1
1967	483	314	225	146.3
1968	507	339	225	150.4
1969	555	361	225	146.4
1970	587	377	225	144.5
1971	602	387	225	144.6
1972	611	423	224	155.1
1973	620	439	223	157.9
1974	625	475	223	169.5
1975	637	482	223	168.7
1976	640	476	223	165.9

Based on Equation IV
See Appendix II for notation

CZECHOSLOVAKIA

APPENDIX VIIIc

Mechanised longwall output in million tons
and
Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1960	9.0	9.0	269	133	.80	1.70	1.36	112	1.22	253	245
1961	10.6	10.4	269	152	.80	1.70	1.36	112	1.23	255	250
1962	12.3	12.8	269	188	.79	1.69	1.36	112	1.25	254	250
1963	16.8	16.9	268	250	.79	1.69	1.35	112	1.25	252	248
1964	18.9	18.9	265	265	.77	1.71	1.35	112	1.35	269	260
1965	20.0	20.4	262	260	.77	1.71	1.35	116	1.45	299	290
1966	20.0	20.3	262	232	.77	1.71	1.40	119	1.52	333	320
1967	19.6	19.7	262	208	.77	1.71	1.40	121	1.62	361	360
1968	21.1	21.1	260	208	.77	1.71	1.45	124	1.65	391	390
1969	23.2	23.2	260	220	.77	1.71	1.47	127	1.65	406	414
1970	23.9	23.8	260	217	.77	1.71	1.47	128	1.70	421	432
1971	22.2	22.3	260	195	.77	1.71	1.50	127	1.75	439	451
1972	21.8	22.4	260	180	.77	1.71	1.52	126	1.90	479	482
1973	21.8	22.3	262	168	.75	1.73	1.67	120	1.95	507	492
1974	21.9	22.4	262	160	.75	1.73	1.69	119	2.05	535	528
1975	22.5	22.2	262	156	.75	1.73	1.71	117	2.09	542	524
1976	22.3	22.0	262	153	.75	1.73	1.72	120	2.05	549	529

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

CZECHOSLOVAKIA

Mechanised longwall output in million tons
and
mechanised advance in centimetres
related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1960	9.0	269	133	372	.338	2.0	.164
1961	10.6	269	152	371	.349	2.0	.166
1962	12.3	269	188	370	.346	1.9	.178
1963	16.8	268	250	369	.358	1.9	.178
1964	18.9	265	265	368	.366	2.0	.183
1965	20.0	262	260	366	.382	2.1	.189
1966	20.0	262	232	364	.411	2.2	.190
1967	19.6	262	208	362	.452	2.2	.203
1968	21.1	260	208	360	.493	2.2	.208
1969	23.2	260	220	358	.515	2.2	.209
1970	23.9	260	217	356	.541	2.2	.217
1971	22.2	260	195	354	.538	2.3	.215
1972	21.8	260	180	352	.551	2.4	.225
1973	21.8	262	168	350	.566	2.5	.223
1974	21.9	262	160	349	.599	2.5	.235
1975	22.5	262	156	348	.633	2.5	.240
1976	22.3	262	153	345	.645	2.5	.238

Based on Equations V and III
See Appendix II for notation

CZECHOSLOVAKIA

Total input per ton in US dollars at 1960 prices and exchange rate, and its percentage breakdown

	$\frac{TI}{O}$	Manpower	Capital	Supplies/ Overheads
		%	%	%
1960	13.05	45.0	10.9	44.1
1961	13.05	44.6	10.9	44.5
1962	13.07	44.1	11.0	44.9
1963	13.10	43.8	11.0	45.2
1964	13.10	43.3	11.6	45.1
1965	13.38	42.7	12.0	45.3
1966	13.36	42.6	12.0	45.4
1967	13.11	40.4	12.6	47.0
1968	13.11	37.6	13.0	49.4
1969	13.01	35.7	13.1	51.2
1970	13.01	34.4	13.1	52.5
1971	13.76	32.6	13.1	54.3
1972	13.93	32.0	13.0	55.0
1973	14.63	31.2	13.1	55.7
1974	15.00	30.4	13.0	56.6
1975	14.95	29.4	13.3	57.3
1976	15.62	28.1	13.3	58.6

CZECHOSLOVAKIA

APPENDIX VIIIf

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1960	76.63	76.39	388	3.29	6.83	.450	.682	.379	2.93	414	6.21
1961	76.62	76.38	404	3.38	7.61	.446	.684	.376	2.59	389	6.36
1962	76.50	76.63	412	3.30	9.41	.441	.687	.357	2.28	376	6.46
1963	76.34	76.64	403	3.39	12.26	.438	.691	.363	1.68	370	6.70
1964	76.34	75.94	400	3.44	13.04	.433	.700	.378	1.48	372	6.71
1965	74.74	74.85	401	3.14	14.10	.427	.719	.397	1.39	350	7.11
1966	74.85	74.66	434	2.88	14.72	.426	.719	.428	1.34	300	7.70
1967	76.27	76.00	483	2.79	15.31	.404	.721	.460	1.33	262	7.89
1968	76.27	75.99	507	3.02	15.79	.376	.723	.477	1.23	243	8.11
1969	76.86	76.90	555	3.08	17.30	.357	.725	.476	1.17	220	8.20
1970	76.86	77.16	587	3.32	17.76	.344	.728	.446	1.17	200	8.53
1971	72.68	72.71	602	3.65	17.16	.326	.728	.422	1.16	172	9.65
1972	71.79	72.00	611	3.83	16.53	.320	.730	.427	1.14	167	9.80
1973	68.36	68.39	620	3.95	16.25	.312	.731	.410	1.14	155	10.40
1974	66.67	66.34	625	3.96	15.86	.304	.735	.419	1.13	142	11.25
1975	66.88	66.56	637	4.01	16.25	.294	.738	.429	1.10	129	12.14
1976	64.03	64.35	640	4.05	15.80	.281	.738	.432	1.12	127	12.33

Based on Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

UKRAINE

APPENDIX IXa

Total longwall output in million tons
and
Daily output per face in tons

	O_A	O_P	$\bar{d}$	$\bar{n}$	$\bar{c}$	$\bar{k}$	$\bar{s}$	$\bar{l}$	$\bar{a}$	$\overline{DOF}_P$	$\overline{DOF}_A$
1960	137.0	134.1	320	2110	.86	1.70	.95	110	1.30	199	192
1961	138.5	138.6	320	2110	.86	1.70	.95	112	1.32	205	207
1962	140.0	138.7	320	2077	.86	1.70	.95	113	1.33	209	211
1963	142.0	140.2	320	1975	.86	1.70	.97	115	1.36	222	215
1964	144.8	140.2	320	1942	.86	1.70	.97	117	1.36	226	230
1965	148.0	148.6	320	1815	.85	1.72	1.00	125	1.40	256	248
1966	152.5	149.2	319	1785	.85	1.72	1.00	128	1.40	262	256
1967	153.5	150.6	319	1700	.85	1.72	1.02	133	1.40	278	268
1968	155.0	156.7	319	1705	.85	1.72	1.02	138	1.40	288	288
1969	158.0	162.0	319	1648	.85	1.72	1.06	142	1.40	308	302
1970	169.2	165.1	319	1626	.85	1.72	1.05	146	1.42	318	320
1971	171.6	167.9	319	1558	.85	1.72	1.07	150	1.44	338	350
1972	171.5	170.9	318	1480	.85	1.72	1.09	155	1.47	363	365
1973	172.1	170.9	310	1460	.85	1.72	1.12	158	1.46	378	385
1974	171.8	170.0	307	1448	.85	1.72	1.12	160	1.46	382	385
1975	171.9	171.6	305	1440	.85	1.72	1.13	162	1.46	391	389
1976	172.5	173.7	305	1438	.85	1.72	1.13	162	1.48	396	402

Based on Equations I and III
See Appendix II for notation

Suffix A = actual

UKRAINE

Output per man-year underground
in tons

	$\frac{O}{MY_u}$	$\overline{DOF}$	$\frac{MS_u}{MY_u}$	MS_u/dn
1960	405	192	270	128.0
1961	412	207	270	135.6
1962	420	211	270	135.6
1963	423	215	268	136.2
1964	430	230	268	143.3
1965	438	248	267	151.2
1966	445	256	266	153.0
1967	457	268	261	153.1
1968	473	288	259	157.7
1969	489	302	255	157.5
1970	501	320	255	162.9
1971	518	350	240	162.2
1972	541	365	240	161.9
1973	557	385	230	159.0
1974	556	385	230	159.2
1975	557	389	229	159.9
1976	560	402	229	164.4

Based on Equation IV
See Appendix II for notation

UKRAINE

APPENDIX IXc

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1960	41.0	42.0	320	595	.86	1.70	1.00	116	1.30	220	212
1961	46.4	46.1	320	632	.86	1.70	1.01	117	1.32	228	230
1962	51.8	52.9	320	695	.86	1.70	1.02	119	1.34	238	235
1963	56.8	58.3	320	747	.86	1.70	1.03	120	1.35	244	240
1964	87.0	86.8	320	1067	.86	1.70	1.03	125	1.35	254	250
1965	99.2	96.5	320	1122	.85	1.72	1.04	130	1.36	269	270
1966	110.0	114.2	319	1273	.85	1.72	1.04	135	1.37	281	279
1967	122.8	125.6	319	1328	.85	1.72	1.05	140	1.38	297	292
1968	131.8	135.6	319	1370	.85	1.72	1.06	144	1.39	310	313
1969	143.0	146.7	319	1438	.85	1.72	1.07	146	1.40	320	328
1970	165.0	164.8	319	1550	.85	1.72	1.07	149	1.43	333	322
1971	168.0	162.4	319	1513	.85	1.72	1.08	147	1.45	337	350
1972	166.4	162.8	318	1410	.85	1.72	1.09	155	1.47	363	369
1973	167.0	167.7	310	1410	.85	1.72	1.13	158	1.47	384	386
1974	168.4	168.5	307	1388	.85	1.72	1.15	160	1.47	395	408
1975	170.0	167.7	305	1350	.85	1.72	1.17	162	1.47	407	408
1976	170.4	170.6	305	1352	.85	1.72	1.18	162	1.48	414	410

Based on Equations I and III
See Appendix II for notation

Suffix A = actual
P = predicted

UKRAINE

Mechanised longwall output in million tons
and
mechanised advance in centimetres
related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1960	41.0	320	595	340	.244	2.6	.147
1961	46.4	320	632	339	.260	2.6	.149
1962	51.8	320	695	338	.265	2.6	.152
1963	56.8	320	747	337	.271	2.6	.154
1964	87.0	320	1067	336	.292	2.6	.155
1965	99.2	320	1122	335	.317	2.6	.156
1966	110.0	319	1273	335	.311	2.6	.157
1967	122.8	319	1328	335	.333	2.6	.158
1968	131.8	319	1370	335	.346	2.6	.160
1969	143.0	319	1438	334	.359	2.6	.161
1970	165.0	319	1550	332	.372	2.7	.160
1971	168.0	319	1513	330	.391	2.7	.163
1972	166.4	318	1410	330	.416	2.7	.165
1973	167.0	310	1410	327	.433	2.7	.166
1974	168.4	307	1388	324	.452	2.7	.168
1975	170.0	305	1350	322	.475	2.7	.169
1976	170.4	305	1352	319	.480	2.7	.172

Based on Equations V and III
See Appendix II for notation

APPENDIX IXe

UKRAINE

Total input per ton
in US dollars at 1960 prices and exchange rate,
and its percentage breakdown

	TI/O	Manpower	Capital	Supplies/ Overheads
		%	%	%
1960	11.79	52.0	15.8	32.2
1961	11.79	51.7	16.0	32.3
1962	12.24	51.7	16.1	32.2
1963	12.61	51.1	16.3	32.6
1964	12.72	50.8	16.3	32.9
1965	12.80	50.5	16.5	33.0
1966	12.93	50.4	16.5	33.1
1967	13.04	50.3	16.5	33.2
1968	13.12	49.8	16.8	33.4
1969	13.70	49.1	17.0	33.9
1970	13.49	47.9	17.2	34.9
1971	14.22	47.0	16.9	36.1
1972	14.49	46.0	17.2	36.8
1973	15.20	45.5	17.0	37.5
1974	15.64	43.7	17.1	39.2
1975	15.64	42.1	17.1	40.8
1976	15.73	40.7	17.2	42.1

UKRAINE

APPENDIX IXf

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1960	84.82	84.85	405	2.55	7.39	.520	.713	.364	3.34	407	6.06
1961	84.82	84.70	412	2.48	8.02	.517	.714	.387	2.98	386	6.29
1962	81.70	81.30	420	2.28	9.14	.517	.717	.390	2.70	365	6.52
1963	79.30	79.25	423	2.12	10.36	.511	.719	.393	2.50	347	6.81
1964	78.61	78.32	430	1.94	16.08	.508	.723	.412	1.66	326	7.13
1965	78.12	78.10	438	2.07	16.33	.505	.724	.424	1.49	283	8.07
1966	77.34	77.33	445	2.10	16.94	.504	.727	.427	1.39	269	8.35
1967	76.69	76.84	457	2.21	17.45	.503	.730	.434	1.25	249	8.79
1968	76.22	76.62	473	2.41	17.60	.498	.733	.419	1.18	229	9.24
1969	73.01	72.80	489	2.51	17.41	.491	.738	.418	1.10	215	9.51
1970	74.13	73.91	501	2.75	17.52	.479	.745	.421	1.02	185	10.80
1971	70.33	70.19	518	2.79	17.55	.470	.752	.398	1.02	168	11.48
1972	69.01	68.85	541	2.79	17.61	.460	.760	.389	1.03	159	11.63
1973	65.79	65.67	557	2.93	17.59	.455	.776	.351	1.03	152	11.79
1974	63.94	63.76	556	3.03	17.54	.437	.785	.343	1.02	147	12.23
1975	63.94	63.72	557	3.00	18.65	.421	.792	.338	1.01	140	12.83
1976	63.57	63.13	560	3.06	19.20	.407	.792	.331	1.01	139	12.81

Based on Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

Total longwall output in million tons (O)

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	174.0	140.6	39.2	22.0	62.4	26.4	137.0
1961	170.0	140.9	37.2	21.5	66.1	27.5	138.5
1962	177.3	139.7	37.2	21.2	69.4	28.0	140.0
1963	178.8	140.8	32.6	21.2	74.6	28.2	142.0
1964	175.6	140.9	32.2	21.2	81.0	28.0	144.8
1965	166.3	134.0	34.4	19.6	85.0	27.7	148.0
1966	157.2	125.0	33.8	17.3	92.7	26.9	152.5
1967	155.4	111.0	31.7	16.3	95.4	26.1	153.5
1968	150.8	111.3	27.3	14.7	101.5	26.0	155.0
1969	137.8	110.1	29.6	13.0	106.7	27.2	158.0
1970	131.4	110.2	27.8	11.2	113.4	27.2	169.2
1971	108.1	110.9	22.0	10.8	122.2	25.7	171.6
1972	125.7	103.3	20.2	10.3	123.5	25.6	171.5
1973	96.1	98.5	16.8	8.6	132.9	24.8	172.1
1974	113.6	95.9	15.0	7.9	140.9	24.8	171.8
1975	111.7	93.8	13.8	7.2	151.0	24.8	171.9
1976	106.0	91.0	13.1	7.0	156.9	24.9	172.5
% change 1960/76	-39.1%	-35.3%	-66.6%	-68.2%	+151.4%	-5.7%	+25.9%

APPENDIX Xb

Total input for longwall output
in million US dollars at 1960 prices and exchange rates (TI)

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	2042.8	1898.1	584.1	352.9	720.7	344.5	1615.2
1961	1985.6	1838.7	566.6	341.4	761.5	358.9	1632.9
1962	1976.9	1740.6	552.8	329.9	798.8	366.0	1713.6
1963	1927.5	1740.3	471.7	321.2	858.6	369.4	1790.6
1964	1843.8	1724.6	434.0	316.3	939.6	366.8	1841.9
1965	1742.8	1705.8	455.8	277.5	1006.4	370.6	1894.4
1966	1691.5	1552.5	449.2	251.9	1096.6	359.4	1971.8
1967	1605.3	1362.0	433.3	236.7	1115.2	342.2	2001.6
1968	1511.0	1249.0	379.5	220.6	1169.3	340.9	2033.6
1969	1412.4	1178.1	398.7	185.0	1223.4	353.9	2164.6
1970	1391.5	1160.0	383.9	163.9	1303.0	353.9	2282.5
1971	1394.5	1194.3	304.0	168.3	1506.7	353.6	2440.0
1972	1390.2	1172.5	293.5	164.0	1519.0	356.6	2485.0
1973	1359.8	1111.1	268.1	144.6	1719.7	362.8	2615.9
1974	1443.9	1216.0	253.5	136.7	1868.3	372.0	2687.0
1975	1464.4	1346.0	247.2	145.5	1991.7	370.8	2688.5
1976	1463.9	1340.4	236.0	141.4	2163.6	388.9	2713.4
% change 1960/76	-28.3%	-29.4%	-59.6%	-59.9%	+200.2%	+12.9%	+68.0%

APPENDIX Xc

Man-years underground in thousands for longwall output (MY_u)

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	403.7	293.5	92.7	77.0	128.4	68.0	338.0
1961	382.0	273.6	85.8	65.5	133.3	68.0	336.2
1962	360.8	251.8	83.7	59.2	132.9	68.0	333.3
1963	347.8	236.1	78.7	58.9	137.9	70.0	335.7
1964	329.4	228.0	75.4	58.6	143.6	70.0	336.7
1965	315.0	213.9	72.8	54.5	149.4	69.0	337.9
1966	286.7	190.6	70.0	46.4	158.7	62.0	342.7
1967	267.9	161.4	63.4	39.8	158.2	54.0	336.0
1968	240.6	143.0	55.4	35.0	160.1	51.3	328.0
1969	202.7	135.8	54.6	30.4	163.4	49.0	323.0
1970	190.2	136.4	49.7	25.4	169.0	46.3	338.0
1971	180.7	137.2	40.2	23.7	176.6	42.7	331.0
1972	180.0	128.0	37.5	22.5	175.4	41.9	317.0
1973	170.0	117.4	31.7	19.6	180.6	40.0	309.0
1974	164.3	114.4	28.6	18.3	185.2	39.7	309.0
1975	168.8	116.1	26.1	18.0	192.6	38.9	308.6
1976	166.4	112.8	24.4	17.1	193.2	38.9	308.1
% change 1960/76	-58.8%	-61.6%	-73.7%	-77.8%	+50.5%	-42.8%	-8.8%

APPENDIX Xd

Capital stock in longwall face mechanisation in million US dollars at 1960 prices and exchange rates (CS_m)

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	192.7	118.4	63.6	36.0	48.2	34.8	158.1
1961	221.5	147.2	66.4	44.5	51.2	41.2	167.9
1962	272.3	177.6	69.0	49.0	53.2	50.1	185.0
1963	294.7	188.8	68.9	54.8	67.0	67.0	201.0
1964	332.8	209.4	68.1	55.3	77.4	71.3	291.9
1965	358.5	211.9	70.5	54.2	86.5	70.1	323.4
1966	407.8	203.3	72.6	51.8	102.8	65.0	354.1
1967	499.2	200.0	73.7	48.9	118.3	59.1	387.5
1968	463.3	196.2	65.3	44.3	132.3	61.2	429.6
1969	439.8	197.5	66.0	40.7	135.4	67.2	463.7
1970	431.9	230.1	74.2	41.9	160.1	71.7	526.8
1971	486.5	259.0	69.6	46.3	190.0	72.2	560.9
1972	486.8	277.8	70.2	48.2	197.8	72.2	562.6
1973	467.8	280.0	68.2	44.4	216.8	72.7	613.6
1974	460.0	305.7	63.2	44.5	246.7	71.1	624.6
1975	472.4	309.6	58.9	41.8	273.3	71.1	634.2
1976	475.0	327.2	55.9	40.1	290.2	69.9	649.4
% change 1960/76	+146.5%	+176.4%	-12.1%	-11.4%	+502.1%	+100.9%	+310.7%

Mechanised longwall face manpower input
in million US dollars at 1960 prices and exchange rates (MI_m)

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	78.7	55.3	21.4	14.5	16.5	10.6	62.1
1961	99.6	69.2	22.4	16.5	17.5	12.2	67.7
1962	123.9	83.0	23.5	17.7	18.9	15.2	81.0
1963	136.0	85.1	24.5	19.5	24.0	19.8	94.8
1964	145.8	95.6	23.2	18.2	30.0	20.7	150.4
1965	145.8	99.0	24.4	17.5	35.4	22.3	156.2
1966	147.3	90.6	27.1	16.3	44.3	22.5	168.4
1967	151.0	82.0	26.9	15.7	51.7	21.2	175.7
1968	132.1	74.9	23.7	14.5	54.6	20.2	178.2
1969	115.6	72.0	24.2	11.5	57.0	21.8	185.0
1970	109.1	71.5	24.5	9.9	58.0	21.6	191.5
1971	103.8	70.2	20.1	9.6	62.7	19.8	201.3
1972	99.6	66.0	17.8	7.5	62.4	18.9	201.3
1973	87.0	56.8	15.3	6.4	65.2	18.4	209.3
1974	85.8	52.4	13.7	5.8	68.4	17.9	206.0
1975	83.6	52.7	11.7	5.4	72.7	17.7	211.1
1976	84.6	54.0	10.9	5.1	74.8	17.2	212.0
% change 1960/76	+7.5%	-2.3%	-49.1%	-64.8%	+353.3%	+62.3%	+241.4%

APPENDIX Xf

Manpower input for longwall output
in million US dollars at 1960 prices and exchange rates (MI)

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	1233.9	1070.5	341.0	188.1	318.5	155.0	840.0
1961	1165.5	1011.3	333.7	175.8	327.4	160.1	844.2
1962	1122.9	945.1	327.8	169.6	333.1	161.4	885.9
1963	1065.9	892.8	279.2	165.1	345.1	161.4	915.0
1964	1012.2	858.9	253.9	163.2	382.4	158.8	935.7
1965	935.9	820.5	266.2	137.6	418.7	158.2	956.7
1966	862.7	750.0	260.5	119.1	445.2	153.1	993.8
1967	809.1	642.9	247.8	108.6	445.0	138.2	1006.8
1968	717.7	575.8	214.0	100.4	458.4	128.2	1012.7
1969	648.3	540.7	220.0	80.3	473.4	126.3	1062.8
1970	610.9	524.3	210.8	63.8	496.4	121.7	1093.3
1971	587.0	523.1	165.4	63.3	528.9	115.3	1146.8
1972	570.0	486.6	155.3	61.0	525.6	114.1	1143.0
1973	535.8	445.6	138.3	54.2	550.3	113.2	1190.2
1974	524.1	426.8	125.5	50.0	569.8	113.1	1174.2
1975	528.6	430.7	115.4	47.7	603.5	109.0	1131.9
1976	531.4	418.2	108.1	45.4	621.0	109.2	1104.3
% change 1960/76	-56.9%	-60.9%	-68.3%	-75.9%	+95.0%	-29.5%	+31.5%

APPENDIX Xg

Mechanised longwall output in million tons (O_m)

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	78.3	55.5	17.6	10.4	17.6	9.0	41.0
1961	91.8	70.0	18.4	12.9	19.8	10.6	46.4
1962	117.0	83.8	20.8	14.0	23.1	12.3	51.8
1963	133.2	94.6	19.6	15.9	29.8	16.8	56.8
1964	142.2	104.8	21.2	16.0	38.8	18.9	87.0
1965	145.3	105.9	23.3	14.9	46.7	20.0	99.2
1966	145.4	101.9	24.4	13.3	58.0	20.0	110.0
1967	145.3	93.2	23.9	12.6	66.5	19.6	122.8
1968	143.1	97.5	20.6	11.3	71.0	21.1	131.8
1969	132.3	99.4	22.3	10.0	77.3	23.2	143.0
1970	127.3	101.9	24.5	9.1	85.0	23.9	165.0
1971	104.9	103.2	19.4	9.2	95.2	22.2	168.0
1972	122.3	98.7	17.8	8.9	96.5	22.5	166.4
1973	94.3	94.8	14.9	7.3	106.0	21.8	167.0
1974	111.6	92.9	13.2	7.2	118.4	21.9	168.4
1975	109.8	91.8	12.1	7.0	127.6	22.5	170.0
1976	104.5	89.5	11.5	6.9	135.4	22.3	170.4
% change 1960/76	+33.5%	+61.3%	-34.7%	-33.6%	+669.3%	+147.8%	+315.6%

APPENDIX Xh

Capacity of mechanised longwall face system in million tons (CAP_m)

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	130.0	91.4	31.3	18.7	26.3	13.2	57.5
1961	151.7	113.6	32.6	23.2	29.5	15.5	65.0
1962	193.4	135.4	36.6	25.3	34.2	17.9	72.2
1963	219.4	151.4	35.8	28.4	43.5	24.3	79.0
1964	233.5	166.6	39.5	28.8	55.7	27.0	120.3
1965	237.8	167.6	40.8	26.5	66.7	27.8	137.0
1966	238.0	159.7	42.4	24.6	82.5	27.8	151.3
1967	237.0	152.0	41.9	22.3	92.1	27.2	168.2
1968	232.7	151.2	37.7	20.0	98.1	29.2	179.8
1969	214.8	153.4	38.5	17.7	106.3	32.0	193.8
1970	206.3	156.5	42.2	16.9	117.2	32.0	221.5
1971	200.0	157.8	33.4	16.2	130.6	30.5	223.4
1972	197.9	152.7	30.3	15.7	132.0	30.8	219.0
1973	184.0	144.1	25.3	12.9	144.4	29.8	215.2
1974	180.3	141.0	22.8	12.7	160.2	29.8	214.5
1975	176.8	138.7	20.5	12.3	171.7	30.5	214.6
1976	168.3	135.2	19.4	12.1	182.2	30.2	215.1
% change 1960/76	+29.5%	+47.9%	-38.0%	-35.3%	+592.8%	+128.8%	+274.1%

Electrical energy utilised underground in longwall output in million kilowatt-hours (kWh_u)

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	1141	813	263	195	338	164	830
1961	1122	841	258	192	373	175	871
1962	1198	858	260	190	416	181	913
1963	1212	873	252	190	462	189	967
1964	1210	900	252	190	518	188	1033
1965	1292	945	274	179	561	197	1194
1966	1286	929	277	169	662	207	1274
1967	1315	875	278	168	701	206	1349
1968	1294	872	257	151	767	211	1432
1969	1283	909	279	135	829	223	1502
1970	1301	990	271	124	948	232	1827
1971	1324	1056	234	124	1124	248	1970
1972	1327	1060	221	121	1181	251	1994
1973	1414	1037	203	107	1376	258	2029
1974	1417	1122	203	106	1555	279	2102
1975	1458	1177	195	106	1701	301	2205
1976	1472	1212	195	107	1823	307	2210
% change 1960/76	+29.0%	+49.1%	-25.9%	-45.1%	+439.3%	+87.2%	+166.3%

APPENDIX XI

Indices of the relative equivalents of the national currencies to the US dollar (1960 = 100)

National currency equivalent to a US dollar in 1960:
£ = 0.3571, DM = 4.171, Fr.Fr. = 4.903, B.Fr. = 49.70, Kr. = 14.36, Zl. = 24.00, R = .90

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1961	100.00	103.47	100.00	100.00	100.00	100.00	100.00
1962	100.00	104.25	100.00	100.00	100.00	100.00	100.00
1963	100.00	104.25	100.00	100.00	100.00	100.00	100.00
1964	100.00	104.25	100.00	100.00	100.00	100.00	100.00
1965	100.00	104.25	100.00	100.00	100.00	100.00	100.00
1966	100.00	104.88	98.99	99.30	100.00	100.00	100.00
1967	92.75	104.25	100.00	100.00	100.00	100.00	100.00
1968	85.70	104.27	99.09	99.12	100.00	88.64	100.00
1969	85.70	105.86	94.23	100.00	100.00	88.64	100.00
1970	85.70	114.34	88.82	100.00	100.00	88.64	100.00
1971	87.63	129.10	93.85	111.04	100.00	95.99	108.56
1972	87.48	130.26	95.67	112.80	100.00	95.99	108.56
1973	85.35	154.48	104.14	120.28	120.48	120.67	120.64
1974	84.64	173.10	110.30	137.60	120.48	142.74	120.64
1975	75.66	159.08	109.30	125.73	120.60	141.48	120.64
1976	61.95	176.59	98.65	138.13	120.60	125.31	120.64

Source: Reference 303

$\left\{\frac{O}{MY_u}\right\}$ Output per man-year underground for longwall workers in tons

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	431	479	423	286	486	388	405
1961	445	515	434	328	496	404	412
1962	491	555	444	358	522	412	420
1963	514	596	414	360	541	403	423
1964	533	618	427	362	564	400	430
1965	528	626	472	360	569	401	438
1966	548	656	483	373	584	434	445
1967	580	688	500	409	603	483	457
1968	627	778	493	420	634	507	473
1969	680	811	542	428	653	555	489
1970	691	808	559	441	671	587	501
1971	598	808	547	456	692	602	518
1972	698	807	539	458	704	611	541
1973	565	839	530	439	736	620	557
1974	691	838	525	432	761	625	556
1975	662	808	528	400	784	637	557
1976	637	807	537	409	812	640	560
% change 1960/76	+47.8%	+68.5%	+27.0%	+43.0%	+67.1%	+65.0%	+38.3%

$\left\{\frac{O}{O_m}\right\}$ Mechanised longwall output factor

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	2.22	2.53	2.23	2.11	3.55	2.93	3.34
1961	1.85	2.01	2.02	1.67	3.34	2.59	2.98
1962	1.51	1.67	1.79	1.51	3.00	2.28	2.70
1963	1.34	1.49	1.66	1.33	2.50	1.68	2.50
1964	1.23	1.34	1.52	1.32	2.09	1.48	1.66
1965	1.14	1.27	1.48	1.31	1.82	1.39	1.49
1966	1.08	1.23	1.38	1.30	1.60	1.34	1.39
1967	1.07	1.19	1.33	1.29	1.43	1.33	1.25
1968	1.05	1.14	1.33	1.30	1.43	1.23	1.18
1969	1.04	1.11	1.33	1.30	1.38	1.17	1.10
1970	1.03	1.08	1.13	1.23	1.33	1.17	1.02
1971	1.03	1.07	1.13	1.17	1.28	1.16	1.02
1972	1.03	1.05	1.13	1.16	1.28	1.14	1.03
1973	1.02	1.04	1.13	1.18	1.25	1.14	1.03
1974	1.02	1.03	1.14	1.10	1.19	1.13	1.02
1975	1.02	1.02	1.14	1.03	1.18	1.10	1.01
1976	1.01	1.02	1.14	1.01	1.16	1.12	1.01
% change 1960/76	-54.5%	-59.7%	-48.9%	-52.1%	-67.7%	-61.8%	-69.8%

APPENDIX XIIc

$\left\{\frac{kWh_u}{O}\right\}$ Electrical energy utilised underground per ton, in kilowatt-hours

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	6.56	5.78	6.71	8.86	5.42	6.21	6.06
1961	6.60	5.97	6.93	8.93	5.64	6.36	6.29
1962	6.76	6.14	6.99	8.96	6.00	6.46	6.52
1963	6.78	6.20	7.73	8.96	6.19	6.70	6.81
1964	6.89	6.39	7.83	8.96	6.39	6.71	7.13
1965	7.77	7.05	7.96	9.13	6.60	7.11	8.07
1966	8.18	7.43	8.19	9.77	7.14	7.70	8.35
1967	8.46	7.88	8.77	10.31	7.35	7.89	8.79
1968	8.58	7.83	9.41	10.27	7.56	8.11	9.24
1969	9.31	8.26	9.43	10.38	7.77	8.20	9.51
1970	9.90	8.98	9.75	11.07	8.36	8.53	10.80
1971	12.25	9.52	10.64	11.48	9.20	9.65	11.48
1972	10.56	10.26	10.94	11.75	9.56	9.80	11.63
1973	14.71	10.52	12.08	12.44	10.35	10.40	11.79
1974	12.47	11.70	13.53	13.42	11.04	11.25	12.23
1975	13.05	12.55	14.13	14.72	11.26	12.14	12.83
1976	13.89	13.32	14.88	15.29	11.62	12.33	12.81
% change 1960/76	+111.7%	+130.4%	+121.8%	+72.6%	+114.4%	+98.5%	+111.4%

APPENDIX XIId

$\left\{\frac{MY_u}{kWh_u}\right\}$ Man-years underground to underground electrical energy in million kilowatt-hours for longwall output

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	354	361	352	395	380	414	407
1961	340	325	332	341	357	389	386
1962	301	293	322	316	319	376	365
1963	287	270	312	310	298	370	347
1964	272	253	299	308	277	372	326
1965	244	226	264	305	266	350	283
1966	223	205	253	274	240	300	269
1967	204	184	228	237	226	262	249
1968	186	164	215	232	209	243	229
1969	158	149	196	225	197	220	215
1970	146	138	183	205	178	200	185
1971	136	130	172	191	157	172	168
1972	136	121	170	186	148	167	159
1973	120	113	156	183	131	155	152
1974	116	102	141	173	119	142	147
1975	116	99	134	170	113	129	140
1976	113	93	125	160	106	127	139
% change 1960/76	-68.1%	-74.2%	-64.5%	-59.5%	-72.1%	-69.3%	-65.9%

APPENDIX XIIe

$\left\{\frac{CS_m}{MI_m}\right\}$ Capital stock in longwall face mechanisation to mechanised longwall face manpower input

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	2.45	2.14	2.97	2.48	2.92	3.29	2.55
1961	2.22	2.13	2.96	2.70	2.93	3.38	2.48
1962	2.20	2.14	2.94	2.77	2.82	3.30	2.28
1963	2.17	2.22	2.81	2.81	2.79	3.39	2.12
1964	2.28	2.19	2.93	3.03	2.58	3.44	1.94
1965	2.46	2.14	2.89	3.10	2.44	3.14	2.07
1966	2.77	2.24	2.68	3.18	2.32	2.88	2.10
1967	3.31	2.44	2.74	3.10	2.29	2.79	2.21
1968	3.51	2.62	2.75	3.06	2.42	3.02	2.41
1969	3.80	2.74	2.73	3.54	2.37	3.08	2.51
1970	3.96	3.22	3.03	4.23	2.76	3.32	2.75
1971	4.69	3.69	3.46	4.82	3.03	3.65	2.79
1972	4.89	4.21	3.94	6.42	3.17	3.83	2.79
1973	5.38	4.93	4.46	6.94	3.32	3.95	2.93
1974	5.38	5.83	4.62	7.67	3.61	3.96	3.03
1975	5.65	5.88	5.03	7.74	3.76	4.01	3.00
1976	5.62	6.06	5.13	7.86	3.88	4.05	3.06
% change 1960/76	+129.4%	+183.2%	+72.7%	+216.9%	+32.9%	+23.1%	+20.0%

APPENDIX XIIf

$\left\{\frac{MI_m}{MI}\right\}$ Mechanised longwall face manpower input as a percentage of total manpower input

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	6.37	5.16	6.28	7.71	5.19	6.83	7.39
1961	8.54	6.84	6.72	9.38	5.34	7.61	8.02
1962	11.03	8.78	7.16	10.44	5.66	9.41	9.14
1963	12.75	9.54	8.77	11.81	6.95	12.26	10.36
1964	14.40	11.13	9.13	11.18	7.84	13.04	16.08
1965	15.57	12.07	9.16	12.71	8.46	14.10	16.33
1966	17.06	12.08	10.40	13.68	9.94	14.72	16.94
1967	18.66	12.75	10.85	14.50	11.62	15.31	17.45
1968	18.40	13.01	11.08	14.44	11.91	15.79	17.60
1969	17.83	13.32	11.00	14.32	12.04	17.30	17.41
1970	17.85	13.64	11.61	15.51	11.68	17.76	17.52
1971	17.67	13.42	12.15	15.16	11.85	17.16	17.55
1972	17.47	13.56	11.46	12.29	11.88	16.53	17.61
1973	16.23	12.76	11.06	11.80	11.85	16.25	17.59
1974	16.37	12.28	10.89	11.60	12.00	15.86	17.54
1975	15.81	12.23	10.14	11.32	12.05	16.25	18.65
1976	15.92	12.91	10.08	11.23	12.04	15.80	19.20
% change 1960/76	+149.9%	+150.2%	+60.5%	+45.6%	+132.0%	+131.3%	+159.8%

$\left\{\frac{O_m}{CAP_m}\right\}$ Mechanised longwall face capacity utilisation

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	.603	.607	.562	.556	.669	.682	.713
1961	.605	.616	.565	.557	.671	.684	.714
1962	.605	.619	.568	.553	.675	.687	.717
1963	.607	.625	.547	.559	.685	.691	.719
1964	.609	.629	.537	.555	.697	.700	.723
1965	.611	.632	.571	.562	.700	.719	.724
1966	.611	.638	.576	.540	.703	.719	.727
1967	.613	.613	.570	.565	.722	.721	.730
1968	.615	.645	.546	.565	.724	.723	.733
1969	.616	.648	.579	.566	.727	.725	.738
1970	.617	.651	.581	.539	.725	.728	.745
1971	.525	.654	.580	.568	.729	.728	.752
1972	.618	.646	.588	.567	.731	.730	.760
1973	.512	.658	.589	.567	.734	.731	.776
1974	.618	.659	.578	.567	.739	.735	.785
1975	.621	.661	.590	.568	.743	.738	.792
1976	.621	.662	.592	.570	.743	.738	.792
% change 1960/76	+3.0%	+9.1%	+5.3%	+2.5%	+11.1%	+8.2%	+11.1%

APPENDIX XIIh

$\left\{\frac{CAP_m}{CS_m}\right\}$ Mechanised longwall face capital stock efficiency in tons per US dollar at 1960 prices and exchange rates

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	.674	.772	.492	.519	.546	.379	.364
1961	.685	.772	.491	.521	.576	.376	.387
1962	.710	.762	.530	.516	.643	.357	.390
1963	.744	.802	.520	.518	.649	.363	.393
1964	.702	.796	.580	.521	.720	.378	.412
1965	.663	.791	.579	.489	.771	.397	.424
1966	.583	.785	.584	.475	.802	.428	.427
1967	.475	.760	.568	.456	.779	.460	.434
1968	.502	.774	.577	.451	.741	.477	.419
1969	.488	.777	.583	.435	.785	.476	.418
1970	.478	.681	.569	.403	.732	.446	.421
1971	.411	.609	.480	.350	.687	.422	.398
1972	.406	.550	.432	.326	.667	.427	.389
1973	.393	.515	.371	.290	.666	.410	.351
1974	.392	.461	.361	.285	.649	.419	.343
1975	.374	.448	.348	.294	.628	.429	.338
1976	.354	.413	.347	.302	.628	.432	.331
% change 1960/76	-47.5%	-46.5%	-29.5%	-41.8%	+15.0%	+14.0%	-9.1%

$\left\{\frac{MI}{TI}\right\}$ Manpower input as a proportion of total input

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	.604	.564	.584	.533	.442	.450	.520
1961	.587	.550	.589	.515	.430	.446	.517
1962	.568	.543	.593	.514	.417	.441	.517
1963	.553	.513	.592	.514	.402	.438	.511
1964	.549	.498	.585	.516	.407	.433	.508
1965	.537	.481	.584	.496	.416	.427	.505
1966	.510	.483	.580	.473	.406	.426	.504
1967	.504	.474	.572	.459	.399	.404	.503
1968	.475	.461	.564	.455	.392	.376	.498
1969	.459	.459	.552	.434	.387	.357	.491
1970	.439	.452	.549	.389	.381	.344	.479
1971	.421	.438	.544	.376	.351	.326	.470
1972	.410	.415	.529	.372	.346	.320	.460
1973	.394	.401	.516	.375	.320	.312	.455
1974	.363	.351	.495	.366	.305	.304	.437
1975	.361	.320	.467	.328	.303	.294	.421
1976	.363	.312	.458	.321	.287	.281	.407
% change 1960/76	-39.9%	-44.7%	-21.6%	-39.8%	-35.1%	-37.6%	-21.7%

APPENDIX XIIj

$\left\{\frac{O}{TI}\right\}$ Total productivity measure in kilogrammes per US dollar at 1960 prices and exchange rates

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	85.18	74.07	67.11	62.34	86.58	76.63	84.82
1961	85.61	76.63	65.65	62.97	86.80	76.62	84.82
1962	89.68	80.26	67.29	65.17	86.88	76.50	81.70
1963	92.76	80.91	69.11	66.00	86.89	76.34	79.30
1964	95.24	81.70	74.19	67.02	86.21	76.34	78.61
1965	95.42	78.56	75.47	70.63	84.46	74.74	78.12
1966	92.93	80.52	75.24	68.69	84.53	74.85	77.34
1967	96.80	81.50	73.15	68.86	85.54	76.27	76.69
1968	99.80	89.11	71.93	66.64	86.80	76.27	76.22
1969	97.56	93.46	74.24	70.27	87.22	76.86	73.01
1970	94.43	95.00	72.41	68.33	87.03	76.86	74.13
1971	77.52	92.86	72.36	64.17	81.10	72.68	70.33
1972	90.42	88.10	68.82	62.80	81.30	71.79	69.01
1973	70.67	88.65	62.66	59.47	77.28	68.36	65.79
1974	78.67	78.87	59.17	57.79	75.42	66.67	63.94
1975	76.28	69.69	55.82	49.48	75.81	66.88	63.94
1976	72.41	67.89	55.50	49.50	72.52	64.03	63.57
% change 1960/76	-15.0%	-8.3%	-17.3%	-20.6%	-16.2%	-16.4%	-25.1%

(DOF) Average daily output per longwall face in tons

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	193	322	189	181	245	195	192
1961	224	368	198	187	258	210	207
1962	256	398	209	190	283	210	211
1963	288	439	229	188	317	208	215
1964	318	466	242	197	351	215	230
1965	335	486	254	209	383	242	248
1966	386	543	282	219	399	267	256
1967	417	616	306	258	431	314	268
1968	492	707	329	274	460	339	288
1969	538	815	415	308	482	361	302
1970	547	912	433	332	503	377	320
1971	550	966	435	350	520	387	350
1972	556	1046	439	366	562	423	365
1973	558	1158	448	400	617	439	385
1974	593	1231	450	430	617	475	385
1975	583	1250	457	545	713	482	389
1976	582	1296	493	585	794	476	402
% change 1960/76	+201.5%	+302.5%	+160.8%	+223.2%	+224.1%	+144.1%	+109.4%

$\left\{\frac{MS_u}{MY_u}\right\}$ Average manshifts per man-year for underground longwall workers

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	220	226	230	190	274	237	270
1961	218	226	230	200	275	238	270
1962	218	224	231	201	273	237	270
1963	217	226	209	202	275	238	268
1964	215	227	229	202	274	240	268
1965	212	219	229	202	269	231	267
1966	212	212	229	193	269	231	266
1967	212	202	222	193	266	225	261
1968	214	209	210	190	262	225	259
1969	215	211	214	184	262	225	255
1970	213	205	211	175	262	225	255
1971	181	201	204	180	261	225	240
1972	207	190	200	183	256	224	240
1973	182	194	193	180	259	223	230
1974	207	200	187	177	259	223	230
1975	201	199	191	173	262	223	229
1976	197	194	193	170	259	223	229
% change 1960/76	-10.4%	-14.2%	-16.1%	-10.5%	-5.5%	-5.9%	-15.2%

{MS_u/dn} Average underground manshifts per longwall face-day worked

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	98.5	151.9	102.8	120.2	138.1	119.1	128.0
1961	109.7	161.5	104.9	114.0	143.0	123.7	135.6
1962	113.7	160.6	108.7	106.7	148.0	120.8	135.6
1963	121.6	166.5	115.6	105.5	161.1	122.8	136.2
1964	128.3	171.2	129.8	109.9	170.5	129.0	143.3
1965	134.5	170.0	123.2	117.3	181.1	139.4	151.2
1966	149.3	175.5	133.7	113.3	183.8	142.1	153.0
1967	152.4	180.9	135.9	121.7	190.1	146.3	153.1
1968	167.9	189.9	140.1	124.0	190.1	150.4	157.7
1969	170.1	212.0	163.9	132.4	193.4	146.4	157.5
1970	168.6	231.4	163.4	131.7	196.4	144.5	162.9
1971	166.5	240.3	162.2	138.2	196.1	144.6	162.2
1972	164.9	246.3	162.9	146.2	204.3	155.1	161.9
1973	179.7	267.8	163.1	164.0	217.1	157.9	159.0
1974	177.6	293.8	160.3	176.2	210.0	169.5	159.2
1975	177.0	307.9	165.3	235.7	238.3	168.7	159.9
1976	180.0	311.5	177.2	243.1	253.3	165.9	164.4
% change 1960/76	+82.7%	+105.1%	+72.4%	+102.2%	+83.4%	+39.3%	+28.4%

$(\overline{DOF}_m)$ Average daily output per mechanised longwall face in tons

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	322	541	260	320	325	245	212
1961	332	580	267	327	350	250	230
1962	386	602	297	353	369	250	235
1963	419	615	313	341	398	248	240
1964	428	606	309	340	441	260	250
1965	430	626	325	352	478	290	270
1966	444	691	368	360	508	320	279
1967	468	747	388	401	520	360	292
1968	547	829	423	408	513	390	313
1969	592	931	504	447	606	414	328
1970	594	1029	512	483	631	432	322
1971	604	1081	520	485	638	451	350
1972	594	1109	538	486	691	482	369
1973	589	1276	520	499	763	492	386
1974	620	1330	478	534	798	528	408
1975	606	1265	468	550	820	524	408
1976	599	1340	522	600	860	529	410
% change 1960/76	+86.0%	+147.7%	+100.8%	+87.5%	+164.6%	+115.9%	+93.4%

$\left\{\frac{a_m}{MAT}\right\}$ Average mechanised advance in centimetres per minute of machine available time

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	.236	.196	.210	.192	.164	.164	.147
1961	.233	.196	.213	.202	.175	.166	.149
1962	.241	.198	.218	.201	.184	.178	.152
1963	.235	.200	.223	.205	.183	.178	.154
1964	.226	.202	.211	.209	.186	.183	.155
1965	.226	.204	.205	.215	.196	.189	.156
1966	.231	.209	.221	.210	.201	.190	.157
1967	.239	.208	.225	.212	.202	.203	.158
1968	.270	.230	.239	.212	.203	.208	.160
1969	.289	.249	.263	.217	.207	.209	.161
1970	.310	.261	.272	.222	.209	.217	.160
1971	.312	.267	.283	.224	.208	.215	.163
1972	.303	.274	.281	.221	.220	.225	.165
1973	.310	.309	.275	.223	.229	.223	.166
1974	.311	.309	.271	.227	.229	.235	.168
1975	.314	.311	.273	.233	.234	.240	.169
1976	.305	.313	.273	.241	.235	.238	.172
% change 1960/76	+29.2%	+59.7%	+30.0%	+25.5%	+43.3%	+45.1%	+17.0%

APPENDIX XIIIf

$\left\{\frac{O_m}{MAT}\right\}$ Average mechanised longwall output in tons per minute of machine available time

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	.617	.665	.399	.481	.422	.338	.244
1961	.586	.673	.405	.506	.449	.349	.260
1962	.640	.682	.441	.508	.505	.346	.265
1963	.651	.746	.467	.533	.506	.358	.271
1964	.635	.716	.465	.524	.552	.366	.292
1965	.631	.732	.482	.547	.606	.382	.317
1966	.653	.811	.510	.532	.622	.411	.311
1967	.628	.833	.513	.551	.635	.452	.333
1968	.723	.923	.558	.551	.641	.493	.346
1969	.794	1.025	.643	.633	.700	.541	.359
1970	.867	1.060	.676	.681	.784	.525	.372
1971	.900	1.123	.675	.694	.817	.538	.391
1972	.870	1.197	.713	.675	.837	.551	.416
1973	.915	1.348	.692	.707	.929	.566	.433
1974	.946	1.401	.682	.752	.935	.599	.452
1975	.962	1.416	.707	.820	.963	.633	.475
1976	.968	1.455	.755	.863	1.011	.645	.480
% change 1960/76	+56.9%	+118.8%	+89.2%	+79.4%	+139.6%	+90.8%	+96.7%

APPENDIX XIV

Hard Coal Equivalent conversion factor
- fraction of a ton of standard hard coal

	United Kingdom	West Germany	France	Belgium	Poland	Czechoslovakia	Ukraine
1960	.930	.962	.914	.918	.860	.890	.858
1961	.930	.964	.918	.914	.857	.888	.858
1962	.929	.963	.917	.912	.857	.888	.856
1963	.929	.962	.908	.910	.855	.885	.856
1964	.929	.960	.900	.904	.854	.884	.854
1965	.928	.961	.906	.900	.852	.882	.854
1966	.928	.962	.910	.895	.850	.882	.853
1967	.930	.965	.905	.904	.850	.880	.852
1968	.930	.961	.914	.909	.850	.880	.850
1969	.930	.960	.925	.909	.850	.880	.850
1970	.928	.959	.923	.908	.850	.880	.848
1971	.924	.956	.916	.905	.848	.878	.847
1972	.915	.953	.912	.904	.848	.878	.847
1973	.908	.953	.907	.905	.848	.878	.845
1974	.908	.946	.909	.911	.848	.878	.845
1975	.908	.945	.912	.908	.848	.880	.845
1976	.908	.945	.912	.907	.848	.880	.845

Based on Reference 315

UNITED KINGDOM - Mine UK1

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.125	1.139	238	4.4	.81	1.49	1.40	222	2.90	1088	1086
1973	.701	.698	196	3.8	.82	1.48	1.40	225	2.45	937	925
1974	.990	.961	237	3.9	.83	1.47	1.37	227	2.74	1040	1070
1975	.978	.972	232	4.0	.83	1.47	1.38	227	2.74	1047	1033
1976	1.001	.988	229	4.1	.83	1.47	1.30	232	2.86	1052	1021

Mechanised longwall output in million tons and
Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.125	238	4.4	318	1.351	2.5	.365
1973	.701	196	3.8	315	1.149	2.6	.299
1974	.990	237	3.9	318	1.310	2.6	.331
1975	.978	232	4.0	318	1.275	2.6	.331
1976	1.001	229	4.1	335	1.326	2.4	.356

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	120.19	120.20	937	6.45	16.53	.400	.674	.417	1.00	118	9.07
1973	85.49	85.46	629	6.77	16.57	.381	.552	.363	1.00	137	11.58
1974	109.15	109.07	884	6.25	17.61	.351	.761	.371	1.00	112	10.10
1975	95.32	95.44	859	6.35	16.33	.348	.751	.352	1.00	112	10.40
1976	99.21	98.82	867	6.40	16.75	.342	.753	.359	1.00	115	10.00

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

UNITED KINGDOM - Mine UK2

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.059	1.042	238	3.8	.85	1.45	1.65	236	2.40	1152	1162
1973	.909	.900	196	3.8	.85	1.45	1.64	241	2.48	1208	1199
1974	1.045	1.034	237	3.7	.85	1.45	1.64	241	2.42	1179	1207
1975	1.122	1.105	232	3.9	.84	1.46	1.73	238	2.42	1222	1245
1976	1.072	1.058	230	4.0	.84	1.46	1.75	229	2.34	1150	1174

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.059	238	3.8	294	1.593	2.5	.326
1973	.909	196	3.8	306	1.596	2.5	.324
1974	1.045	237	3.7	311	1.596	2.4	.324
1975	1.122	232	3.9	308	1.591	2.4	.327
1976	1.072	230	4.0	307	1.581	2.4	.312

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	136.64	136.29	1112	5.47	16.83	.406	.662	.551	1.00	100	8.99
1973	117.29	116.80	1016	5.82	16.46	.391	.568	.551	1.00	114	8.60
1974	128.22	127.90	1135	5.92	16.90	.356	.653	.551	1.00	101	8.71
1975	120.00	119.23	1192	5.71	15.81	.355	.701	.533	1.00	103	8.11
1976	117.15	117.10	1119	5.55	16.53	.359	.670	.530	1.00	101	8.86

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

APPENDIX XVc

UNITED KINGDOM - Mine UK3

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.433	1.427	238	6.3	.85	1.45	1.65	209	2.24	952	936
1973	1.132	1.149	196	6.3	.84	1.46	1.65	209	2.20	930	918
1974	1.397	1.393	237	6.1	.84	1.46	1.64	213	2.25	964	971
1975	1.247	1.280	232	5.8	.83	1.47	1.56	210	2.38	951	925
1976	1.289	1.316	230	6.0	.83	1.47	1.54	215	2.36	953	929

Mechanised longwall output in million tons and
Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.433	238	6.3	320	1.493	2.0	.350
1973	1.132	196	6.3	320	1.432	2.0	.344
1974	1.397	237	6.1	315	1.534	2.0	.351
1975	1.247	232	5.8	324	1.580	1.9	.387
1976	1.289	230	6.0	321	1.455	2.0	.368

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	143.30	143.60	1256	7.15	17.71	.398	.682	.417	1.00	93	8.58
1973	115.75	116.17	1071	7.64	17.74	.380	.566	.397	1.00	101	9.28
1974	130.92	131.10	1277	7.41	18.13	.351	.724	.383	1.00	89	8.80
1975	116.87	116.82	1143	7.64	16.40	.351	.670	.396	1.00	95	9.22
1976	119.68	119.38	1210	7.06	18.13	.348	.668	.402	1.00	80	10.31

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

UNITED KINGDOM - Mine UK4

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.641	1.608	238	8.2	.83	1.47	1.72	210	1.87	824	830
1973	1.177	1.156	196	8.0	.83	1.47	1.68	202	1.78	737	756
1974	1.585	1.524	238	8.0	.83	1.47	1.71	204	1.88	800	809
1975	1.349	1.306	234	8.2	.83	1.47	1.68	205	1.62	681	681
1976	1.270	1.234	234	8.8	.80	1.50	1.68	205	1.45	599	601

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.641	238	8.2	322	.967	2.7	.215
1973	1.177	196	8.0	321	1.017	2.3	.241
1974	1.585	238	8.0	323	1.074	2.4	.243
1975	1.349	234	8.2	342	.894	2.3	.206
1976	1.270	234	8.8	335	.837	2.2	.197

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	110.88	110.99	779	4.84	20.84	.402	.601	.455	1.00	155	8.29
1973	81.74	81.61	574	6.24	17.36	.385	.442	.444	1.00	127	13.68
1974	96.65	96.99	755	5.58	18.38	.357	.560	.472	1.00	122	10.88
1975	78.43	78.15	619	5.58	17.86	.350	.545	.413	1.00	134	12.00
1976	74.71	74.46	592	5.73	18.60	.354	.469	.422	1.00	132	12.76

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

APPENDIX XVe

UNITED KINGDOM - Mine UK5

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.566	1.529	238	4.7	.82	1.48	2.21	216	2.36	1367	1388
1973	1.113	1.120	196	4.7	.82	1.48	2.21	208	2.18	1216	1222
1974	1.292	1.263	238	4.7	.82	1.48	2.09	212	2.10	1129	1147
1975	1.276	1.225	234	4.9	.81	1.49	2.03	218	2.00	1068	1108
1976	1.413	1.365	230	5.6	.81	1.49	1.98	224	1.98	1060	1087

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$
1972	1.566	238	4.7	327	2.141	2.0
1973	1.113	196	4.7	327	1.787	2.1
1974	1.292	238	4.7	340	1.477	2.3
1975	1.276	234	4.9	335	1.444	2.3
1976	1.413	230	5.6	335	1.364	2.4

$\frac{a_m}{MAT}$
.361
.318
.269
.260
.246

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	130.50	130.29	1572	7.33	13.46	.325	.681	.597	1.00	83	7.66
1973	96.78	96.39	1180	7.33	13.82	.330	.484	.597	1.00	88	9.61
1974	97.88	97.70	968	6.33	12.80	.360	.630	.532	1.00	116	8.90
1975	91.14	90.65	956	7.37	11.30	.351	.622	.500	1.00	106	9.84
1976	91.16	90.70	1037	6.01	13.71	.360	.631	.487	1.00	96	10.00

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

WEST GERMANY - Mine WG1

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	2.621	2.674	243	5.0	.68	1.73	1.98	254	3.72	2201	2131
1973	2.809	2.890	248	5.2	.68	1.73	2.00	254	3.75	2241	2200
1974	2.910	2.978	249	5.3	.68	1.73	2.03	252	3.75	2257	2207
1975	3.108	3.084	248	5.5	.67	1.75	2.03	252	3.77	2261	2240
1976	3.305	3.386	247	6.0	.67	1.75	2.04	252	3.79	2284	2245

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	2.621	243	5.0	337	2.371	2.7	.409
1973	2.809	248	5.2	335	2.408	2.7	.415
1974	2.910	249	5.3	333	2.453	2.7	.417
1975	3.108	248	5.5	333	2.443	2.8	.404
1976	3.305	247	6.0	330	2.413	2.8	.410

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	101.27	101.10	1143	7.56	10.06	.409	.681	.478	1.00	120	7.28
1973	102.04	101.90	1244	7.27	10.36	.404	.686	.489	1.00	107	7.50
1974	91.49	91.54	1310	7.27	10.30	.358	.685	.498	1.00	90	8.49
1975	79.39	79.44	1442	6.76	10.62	.315	.685	.512	1.00	76	9.14
1976	77.46	77.91	1539	7.00	10.54	.307	.687	.498	1.00	67	9.75

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

WEST GERMANY - Mine WG2

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	2.019	2.068	243	3.2	.70	1.71	2.25	226	4.37	2660	2725
1973	2.200	2.191	248	3.3	.70	1.71	2.25	228	4.36	2677	2710
1974	2.250	2.191	249	3.3	.69	1.72	2.25	228	4.38	2666	2690
1975	2.233	2.274	247	3.5	.69	1.72	2.23	228	4.36	2631	2583
1976	2.708	2.686	247	4.2	.69	1.72	2.20	228	4.35	2590	2476

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	2.019	243	3.2	336	2.972	2.6	.500
1973	2.200	248	3.3	335	3.086	2.6	.501
1974	2.250	249	3.3	334	3.036	2.7	.486
1975	2.233	247	3.5	332	2.881	2.7	.486
1976	2.708	247	4.2	335	2.886	2.7	.481

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	92.75	92.73	1068	7.13	7.60	.413	.707	.588	1.00	85	10.98
1973	93.15	93.06	1137	7.24	7.50	.406	.705	.599	1.00	78	11.27
1974	83.33	83.10	1184	7.24	7.50	.363	.705	.599	1.00	68	12.40
1975	75.64	75.21	1175	7.05	7.95	.322	.711	.590	1.00	64	13.21
1976	74.40	74.12	1419	7.04	8.07	.310	.711	.597	1.00	51	13.70

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

WEST GERMANY - Mine WG3

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	3.379	3.338	243	8.4	.70	1.71	1.70	222	3.62	1635	1580
1973	3.500	3.565	248	8.5	.70	1.71	1.72	222	3.70	1691	1636
1974	3.767	3.797	248	8.8	.70	1.71	1.76	222	3.72	1740	1702
1975	3.875	3.943	248	9.0	.69	1.72	1.78	223	3.75	1767	1740
1976	3.896	3.996	247	9.2	.69	1.72	1.78	222	3.75	1759	1716

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	3.379	243	8.4	338	1.814	2.7	.397
1973	3.500	248	8.5	336	1.830	2.7	.408
1974	3.767	248	8.8	336	1.903	2.7	.410
1975	3.875	248	9.0	334	1.925	2.7	.416
1976	3.896	247	9.2	330	1.924	2.7	.421

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	108.74	108.94	1469	6.52	15.70	.396	.722	.371	1.00	74	9.23
1973	109.25	109.70	1537	6.52	15.56	.392	.722	.380	1.00	69	9.48
1974	97.21	97.10	1658	6.77	14.72	.349	.725	.385	1.00	56	10.76
1975	95.54	95.22	1709	6.52	14.70	.347	.725	.396	1.00	50	11.67
1976	82.66	82.59	1732	6.52	14.91	.301	.727	.388	1.00	44	13.13

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

FRANCE - Mine FR1

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.567	1.538	245	4.3	.63	1.76	2.15	176	3.48	1460	1489
1973	1.575	1.527	242	4.3	.63	1.76	2.18	176	3.45	1468	1502
1974	1.500	1.484	240	4.3	.63	1.76	2.18	175	3.40	1438	1496
1975	1.608	1.585	238	4.5	.63	1.76	2.18	178	3.44	1480	1520
1976	1.666	1.625	235	4.5	.63	1.76	2.20	180	3.50	1537	1590

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.567	245	4.3	316	1.961	2.4	.459
1973	1.575	242	4.3	314	2.008	2.4	.458
1974	1.500	240	4.3	307	1.973	2.4	.461
1975	1.608	238	4.5	304	2.058	2.4	.471
1976	1.666	235	4.5	300	2.100	2.5	.467

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	102.72	103.08	1440	7.37	9.22	.456	.649	.510	1.00	83	8.41
1973	93.28	92.83	1476	7.37	8.80	.432	.650	.512	1.00	73	9.24
1974	91.03	90.83	1429	7.69	8.98	.416	.622	.510	1.00	67	10.41
1975	88.00	87.59	1534	7.37	9.52	.387	.624	.521	1.00	60	10.78
1976	87.38	87.78	1610	7.07	9.63	.381	.623	.540	1.00	54	11.57

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

FRANCE - Mine FR2

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.477	1.422	245	7.2	.64	1.75	2.22	138	2.35	806	815
1973	1.399	1.348	241	7.0	.64	1.75	2.20	138	2.35	799	820
1974	1.385	1.379	240	7.2	.63	1.76	2.20	141	2.32	798	805
1975	1.382	1.330	237	7.0	.63	1.76	2.20	141	2.33	802	812
1976	1.408	1.366	237	7.0	.63	1.76	2.22	143	2.34	824	830

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.477	245	7.2	315	1.329	2.0	.373
1973	1.399	241	7.0	314	1.321	2.0	.374
1974	1.385	240	7.2	312	1.223	2.1	.345
1975	1.382	237	7.0	312	1.271	2.1	.356
1976	1.408	237	7.0	313	1.291	2.1	.356

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	74.95	74.88	673	6.45	7.61	.521	.596	.492	1.00	136	10.91
1973	71.04	71.09	664	6.51	7.89	.485	.602	.474	1.00	127	11.86
1974	66.03	66.26	674	6.20	8.36	.464	.608	.452	1.00	112	13.28
1975	62.36	62.63	675	6.20	8.22	.434	.605	.466	1.00	109	13.65
1976	58.73	58.88	683	6.20	8.30	.397	.610	.471	1.00	102	14.40

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

BELGIUM - Mine BEL1

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	.438	.436	238	7.7	.60	1.84	1.52	165	.86	238	243
1973	.427	.414	238	6.5	.60	1.84	1.52	166	.96	267	272
1974	.403	.400	239	5.2	.60	1.84	1.55	168	1.12	322	330
1975	.405	.402	237	5.0	.60	1.84	1.55	168	1.18	339	348
1976	.400	.406	237	4.8	.60	1.84	1.56	170	1.22	357	365

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	.438	238	7.7	325	.387	1.9	.139
1973	.427	238	6.5	323	.427	2.0	.149
1974	.403	239	5.2	321	.481	2.1	.166
1975	.405	237	5.0	320	.509	2.1	.176
1976	.400	237	4.8	318	.503	2.2	.174

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	54.85	54.74	366	9.68	21.90	.418	.528	.117	1.00	196	13.94
1973	49.09	48.97	377	9.20	18.68	.400	.530	.135	1.00	186	14.20
1974	51.63	51.40	378	8.75	19.43	.360	.530	.159	1.00	170	15.51
1975	43.21	43.27	403	8.76	15.56	.360	.531	.166	1.00	152	16.33
1976	43.23	43.25	417	8.37	15.95	.358	.535	.169	1.00	146	16.44

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

BELGIUM - Mine BEL2

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.421	1.398	243	7.0	.60	1.84	1.66	203	2.21	822	830
1973	1.450	1.429	241	7.0	.60	1.84	1.68	203	2.25	847	875
1974	1.452	1.481	242	7.0	.60	1.84	1.68	205	2.30	874	899
1975	1.477	1.436	244	6.7	.59	1.85	1.70	204	2.32	878	905
1976	1.460	1.412	240	6.7	.59	1.85	1.70	204	2.32	878	908

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.421	243	7.0	320	1.187	2.2	.314
1973	1.450	241	7.0	320	1.221	2.2	.320
1974	1.452	242	7.0	320	1.217	2.2	.327
1975	1.477	244	6.7	318	1.291	2.2	.332
1976	1.460	240	6.7	316	1.306	2.2	.334

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	77.55	77.57	535	11.28	11.30	.353	.743	.232	1.00	128	14.64
1973	71.04	71.02	547	10.73	10.79	.349	.752	.233	1.00	123	14.91
1974	72.62	72.33	548	10.72	11.36	.329	.750	.241	1.00	113	16.13
1975	63.72	63.38	560	10.21	9.95	.325	.763	.252	1.00	105	16.98
1976	61.12	61.30	563	9.76	10.76	.306	.772	.246	1.00	105	16.99

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

POLAND - Mine POL1

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	4.359	4.507	309	16.3	.82	1.56	1.67	187	2.24	895	926
1973	4.480	4.533	307	16.5	.82	1.56	1.67	187	2.24	895	930
1974	4.525	4.512	305	16.2	.82	1.56	1.68	188	2.26	913	950
1975	4.550	4.555	305	15.8	.82	1.56	1.70	189	2.30	945	980
1976	4.625	4.689	304	16.0	.83	1.55	1.70	190	2.32	964	990

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	4.359	309	16.3	322	.960	2.8	.248
1973	4.480	307	16.5	322	.981	2.8	.248
1974	4.525	305	16.2	320	1.022	2.8	.252
1975	4.550	305	15.8	324	1.041	2.8	.254
1976	4.625	304	16.0	324	1.048	2.8	.256

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	117.71	117.56	1032	7.35	20.04	.335	.741	.321	1.00	101	9.61
1973	111.50	111.17	1043	7.34	20.19	.311	.742	.326	1.00	93	10.28
1974	107.62	107.62	1048	7.59	19.20	.295	.742	.337	1.00	87	10.98
1975	109.30	108.68	1054	7.34	19.68	.294	.746	.344	1.00	81	11.68
1976	101.95	101.27	1072	7.33	19.00	.283	.745	.346	1.00	79	11.77

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

POLAND - Mine POL2

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	3.222	3.199	307	16.0	.82	1.56	1.65	187	1.65	651	669
1973	3.360	3.296	307	16.0	.82	1.56	1.65	187	1.70	671	682
1974	3.480	3.415	305	16.2	.82	1.56	1.66	186	1.75	691	700
1975	3.626	3.661	305	16.5	.82	1.56	1.68	186	1.82	728	730
1976	3.910	3.925	304	17.0	.82	1.56	1.68	186	1.90	759	763

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	3.222	307	16.0	319	.762	2.7	.192
1973	3.360	307	16.0	319	.794	2.7	.197
1974	3.480	305	16.2	318	.830	2.7	.204
1975	3.626	305	16.5	317	.812	2.8	.205
1976	3.910	304	17.0	317	.852	2.8	.214

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	83.86	83.43	713	7.54	18.53	.333	.740	.243	1.00	146	9.58
1973	79.72	79.94	747	7.54	18.10	.311	.743	.252	1.00	131	10.28
1974	77.75	77.38	781	7.54	18.39	.292	.754	.254	1.00	117	10.92
1975	78.51	78.43	807	7.27	19.00	.289	.759	.258	1.00	107	11.62
1976	74.87	74.58	844	6.95	19.22	.273	.761	.270	1.00	101	11.72

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

POLAND - Mine POL3

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	2.957	3.059	308	19.0	.82	1.56	2.27	120	1.50	523	536
1973	3.212	3.282	307	18.8	.82	1.56	2.28	123	1.56	569	555
1974	3.580	3.620	305	18.5	.83	1.55	2.28	125	1.75	642	636
1975	3.687	3.731	304	18.0	.83	1.55	2.30	128	1.80	682	673
1976	3.750	3.788	304	18.0	.83	1.55	2.30	130	1.80	692	690

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$
1972	2.957	308	19.0	320	.686	2.3
1973	3.212	307	18.8	320	.751	2.3
1974	3.580	305	18.5	318	.798	2.3
1975	3.687	304	18.0	318	.847	2.5
1976	3.750	304	18.0	321	.834	2.5

$\frac{a_m}{MAT}$
.204
.212
.220
.226
.224

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	73.03	73.30	540	6.59	14.30	.333	.743	.313	1.00	196	9.49
1973	70.73	70.68	568	6.56	13.78	.303	.745	.345	1.00	173	10.13
1974	69.54	69.30	615	6.05	13.42	.292	.746	.393	1.00	149	10.88
1975	70.86	70.56	613	6.06	13.00	.290	.745	.416	1.00	141	11.53
1976	70.20	69.82	623	5.82	13.71	.279	.753	.418	1.00	138	11.59

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

CZECHOSLOVAKIA - Mine CZ1

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.952	1.977	258	10.0	.75	1.73	2.25	122	2.15	766	769
1973	1.935	1.975	262	9.5	.75	1.73	2.30	122	2.18	794	775
1974	1.909	1.910	262	8.8	.75	1.73	2.32	124	2.22	829	827
1975	1.872	1.906	260	8.5	.74	1.74	2.35	125	2.28	862	850
1976	1.875	1.833	260	8.0	.74	1.74	2.38	125	2.30	881	870

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.952	258	10.0	358	1.057	2.0	.300
1973	1.935	262	9.5	356	.993	2.2	.278
1974	1.909	262	8.8	354	1.017	2.3	.273
1975	1.872	260	8.5	350	1.052	2.3	.283
1976	1.875	260	8.0	350	1.073	2.4	.274

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	89.83	89.68	1024	7.60	12.47	.321	.720	.411	1.00	97	10.03
1973	85.43	85.72	1065	6.91	12.90	.310	.720	.429	1.00	92	10.25
1974	82.26	82.04	1108	6.61	12.54	.302	.732	.449	1.00	81	11.11
1975	82.30	81.88	1151	6.61	12.62	.296	.743	.449	1.00	74	11.67
1976	78.97	78.62	1175	6.34	13.07	.279	.746	.458	1.00	72	11.77

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

CZECHOSLOVAKIA - Mine CZ2

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.924	1.944	260	8.3	.75	1.73	2.50	124	2.24	901	924
1973	1.916	1.912	262	8.0	.75	1.73	2.50	125	2.25	912	925
1974	1.900	1.861	262	8.0	.75	1.73	2.44	123	2.28	888	900
1975	1.872	1.852	260	7.8	.76	1.72	2.45	124	2.30	913	912
1976	1.860	1.820	260	7.5	.76	1.72	2.45	124	2.35	933	930

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.924	260	8.3	357	.999	2.5	.251
1973	1.916	262	8.0	354	1.033	2.5	.254
1974	1.900	262	8.0	348	1.042	2.5	.262
1975	1.872	260	7.8	348	1.061	2.5	.264
1976	1.860	260	7.5	348	1.096	2.5	.270

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	79.70	79.30	980	5.63	12.60	.320	.732	.480	1.00	101	10.05
1973	75.43	75.65	1010	5.63	11.69	.316	.735	.492	1.00	96	10.36
1974	73.26	73.20	1021	5.85	11.20	.311	.738	.488	1.00	87	11.23
1975	72.66	72.48	1064	5.85	11.31	.302	.740	.491	1.00	80	11.73
1976	69.89	70.00	1094	5.85	11.31	.281	.743	.506	1.00	77	11.89

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

CZECHOSLOVAKIA - Mine CZ3

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{i}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.320	1.365	258	7.0	.75	1.73	2.21	108	2.44	756	784
1973	1.305	1.358	260	6.8	.75	1.73	2.22	108	2.47	768	785
1974	1.306	1.337	262	6.5	.75	1.73	2.20	110	2.50	785	801
1975	1.304	1.296	260	6.3	.75	1.73	2.20	110	2.52	791	802
1976	1.310	1.325	260	6.3	.74	1.74	2.20	112	2.55	809	805

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.320	258	7.0	355	.895	2.3	.299
1973	1.305	260	6.8	355	.904	2.3	.302
1974	1.306	262	6.5	352	.908	2.4	.296
1975	1.304	260	6.3	350	.948	2.4	.300
1976	1.310	260	6.3	350	.914	2.5	.291

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	72.05	71.72	926	7.09	10.80	.310	.737	.412	1.00	101	10.64
1973	69.22	69.01	947	7.10	10.36	.304	.737	.419	1.00	99	10.66
1974	67.15	67.13	981	6.80	10.30	.296	.740	.438	1.00	85	11.98
1975	66.80	66.63	1016	6.80	10.61	.286	.739	.438	1.00	78	12.59
1976	64.39	64.24	1057	6.53	10.75	.273	.743	.451	1.00	74	12.79

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

UKRAINE - Mine UKR1

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	.737	.746	319	4.0	.85	1.72	1.48	159	1.70	585	578
1973	.725	.744	310	4.0	.85	1.72	1.50	160	1.71	600	590
1974	.713	.704	307	3.8	.85	1.72	1.50	160	1.72	603	598
1975	.700	.692	305	3.6	.84	1.73	1.52	163	1.75	630	642
1976	.698	.692	305	3.6	.84	1.73	1.52	163	1.75	630	642

Mechanised longwall output in million tons and
Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	.737	319	4.0	330	.650	2.8	.184
1973	.725	310	4.0	330	.633	2.8	.185
1974	.713	307	3.8	325	.672	2.8	.189
1975	.700	305	3.6	325	.706	2.8	.192
1976	.698	305	3.6	325	.724	2.7	.199

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	74.96	75.26	1028	6.07	15.15	.460	.802	.221	1.00	91	10.73
1973	71.51	71.70	1065	6.07	15.07	.449	.802	.217	1.00	85	11.08
1974	69.56	69.13	1109	6.07	14.67	.433	.801	.225	1.00	75	11.96
1975	69.48	69.59	1157	6.06	14.66	.418	.800	.234	1.00	69	12.54
1976	68.95	68.92	1161	6.29	14.30	.399	.798	.240	1.00	67	12.89

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

UKRAINE - Mine UKR2

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.395	1.417	315	5.5	.85	1.72	1.70	140	2.35	818	835
1973	1.425	1.412	310	5.5	.85	1.72	1.70	140	2.38	828	840
1974	1.476	1.456	307	5.5	.85	1.72	1.72	140	2.45	862	875
1975	1.500	1.461	305	5.2	.85	1.72	1.75	144	2.50	921	925
1976	1.542	1.499	305	5.0	.85	1.72	1.77	145	2.62	983	980

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$
1972	1.395	315	5.5	330	.904	2.7
1973	1.425	310	5.5	325	.952	2.7
1974	1.476	307	5.5	325	1.014	2.8
1975	1.500	305	5.2	325	1.039	2.8
1976	1.542	305	5.0	328	1.101	2.8

$\frac{a_m}{MAT}$
.263
.271
.269
.275
.285

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	80.82	80.84	1198	3.85	13.30	.456	.803	.431	1.00	95	8.79
1973	77.67	77.34	1267	3.85	13.16	.449	.810	.421	1.00	86	9.15
1974	74.21	74.00	1359	3.97	11.58	.433	.796	.468	1.00	75	9.79
1975	75.32	74.90	1437	3.97	12.16	.412	.797	.476	1.00	67	10.31
1976	74.86	74.73	1494	3.97	12.07	.394	.786	.504	1.00	64	10.45

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

UKRAINE - Mine UKR3

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.699	1.719	319	9.2	.85	1.72	1.50	159	1.68	586	578
1973	1.675	1.701	310	9.2	.85	1.72	1.50	160	1.70	596	590
1974	1.666	1.668	307	9.0	.85	1.72	1.50	160	1.72	603	598
1975	1.660	1.681	305	8.8	.85	1.72	1.52	162	1.74	626	652
1976	1.648	1.682	305	8.8	.85	1.72	1.52	163	1.73	627	652

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.699	319	9.2	330	.650	2.7	.189
1973	1.675	310	9.2	330	.659	2.7	.191
1974	1.666	307	9.0	330	.677	2.7	.193
1975	1.660	305	8.8	325	.680	2.8	.191
1976	1.648	305	8.8	325	.675	2.8	.190

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	77.11	77.15	963	5.32	19.50	.459	.811	.200	1.00	115	9.02
1973	73.32	73.30	1026	5.32	19.08	.452	.799	.200	1.00	104	9.37
1974	71.20	70.92	1104	5.48	18.45	.434	.795	.204	1.00	90	10.03
1975	71.03	71.30	1162	5.48	18.54	.423	.792	.209	1.00	82	10.52
1976	70.68	70.81	1215	5.64	19.09	.399	.790	.209	1.00	77	10.67

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

UKRAINE - Mine UKR4

Mechanised longwall output in million tons and Daily output per mechanised face in tons

	O_{m_A}	O_{m_P}	$\bar{d}_m$	$\bar{n}_m$	$\bar{c}_m$	$\bar{k}_m$	$\bar{s}_m$	$\bar{l}_m$	$\bar{a}_m$	$\overline{DOF}_{m_P}$	$\overline{DOF}_{m_A}$
1972	1.860	1.840	318	4.2	.85	1.72	1.70	176	3.15	1378	1374
1973	1.805	1.768	310	4.0	.85	1.72	1.72	180	3.15	1426	1436
1974	1.776	1.798	307	4.0	.85	1.72	1.75	180	3.18	1464	1475
1975	1.720	1.716	305	3.8	.85	1.72	1.75	182	3.18	1481	1510
1976	1.755	1.755	305	3.8	.84	1.73	1.77	184	3.20	1514	1510

Mechanised longwall output in million tons and Mechanised advance in centimetres related to machine available time

	O_m	$\bar{d}_m$	$\bar{n}_m$	$\frac{MAT}{McS}$	$\frac{O_m}{MAT}$	$\frac{McS}{dn_m}$	$\frac{a_m}{MAT}$
1972	1.860	318	4.2	330	1.563	2.7	.353
1973	1.805	310	4.0	330	1.634	2.7	.353
1974	1.776	307	4.0	330	1.623	2.7	.359
1975	1.720	305	3.8	325	1.691	2.7	.362
1976	1.755	305	3.8	325	1.726	2.7	.365

Total Productivity Model

	$\frac{O}{TI_A}$	$\frac{O}{TI_P}$	$\frac{O}{MY_u}$	$\frac{CS_m}{MI_m}$	$\frac{MI_m}{MI}$	$\frac{MI}{TI}$	$\frac{O_m}{CAP_m}$	$\frac{CAP_m}{CS_m}$	$\frac{O}{O_m}$	$\frac{MY_u}{kWh_u}$	$\frac{kWh_u}{O}$
1972	83.35	83.27	1370	5.99	7.70	.451	.781	.516	1.00	72	10.07
1973	81.45	81.25	1412	6.20	7.26	.441	.780	.526	1.00	68	10.39
1974	77.79	77.61	1486	6.42	7.10	.423	.775	.521	1.00	59	11.37
1975	78.47	78.83	1539	6.42	7.32	.406	.770	.534	1.00	56	11.66
1976	76.93	76.94	1581	6.66	7.12	.386	.771	.544	1.00	53	11.96

Based on Equations I, III and V and Figure 18
See Appendix II for notation

Suffix A = actual
P = predicted

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