

Barzel estimated input functions for fuel, labour and capital for 220 plants installed between 1941 and 1959. Each plant was observed annually from its first full year of operation until any major change occurred in it, or until 1960. His method can be illustrated by concentrating on his fuel and labour equations which are identical. The demands for fuel and labour (dependent variables) are taken to be functions of the same set of independent variables, namely, size of plant, anticipated average load, load index, anticipated average price, price index, age, and date of installation. The equations are estimated in log-linear form so that regression co-efficients are partial elasticities.

Technological change is represented by shifts in the fuel and labour equations between plants of different vintage years. Barzel ran separate regressions, one for each vintage year, and observed that the functions remained stable between years, except for changes in the constant term. Consequently, dummy variables for changes in the constant term only, were introduced. 1941 was taken as the base year and the dummy-variable regression co-efficients for other years were compared with this. On the fuel side, the amount of fuel required to produce one kilowatt hour was 9,6 per cent lower in 1959 than in 1941. On the labour side, the amount of labour required for plants installed in 1941 was 1,61 larger than that required for plants installed in 1959 for a given amount of output. Substantial economies due to scale were indicated. The regression co-efficients on the size variable for the fuel, labour, and capital equations were 0,896, 0,626, and 0,815 respectively.

Komiya employed a stratification technique as his methodological approach for distinguishing between shifts along (scale economies) and shifts of (technological change) the production function. As with Barzel, he observed that over the period 1938 to 1956 there had been substantial declines in labour, fuel and capital requirements and his purpose was to examine how much of the declines was attributable to scale-induced economies as opposed to production-function shifts. To achieve this he fitted a long-run cross-section production function to the observations and examined the shift of the function over time by statistical tests.

He observed only new plants built over the period 1930 - 56 and classified them in terms of the year they were built and the nature of

the fuel used (coal and non-coal groups). A plant built in a certain year is assumed to embody the technology available at the time, so that if differences are observed in the production function between these vintage groups, this provides evidence of production-function shifts due to technological change. Plants were divided into four homogeneous vintage groups : 1930 - 45, 1946 - 50, 1951 - 3, and 1954 - 6. With the further distinction between coal and non-coal groups, this created a total of eight possible sub-groups to which any plant could be allocated. Each plant entered the sample only once, when new, and never appeared again. For each of these eight cells a production function was fitted and analysis of covariance used to test whether the estimated function differed significantly between cells.

Komiya employed a set of three input functions which related the fuel, labour, and capital requirements respectively (as dependent variables) to the level of output at full capacity,  $X_1$ , defined as the average size of generating unit in megawatts (representing the explanatory variable). Also included as a variable was the number of generating units ( $X_2$ ) to test for economies of scale when many units are built in the same plant. The model employed was,

$$F = A_F X_1^{F_1}$$

$$K = A_K X_1^{K_1} X_2^{K_2}$$

$$L = A_L X_1^{L_1} X_2^{L_2}$$

transformed to logarithms where  $F$ ,  $K$ , and  $L$  represent fuel, capital and labour respectively;  $A$  represents the constant terms;  $X_1$  and  $X_2$  are as defined above, and  $F_1$ ,  $K_1$ ,  $K_2$ ,  $L_1$  and  $L_2$  are respective exponents.

His results showed that the dominant factor in the decline in input requirements was the expansion in the scale of production and not the shift in the production function. The fact that it had become possible to build larger and larger generating units outweighed the impact of pure technological change.

Dhrymes and Kurz followed the stratification methodology introduced by Komayai to isolate technological progress from scale-induced economies. They employed a sample of 362 newly-constructed plants built over the period 1937 - 59, but unlike Komayai's analysis which was based

on vintage and fuel type, their classification was based on vintage and size, with size being measured in installed megawatts. They identified four slightly different technological periods - 1937 - 45, 1946 - 50, 1951 - 4, and 1955 - 9 - and four categories of megawatt installation, thus creating sixteen different vintage-size cells. For each cell they estimate the parameters of a generalised version of the CES production function incorporating three inputs, fuel, labour and capital, and assuming cost-minimising behaviour on the part of entrepreneurs. Specific conclusions may then be derived by comparing the parameters estimated for the various cells. Estimation is achieved by the use of two-stage least squares. The authors reported, in common with Komayi, that scale-induced economies were the prevailing phenomenon.

Galatin carried forward and enlarged the methodology created by these authors in his comprehensive 1968 study. Explaining the difficulty of interpretation at the macro level of aggregation, he states that ambiguity in separating out technological progress and scale-induced economies is only avoided at the level of the micro-units of the individual machine and the plant. The problem of evaluating capital in terms of a monetary aggregate is avoided by identifying capital in a plant as a set of machines each of which is characterised by measures of vintage and size. This device of identifying rather than measuring capital enables the necessary differentiation between the effects of scale and technology. The measurements of scale economies are derived by comparing the ex-post production functions for individual machines of different sizes, but of the same vintage. The effects of technological change are measured by examining the shift of the ex-post production function for machines of the same size, but of different vintage. Examination of the exact fuel, labour, and capital-input equations is not necessary as these incorporate many modifications on the traditional approach, but suffice it is to say that his whole approach derives from the stratification technique first employed by Komiya.

(iii) Simultaneous Estimation of Non-Neutral Technological Change and Scale Economies

So far the discussion has concentrated on studies which either differentiated neutral from non-neutral technological change, or

isolated scale economies from technologically-determined economies, but did not perform both simultaneously. This latter task was attempted by Murray Brown in a series of evolving articles, which developed the technique of "epochal estimation" which could be applied to aggregate data.

The earliest published attempt employed a "flexible" approach to the technique (42) where both CES and Cobb-Douglas production functions were fitted to overlapping time periods. The CES function employed was

$$X = \kappa [K^{-\rho} + \delta L^{-\rho}]^{-\frac{1}{\rho}}$$

for which the marginal rate of technical substitution can be written,

$$\frac{r}{\omega} = \frac{1}{\delta} \left( \frac{L}{K} \right)^{\frac{1}{\rho}}$$

With constant factor prices and constant elasticity of substitution, an increase in  $\delta$  implies a capital-saving technological change. The final fitted equation, with a trend term added, was the logarithmic form of,

$$\frac{L}{K} = \delta^{\epsilon} \left( \frac{r}{\omega} \right)^{\epsilon} t^{\beta_1}$$

The fitted Cobb-Douglas equation was,

$$X = A K^{\alpha} L^{\beta} t^{\beta_2}$$

These two expressions above were fitted to four overlapping time periods, 1950 - 60, 1952 - 60, 1954 - 60, and 1955 - 60, for the private domestic non-farm sector of the United States. Successive estimates of  $\delta$  indicate the nature of non-neutral technological change, substantiated by changes in the ratio of  $\sigma/\gamma$ . Changes in the sum  $\sigma + \gamma$  measure changes in economies of scale. The parameters  $\beta_1$  and  $\beta_2$  measure rates of change.

For the sub-periods, the value of  $\delta$  rose steadily as 1960 approached, as did the value of the ratio  $\gamma/\sigma$ , both indicating capital-saving technological progress. In addition, the sum of  $\sigma + \gamma$  always exceeded unity and rose as 1960 was approached. The variable  $t$  is treated as a proxy variable for neutral technological change, but probably acts as a catch-all term for gradually-changing variables (i.e. the level of managerial ability), that influence output but are not explicitly included in the function.

A more-rigid approach to epochal estimation was presented in a later article by Brown and Popkin (43), and subsequently further elaborated in succeeding articles, in which they employed the technique of "technological epochs". The concept of such epochs was examined in chapter 6. A technological change ushers in a new epoch when the long-run structural relationship between inputs and output changes in a significant (statistically) way, for example, when the production function parameters that have ruled for  $N$  years are no longer valid in year  $N + 1$ . Thus a technological epoch encompasses a period of time within which the production-function parameters remain stable. The operational procedure of isolating epochs in time-series data is to specify a production function and apply stability analysis to estimates of the function in order to discover periods of time within which the function is stable. For instance, consider two regressions, one derived from  $N$  observations, and the other from  $N + M$  observations. If the two regressions are homogeneous then no structural change has occurred in the period from which the  $N$  and  $M$  observations were drawn. If they are not homogeneous then a structural break has occurred. Brown and Popkin choose a base period (1890 - 1905) and fit a Cobb-Douglas function to data on output, capital and labour. Another regression is then run on data for 1890 - 1907 to give a second set of estimates. At this point a stability test can be run to test the hypothesis that the two

regressions were generated by the same structure. The tolerance-interval test is used to decide whether new observations are homogeneous with the base period. If the hypothesis is accepted, two more observations are added and a new regression is run. This proceeds until a structural break is discovered. Using Kendrick's data for the United States' non-farm domestic economy 1890 - 1958, they are able to distinguish three epochs: 1890 - 1918, 1919 - 1937, and 1938 - 1958. By definition, these are periods within which no non-neutral technological change has occurred, i.e. there was insufficient "twist" of the production function to indicate a new non-neutral technology. Fitting the production function to each of the epochs allows estimation in the conventional manner of the effects of the weighted change in inputs, economies of scale, and neutral technological change. Non-neutral technological change can be isolated by the change in the parameter estimates between epochs.

equation fitted is,

$$X = A K^{\alpha} L^{\gamma} t^{\beta_2}$$

which is identical to that previously used, and was fitted to each of the three epochs. Economies of scale are measured by  $\sigma + \gamma$ . A change in the A term represents a change in neutral technological progress. Changes in  $\beta_2$  represent changes in the rate of neutral technological progress. Non-neutral progress is measured by the change in the ratio  $\gamma/\gamma + \sigma$ . The authors found that economies of scale existed in the first epoch whilst constant returns were evident thereafter. Neutral technological change was lowest in the first epoch but became increasingly important thereafter. The values of the ratio representing non-neutral change were 0,66, 0,42 and 0,49 for the three epochs respectively, indicating labour-saving change initially and capital-saving change for the latter part of the overall period. It will be noticed that this result confirms that previously reported in Brown and De Cani (42).

The authors also attempt an ordering of the factors on the basis of their importance in contributing to output changes over the period.

this measure is in terms of the percentage contribution of each factor, which can be derived via a total differential of the production function where not only the factor inputs but the parameters have a time dimension. Suppressing all but the linear part of the expansion and approximating derivatives by discrete changes it is possible to decompose and quantify output changes over the period into those due to (i) input changes (ii) economies of scale (iii) neutral technological progress, and (iv) non-neutral technological progress. For this purpose, the measure of economies of scale is added to the measure of the change in inputs, but not in a straightforward manner (which would obviously overstate the contribution of the inputs) but under the assumption of constant returns to scale. This endeavours to answer the question of what would have been the contribution of the inputs had technology remained static from one epoch to another, and under constant returns to scale. The tentative ordering of the factors in terms of importance by the authors was : neutral change, changes in inputs, and non-neutral change. The contribution of the two types of technological progress added together exceeded the contribution of the inputs.

At a later date, Brown (44) developed a modified approach to the above analysis, incorporating two significant changes. Firstly, he employed analysis of variance in preference to the tolerance-interval test as his method of stability analysis in isolating the different technological epochs. Applied to the same data, extended to 1960, he uncovered four, instead of three, epochs, the limits of which differed slightly from those of the Brown-Popkin study : 1890 - 1906, 1907 - 20, 1921 - 39, and 1940 - 60. Applying the Cobb-Douglas function to each epoch he found evidence of increasing returns to scale in the first epoch, but decreasing returns thereafter. The rate of neutral technological progress was not significantly different from zero during the first two epochs, but rose to 2 per cent per annum during the third epoch, and fell back slightly to 1,8 per cent per annum during the fourth epoch. Non-neutral technological progress was labour-saving initially and strongly capital-saving thereafter, again confirming the findings of Brown and De Cani (42) and Brown and Popkin (43).

Secondly, in assessing the relative importance of input changes and neutral and non-neutral technological change in contributing to output changes, Brown dropped the method of a total differential of the production function which was then evaluated with epochal estimates.

This involved discrete differences over long time periods, violating the "neighbourhood rule". The estimate of the total output change deviated too much from the actual output change. In place of this approach he substituted a "finite-differencing" method which eliminated this difficulty.

In two further articles, Brown and co-author De Cani, attempt to measure the impact of technological change on employment (45) and the distribution of income (46). To achieve this, the measurement of biased technological progress and economies of scale are necessary steps in the analysis. In their approach they combine methodologies introduced in the earlier studies (42) and (43), that is, they fit a CES production function to different technological epochs. Using Brown and Popkin's data and technological epochs, they fit a modified version of the marginal-rate-of-technical-substitution side relation to each epoch and monitor the changing values of  $\delta$ . A rising  $\delta$  implies capital-saving technological change, given constant factor prices and a constant elasticity of substitution. Their results are, of course, identical in both articles. Non-neutral technological progress is initially labour-saving and then capital-saving, again confirming the conclusions of their other articles. The value of the elasticity of substitution is less than unity in all epochs. Increasing returns to scale were evident in the first two epochs and decreasing returns in the third.

The technique pioneered by Brown and his co-authors is an ingenious one, but, needless to say, is capable of being criticised on several fronts, mainly statistical. Brown himself lists twelve deficiencies of the model in (43), and five deficiencies with an evaluation of their seriousness in (44). In a major conceptual attack on the technique, Gregory (47) highlighted three serious problem areas - the "adding-up" problem, the choice of epochs, and a questioning of the usefulness of the epoch technique - soliciting a spirited defence and further elaboration by Brown and Popkin.

As a de-composition technique, the method is useful in distinguishing between neutral and non-neutral technological progress and economies or diseconomies of scale previously "lumped together" - the productivity residual. However, it does not distinguish between genuine factor-saving biases in technological change and factor substitution caused by changing relative prices, nor does it distinguish between scale-induced and technologically-determined economies of

scale. However, identification is achieved by the model as acknowledged by Nerlove (30). By assuming an abrupt change the instant one passes over from one epoch to another ("it is moot just how reasonable an assumption this is") this methodology is, in a sense, the opposite of the "smoothness" assumption which "lets us out" of the implications of the impossibility theorem, thus allowing identification.

#### Embodied Technological Progress

A discussion of the concepts of embodied and disembodied technological progress was undertaken in chapter 6 and revolved around the precise method by which technological changes are actually introduced into the production process. In all of the "unrefined studies" of chapter 7 the assumption was made that technological progress is disembodied, thus automatically demoting the role of capital in the growth process. Old and new capital contribute equally to technological progress. New investment is not required to generate economic growth : growth continues even with unchanged factor inputs. New inputs carry no more weight than old inputs in contributing to the growth process, thus greatly reducing the impact which new capital investment has on economic growth.

According to Solow (48), however, this view

"conflicts with the casual observation that many, if not most, innovations need to be embodied in new kinds of durable equipment before they can be made effective. Improvements in technology affect output only to the extent that they are carried into practice either by net capital formation or by the replacement of old-fashioned equipment by the latest models, with a consequent shift in the distribution of equipment by date of birth".

Accordingly, new capital is more productive than old capital. When equipment is introduced it embodies all the technology available up to that moment, but once installed its productive efficiency cannot be increased by subsequent advances. Rather it is the prerogative of the next generation of capital inputs to introduce such technology which is now embodied in their design. Accordingly, technological progress can only take place through new investment. If this reasoning is accepted

then more-recent additions to the capital stock must be weighted more heavily than earlier additions which has the effect of increasing the sensitivity of growth to changes in the capital stock.

If the embodiment hypothesis is important it forces a radical re-assessment of the growth process. But the importance to technological progress remains unimpaired. The disembodied hypothesis places all such progress in the catch-all residual. The embodied hypothesis merely switches it into the measurement of capital.

Applied studies can be divided into two camps : (i) those which accept the embodiment hypothesis and attempt to estimate the precise rate of embodied technological progress, and (ii) those which do not totally accept the embodiment hypothesis and try to assess its relative importance compared with the conventional approach of the role of capital and disembodied progress.

Solow (48) developed his capital-vintage model in 1959 in which all technological progress is embodied in new machinery. Accordingly, capital can no longer be treated as a homogeneous aggregate: in particular, capital of different ages, or "vintages", must be treated separately. Thus, a production function can be specified for each vintage of capital. Solow assumes the following : (a) machines of the same vintage are identical, but different from those of other vintages, (b) machines of the latest vintage are more productive than those of the preceding vintage by a constant exponential factor, (c) the depreciation rate is constant and uniform for all machines of all vintages, (d) the marginal rate of substitution between machines of different vintages is independent of other inputs, (e) a Cobb-Douglas production function with constant returns to scale is specified, (f) the marginal product of labour over all vintages of capital goods is equal. Through these assumptions Solow ensures the existence of an aggregate production function, and is able to specify,

$$X(t) = Ae^{\delta(1-\gamma)t} L(t)^\gamma J(t)^{1-\gamma}$$

where  $\delta$  is a decay factor;  $t$  is the time period; and  $J$  is the appropriate measure of capital to enter the production function in place of the normally-used  $K$  in disembodied studies, and is defined as,

$$J(t) = \int_{-\infty}^t e^{v[\delta+\lambda(1-\gamma)^{-1}]} N(v) dv$$

where  $v$  refers to the vintage;  $\lambda$  is the rate of embodied technological progress; and  $N(v)$  is new capital of year  $v$ . The growth of  $J(t)$  has, in effect, three parts : (i) the growth of the actual capital stock, (ii) the average rate of its improvement, and (iii) the effect of changes in its average age which depends on changes in the investment rate.

The problem now is to estimate the parameters of the production function, particularly  $\lambda$  the rate of embodied technological progress. The higher is  $\lambda$  the more productive is new capital compared with old and thus the greater the scope for raising the growth rate by increasing new investment. The usual method of estimating  $\lambda$  has been an iterative procedure assuming trial values for the other parameters. The value of  $\lambda$  in aggregate data has been found to be extremely sensitive to the trial values chosen and the method of estimation. Solow obtained a value of  $\lambda$  of 2,5 per cent per annum (compared with 1,5 per cent per annum in disembodied studies) which clearly raises the sensitivity of growth to changes in the growth of the capital stock.

Other tests of the embodied hypothesis have been made by Solow. In a 1962 study (49) he attempted to determine how much fixed investment would be necessary to support future alternative growth rates of potential output assuming that all technological progress has to be embodied in new capital units before it can have any effect on output. He assumes that capital goods produced in any year are  $g$  per cent more productive than capital goods produced the year before, and so constructs adjusted estimates of the capital stock corrected for this steadily-increasing efficiency. He shows that for different rates of embodied progress and labour-force growth what percentages of Gross National Product must be invested to achieve different growth rates. His embodied model is found to be more realistic in terms of the necessary investment rates than a model with disembodied progress which demands implausibly high investment rates to achieve an ambitious growth rate. In a 1963 study (50) Solow constructed an embodied model for the U.S.A. and Germany, building up effective capital stock assuming different rates of improvement in capital efficiency. Choosing that result which gave an elasticity of output with respect to capital closest to capital's share of income, a rate of embodied progress of 5

per cent per annum appeared most reasonable.

It must be emphasized, however, that by assuming disembodied progress to be zero, Solow's estimates of embodied progress are probably biased upwards. A measure of both types of progress is the ideal. Several studies which have attempted to assess the relative importance of embodied progress have generally supported disembodied progress. These include Berglas (51), Wickens (52), Massell (53), Intriligator (54), and Lydall (55). Unfortunately, severe statistical difficulties are invariably encountered. The debate is still far from settled. Studies which have assumed either the pure embodied or the pure disembodied hypothesis have found that they seem capable of explaining the facts separately. Studies which attempt to treat both types of progress simultaneously have to contend with severe intercorrelation.

Objections to the embodiment hypothesis have been made on other fronts. Denison (56), consistent with his treatment of measuring capital by cost, prefers to retain efficiency increases in the technological-change residual rather than in the capital measure, so that from his point of view the embodiment effect works solely through the age distribution of capital. However, in practice, the age distribution displays very small variation. Consequently, the embodiment hypothesis is "unimportant". This view is challenged by Nelson (57) who found that variations in the age of the capital stock account almost entirely for variations in U.S.A. productivity over the period 1929 - 60.

Jorgenson (58) is able to show that after dropping the highly-restrictive assumption that technical change proceeds at constant exponential rates it is impossible to distinguish models of embodied progress from models of disembodied progress on the basis of factual evidence. Both types of technical change have precisely the same factual implications. This has importance for economic policy. It has been seen that in measuring potential economic growth it is often useful to calculate the amount of investment required for a given amount of economic growth. Embodied models show a lower investment rate than disembodied models is necessary, and this is attributed to underlying differences in the two models. Jorgenson shows, however, that due to the precise equivalence between the two models the source of the difference lies not in the models but, rather, in different assumptions about the facts. Brown (59) has also attacked the contention that

embodied progress implies a lower investment rate to attain stated growth rates. The distinction between embodied and disembodied progress is a real one from a theoretical viewpoint, and is important from a policy point of view. However, he shows that the distinction between the old-style net-capital-stock model (disembodied) and the productivity-adjusted capital-stock model (embodied) is not a real one: the old and the new concepts of capital are simply two different ways of conceptualising the same phenomenon.

#### The Effect of Inter-Industry Shifts

The deficiency in using aggregate data to try and isolate the impact of technological progress was mentioned in chapter 7. The measure of total factor productivity is biased upwards because it measures not only the effect of pure technological progress within industries but also the re-allocation of resources between industries. Due to the methods of aggregating output in the aggregate production function there is a confounding of changes in the composition of output and changes in the production function itself. Only changes in the production function ought to be classed as technological progress, except to the extent that changes in the composition of output result from advances in knowledge.

The large gains in income per head due to resource shifts from low- to high-productivity sectors was noted by Kuznets (60). Resource re-allocation from agriculture to industry was also shown by Denison (61) to account for a significant proportion of the growth of national income in several European countries over the period 1950 - 62. It is, therefore, worth emphasizing the size of the aggregation bias when trying to separate movements along a production function from shifts of the function at the level of the aggregate economy. To the extent that resource re-allocation is non-innovational, but is simply an extraneous element introduced solely because of the high level of aggregation, it cannot be categorised with pure innovational technological progress.

In order to separate the two, Massell (62) disaggregated to the Standard Industrial Classification two-digit industry level and considered the 19 industry groups within the U.S.A. manufacturing sector for the period 1946 - 57. His method was to amend Solow's 1957 model to express intra-industry improvements in the state of the arts as a weighted sum of the improvement factor for the individual industries.

This component can then be subtracted from the Solow-type aggregate technical advance to leave, as a residual, an inter-industry component representing the shift of resources.

Massell's basic formula is,

$$\dot{A}/A = \gamma_1 + \gamma_2 + \gamma_3$$

where  $A$  is the index of technology and a dot indicates a time derivative.  $\gamma_1$  is intra-industry technical change consisting of a weighted average of the individual industries' rates of technical advance. It results from efficiency improvements within industries only and excludes improvements resulting from resource re-allocation between industries. It is, therefore, innovation as strictly defined.

$\gamma_2 + \gamma_3$  represents inter-industry resource shifts, both capital and labour, from low to high marginal productivity industries, thus improving aggregate technology over and above the improvements in industry groups. This component in itself is not innovational.  $\gamma_2$  refers to improvements resulting from capital shifts whilst  $\gamma_3$  refers to improvements resulting from labour shifts. The  $\gamma$ 's are defined as follows:

$$\gamma_1 = \frac{\sum X_i \dot{A}_i}{X \dot{A}} : \gamma_2 = \sigma \frac{f_i^K}{f^K} \cdot \frac{\dot{K}_i}{K} : \gamma_3 = (1-\sigma) \frac{f_i^L}{f^L} \cdot \frac{\dot{L}_i}{L}$$

where  $X$  = output;  $\sigma$  = capital's share;  $f^K$  and  $f^L$  represent the marginal product of capital and labour respectively;  $K$  and  $L$  represent capital and labour respectively; and  $i$  denotes industry  $i$  where the absence of a subscript denotes an aggregate.

The component  $\gamma_2 + \gamma_3$  is introduced by the aggregation process over industries and indicates that the macro variables are not exact

counterparts of their corresponding micro variables. Actually  $\gamma_1$  is still not really "pure", for further disaggregation is always possible to the level of the firm, or even plants within a firm.

Over the study period Massell found the mean annual rate of total technical change ( $\gamma_1 + \gamma_2 + \gamma_3$ ) to be .028. The average intra-industry change ( $\gamma_1$ ) was .019. The difference ( $\gamma_2 + \gamma_3$ ) representing the inter-industry shift of resources is therefore .009, almost one-third of the total. Of the total inter-industry shift of resources, the shifts of labour ( $\gamma_3$ ) accounted for approximately one-seventh whilst the shifts of capital ( $\gamma_2$ ) accounted for the remainder. This indicates the significance of capital mobility. Massell is able to conclude that since the earlier Solow-Massell results attribute 80 - 90 per cent of the improvements in labour productivity to technological advances, this new study suggests that approximately 25 - 30 per cent of the labour-productivity improvements are attributable to a shift of resources among industries. Massell's study, therefore, represents an important step in further refining and decomposing the catch-all residual previously called technological progress and due to the significant impact of resource re-allocation suggests that only firm, and perhaps industry, production functions may be the only feasible ones. Massell is actually philosophical about the objective of decomposing the technological-progress residual. He admits that terminology is often confusing. The ultimate purpose in separating shifts of, from movements along, a production function is to better understand the sources of labour-productivity increases. Under which category an item is placed, or what terminology is given to it, are aspects of little relevance. This is often semantics. At least an understanding is required of what the components are and where they come from.

#### B. THE EXPLANATION APPROACH

The rationale behind the concept of the "explanation approach" in "forcing the residual to zero", is adequately spelled out by Jorgenson and Griliches (63). They observed that by far the largest portion of the literature on total factor productivity is devoted to the problems of measurement rather than to problems of explanation and, accordingly, changes in total factor productivity have been given such labels as "the

residual" or "the measure of our ignorance". As a result, the problem of explaining growth in total output remains unsolved.

A major portion of the "explanation approach" is concerned with the quality correction of conventionally-measured inputs. Discussion in the earlier part of this chapter touched upon this aspect and in this respect Kennedy and Thirlwall (64) pose the pertinent question,

"...should we accept the implied proposition that inputs should be measured in units of constant quality according to their ability to contribute to production, which almost amounts to measuring total inputs by output?"

They correctly identify that the answer to this question depends upon the purpose of our study. If the purpose is simply to measure the increase in the productivity of factors of production over time then it makes little sense to adjust the factors for quality changes. On the other hand, if the purpose is to lay down the conditions for growth there is a case for adjusting the input series for quality changes to avoid misunderstanding of the growth process - in particular, to avoid the impression from a large productivity term that growth is "costless".

At this stage it is important to conceptually distinguish between the embodiment effect, already discussed, and quality correction of inputs. Not all quality adjustments mean embodiment. In particular, the latter refers only to quality improvement associated with vintage of capital or labour. For example, productivity increases due to age and education are part of the embodiment effect, whilst improvements due to sex and race characteristics are not.

The quality adjustment of the labour-input variable has received most attention from researchers. It is realised that part of technological progress must be transmitted through changes in the characteristics of the labour force such as skill, age, education, sex and race, and, hence, separate indices for each of the labour qualities must be derived to measure their contribution to the growth of output separately. Quality correction of labour input implies that a unit of high-quality labour is weighted proportionately more than a unit of low-quality labour. To achieve this, methods have to be employed to differentiate between such units which are reflective of the actual productivity differences among the various groups.

One method that has been utilised amounts to a quality-corrected series of manhours. This approach starts out with the contribution of the aggregate manhours and then adjusts it to take account of changes in vocational training, length of schooling, or type of education of the workforce, assuming that there is a close relationship between qualifications and quality. For instance, Griliches (65) focuses attention on the contribution of education to the growth of labour input, and thus inflates the conventional labour variable by an index of education per man. Another method is to combine the hours of various employees in terms of pay differentials, with the hours of higher-paid workers being given more weight than lower-paid workers. It is assumed that earnings differences reflect productivity differences. Workers grouped in terms of education, skill, and experience or by demographic characteristics such as age and sex, are then combined in terms of their average earnings in some reference period. For instance, Denison (66) identifies the reduction in hours worked, age-sex composition, and the educational quality of the labour force as the main factors affecting labour services. Relative earnings are used as measures of the marginal productivity of various types of labour and as weights in constructing the aggregate labour input. In such ways, changes in the composition of the workforce are captured in the labour input itself, rather than in a residual productivity term.

An alternative procedure to the above labour-correction approaches is to leave the conventional labour input unchanged and insert an additional variable in the production function to capture the effect of labour improvement. This was the approach of Niitamo (67) who called the additional variable "the level of knowledge", defined as the number of persons who have graduated from lower secondary schools divided by the population in working ages. His study was one of Finnish industry over the period 1925 - 52, and it was found that the additional variable made a substantial contribution towards "explaining" what would otherwise have been an unexplained trend.

It will be appreciated that labour quality can improve not only through increases in the quantity and quality of education but also through the so-called "learning process". This reflects the effect of cumulative experience on labour productivity. Whilst numerous writers have attempted to adjust the labour variable for the effect of education, the learning process, on the other hand, has proved more

intractable. Discussion of the process was undertaken in chapter 6. Rather than incorporating the process in a production function it has been left as part of the residual, often being regarded as a function of time, and, hence, being the purest form of disembodied progress.

In a recent major study, Gollop and Jorgenson (68) have attempted to account for quality characteristics of both labour and capital, and their input index accordingly includes "quality" index components for labour and for capital. Their objective was to describe and analyse post-war patterns of productivity growth in the United States' economy. Labour input was disaggregated for each industry according to the sex, age, education, employment status, and occupation of workers. This cross-classification of industrial and demographic characteristics gave rise to 81 600 cells of a matrix, namely, fifty one industries, two sexes, eight age groups, five education groups, two employment classes, and ten occupation groups. Moreover, they required four such matrices, one for each of the four components of labour input: employment, hours, weeks, and labour compensation. Finally, they required such matrices for each year of their study period. In other words they had undertaken a monumental task of constructing matrices cross-classified by the industrial and demographic characteristics mentioned, for all four components of labour input, for each year of the period 1947 - 73. To accomplish this objective they introduced the technique of a multiproportional matrix model.

In regard to the capital-input measure, the Gollop-Jorgenson paper can be regarded as the termination of a long apprenticeship which Jorgenson spent, firstly, in collaboration with Griliches (69, 7, 70), and, secondly, with Christensen (9, 71, 72), revolving around the contention that neglect in many studies of the effects of changes in the structure of capital had given rise to significant errors of measurement and that such errors had been an important source of measured productivity change. Errors had occurred in the use of input prices in place of output prices for structures; in aggregation; in assuming that service prices are proportional to asset prices; and in assuming that capital services are proportional to capital stock for each type of asset. Elimination of such errors was found to drastically reduce the residual total-factor-productivity term. Basically, Jorgenson with his collaborators, extended to capital the principle of weighting input components by marginal products, and arrived at his more-or-less

definitive methodology with Gollop after corrections inspired by Denison (8, 73). For each of the fifty one industries examined, Gollop and Jorgenson differentiated four types of real capital, which are weighted by the rates of return in four economic sectors. These rates of return are adjusted for the effects of taxation of property income, and for the impact of differences in service lives and rates of change in prices of different types of capital assets.

The authors were able to obtain measures of the increase in efficiency of labour and capital inputs stemming from relative shifts in the composition of the inputs by dividing indices of labour and capital inputs adjusted for quality by the corresponding indices of unadjusted input. In contrast to traditional studies in this field, as well as the "growth accountancy" studies of Denison, examined later, their estimates showed a substantially larger increase in real factor inputs and a correspondingly smaller increase in the residual, most of the difference being due to the different methodologies used in measuring capital.

Christensen, Cummings, and Jorgenson (74) use the same theoretical framework, in principle, as Gollop and Jorgenson in making an international comparison of economic growth for nine separate countries over the period 1947 - 73. However, the difficulties entailed in working with inter-country data meant that their presentation of quality-improvement indices was less ambitious. Thus, labour-input adjustment was based only on educational-attainment data, and the capital-adjustment procedure excluded disaggregation and weighting by industry.

A logical accompaniment to the quality-correction procedure is the "growth-accountancy" approach whereby the aggregate production function is not solely used as an estimation framework but as an organising device or accounting format to isolate the contribution of various factors to the growth of output. Usually a linear homogeneous production function is assumed with relative input prices taken as measures of marginal products. Jorgenson and Griliches (7), as previously seen, try to explain all technical change by making appropriate adjustments for aggregation and measurement errors in prices and quantities of the inputs. Both Denison (66) and Griliches (65) attempt to reduce the magnitude of the residual to a "pure" measure of technological progress after making appropriate adjustments for input quality plus other corrections. In his agricultural study, Griliches

adjusted not only the labour input by inflating it by an index of education per man, but also adjusted the capital measure. He believed that improvements in the quality of machinery had been disguised by biases in the standard price indices used to deflate capital-equipment expenditures. Accordingly, he constructed his own price-index deflator. He was also perturbed that official capital-stock estimates used rates of depreciation which were too high, thus overestimating the annual decrease in the flow of services. He was, therefore, concerned to correct this series to take account of a much smaller decline in the flow of services with age.

Furthermore, he contended that a weighting scheme for inputs based on factor shares is incorrect for productivity comparisons in a sector like agriculture which is believed to have been in continuous disequilibrium. The weighting coefficients for inputs can be approximated by input market prices or their relative shares in total costs if the assumptions are made of linear (or linear-in-logarithms) production functions, constant returns to scale, and competitive equilibrium (at least in the base period). But in a sector like agriculture where it is believed that labour's marginal product is substantially below the wage rate and capital's marginal product substantially above the bank or mortgage rates, a statistically estimated production function provides a conceptually more-appropriate system of weights for compiling inputs into a total-input index. Griliches found the estimated labour coefficient to be smaller and the capital coefficient larger than the official factor-shares estimates.

Using his corrected-input series together with the estimated production-function weights, Griliches was able to account fully for the growth in agricultural output between 1940 and 1960 leaving nothing to be explained by a residual technological-progress category. Substituting his corrected-input series into the conventional weighting scheme reduces the estimated productivity increase by about 33 per cent. Furthermore, using the estimated production-function weights, and allowing for scale effects, fully accounts for what productivity increase is left.

This complete explanation for observed productivity increases does not mean, of course, that there were no meaningful increases in agricultural production over the period. It means rather that Griliches succeeded in providing an explanation (input quality increases,

appropriate weighting system, and economies of scale) for what were previously unexplained increases in farm output. He provided a breakdown of measured productivity growth into its source components. The production function is found to remain constant, at least over substantial stretches of time. What was regarded as a catch-all residual variable has been transformed into movements along a more general production function and into identifiable changes in input qualities.

Denison divided the sources of growth into three main categories:

- (i) the contribution of factor inputs, with labour being adjusted for quality change,
- (ii) economies of scale and resource shifts,
- (iii) advances in knowledge as a "pure" measure of technological progress, obtained as a residual.

Over the period 1929 - 57, the United States' Gross National Product increased by an average of 2,93 per cent per annum. Of this, 2,0 percentage points - or 68 per cent - was accounted for by the increase in total inputs (1,57 for labour and 0,43 for capital), whilst the remaining 0,93 percentage points was accounted for by the increase in output per unit of input.

His estimate of labour input is adjusted for quality change due to improved education. His procedure is interesting, and involves information on the distribution of the labour force by amount of schooling at different dates, and information on income differences between educational cohorts with different amounts of schooling embodied in them, which are then used as weights to obtain an index of labour-quality improvement stemming from education on the assumption that 60 per cent of earnings differences are due to differences in the number of years schooling. For example, if the earnings difference between those with eight-years schooling and those with twelve is 40 per cent, and the former is taken as one unit, then the latter is counted as  $1 + (0,6 \times 0,4) = 1,24$  units. On this basis Denison calculated that education growth had improved labour quality equivalent to an increase in the labour force of 0,93 per cent per annum. With an elasticity of output with respect to labour of 0,73, the contribution of education to the annual growth rate was 0,68 percentage points or 23 per cent.

The increase in output per unit of input is a residual element in his calculations being that portion of the growth rate not accounted for by increased factor inputs. Denison attempts to break down this residual into a number of components, several of them being rather trivial and cancelling out on balance. One factor that was important was economies of scale, calculated to be responsible for 0,34 percentage points of growth per annum, or 11 per cent of total growth rate. Hence, the remaining 0,59 percentage points - amounting to 20 per cent of total growth - is attributed to "pure" advances in knowledge, meaning improvements in technological and managerial ability, enabling existing goods and services to be produced more efficiently. A summary of Denison's findings is presented in table 8.1 below.

TABLE 8.1      ALLOCATION OF GROWTH RATE OF UNITED STATES' REAL GNP  
AMONG THE SOURCES OF GROWTH, 1929-57

	Percentage Points in Growth Rate	Per cent of Growth Rate
REAL GNP - total growth	2,93	100
INCREASE IN TOTAL INPUTS	2,00	68
Labour; adjusted for quality change	1,57	54
Employment	1,00	34
Change in hours of work	-0,20	- 7
Education	0,67	23
Other Factors*	0,10	4
Capital	0,43	15
INCREASE IN OUTPUT PER UNIT OF INPUT	0,93	32
Economies of scale	0,34	12
Advance of knowledge	0,59	20

\* Increased experience and better utilisation of women workers and changes in age-sex composition of the labour force.

Source: Denison, op cit., table 32, page 266.

Denison's work was a milestone in the "explanation approach", and contains many valuable insights into the economic-growth process. However, his breakdown should be regarded as no more than a crude approximation due to the nature of some of his assumptions (for instance, the so-called "60-per-cent rule"), and his resort to pure guesswork in some instances. An excellent critique of Denison's study is provided by Abramovitz (75). Denison updated and refined his United States' study in 1974 (76). Earlier, in 1967, he had also extended his

work to several European countries (61).

The popularity and relevance of the "explanation approach" as against the "measurement approach" has received a substantial boost in view of the retardation of the trend of productivity in the United States' economy, particularly noticeable since 1973. Fabricant (77) observes that previous generations have grown accustomed to favourable news on the productivity front so that the recent record is both disappointing and surprising. Faced with such a situation the modern call is not simply to measure the extent of the demise but to explain the factors causing it, so that identification may be followed, hopefully, by correction. In view of Denison's previous work he was well suited to take the initiative in this direction, applying his methodology to an explanation of the sources accounting for this slower growth in a major 1979 study (78). Other important studies on this topic have been contributed, especially by Kendrick (79), and Norsworthy, Harper and Kunze (80).

Finally, mention must be made of a topic which has increasingly become regarded as an essential element in the "explanation approach" - the economics of the creation of technological change. Technical progress does not just "happen", but results from a combination of research, invention, development, and innovation. In other words, the production and use of knowledge requires resources, and the activities involved may be regarded as inputs into the productive system. If knowledge is not exogenous but must be produced then it is subject to economic analysis. The effect of so-called "research and development" on the creation of new knowledge, and ultimately growth, has now been extensively studied. The popular approach is now to add a research-and-development index into the production-function relationship as an extra input in addition to the usual labour and capital inputs. Generally, rather favourable estimates have been obtained of the effects of industrial research and development on the rate of productivity growth. Amongst a large and still-growing literature the studies of Brown and Conrad (81), Griliches (82), and Terleckyj (83) and (84), are particularly important.

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PART III

PRODUCTIVITY GROWTH IN THE SOUTH AFRICAN

COAL MINING INDUSTRY: 1950-80

CHAPTER NINE  
OBJECTIVE, METHODOLOGY AND DATA MEASUREMENT

The objective of this thesis is to measure the contribution of technological progress to changes in output in the South African coal mining industry over the period 1950-80. In this endeavour the concept of a "catch-all residual", as explained in the studies examined in chapter 7, will be employed. Although this will basically remain "a measure of our ignorance" with its familiar "sponge-like" characteristics, simultaneous efforts will be made to remove as many of the deficiencies as practicable which distinguished these "unrefined" studies. In this manner the catch-all residual will not be unnecessarily inflated to give an abnormal impression of the significance of technological progress. It will more accurately capture the magnitude of such progress and not be merely an amalgamation of errors, wrong specifications, incorrect assumptions, and so on. The methodology which is adopted, therefore, is that of the "measurement approach" as distinct from the "explain-everything approach" characteristic of growth accounting, both of these concepts having been examined in chapter 8.

This adopted approach, therefore, strongly determines the method of measurement of the inputs and output to be used in the analysis. Boulding reminds us that

"in all problems of measurement the fundamental question is, 'what questions can be answered better as a result of the measure devised?' There is perhaps a tendency among statisticians to devise measures for their own sake, rather than with a particular purpose in mind" (1).

Productivity will be regarded as the trend of the ratio of aggregate physical volume of output to physical volume of inputs. Our "particular purpose in mind" concerns the contribution of technological progress to output changes, and the "questions which we seek to answer better" relate to the measurement approach and not the explanation approach. Accordingly, it is necessary to devise measures of inputs and output which make no allowance for quality changes. Quality improvements or retardations will be captured in the size of the residual and not built

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"in all problems of measurement the fundamental question is, 'what questions can be answered better as a result of the measure devised?' There is perhaps a tendency among statisticians to devise measures for their own sake, rather than with a particular purpose in mind" (1).

Productivity will be regarded as the trend of the ratio of aggregate physical volume of output to physical volume of inputs. Our "particular purpose in mind" concerns the contribution of technological progress to output changes, and the "questions which we seek to answer better" relate to the measurement approach and not the explanatory approach. Accordingly, it is necessary to devise measures of inputs and output which make no allowance for quality changes. Quality improvements or retardations will be captured in the size of the residual and not built

into the measurement of the variables. This latter approach is regarded as being valid only in the context of growth accounting in which an explanation of technological progress is sought, but which violates the concept of what productivity indices are trying to measure. Kennedy and Thirlwall also stress that whether inputs are adjusted for changes in quality before total factor productivity is calculated, must depend on the purpose of the study. "If the purpose is simply to measure the increase in the productivity of factors of production over time it makes no sense to adjust the factors for quality changes" (2).

Boulding's contention is that if the efficiency concept of productivity is to mean anything, input and output must be defined so that they are not equal. "If all input is conserved as output, and all output originates as input, the efficiency ratio (output per unit of input) is always unity, and there can be no way of comparing the efficiency of alternative processes" (3). This argument was noted in the discussion of Kendrick's work in chapter 7, in that such a ratio only retains "life and interest" by differentiating between what Boulding calls "significant and non-significant input or output". By concentrating only on "conventionally"-defined inputs and output and ignoring "other forces" to be captured by the residual, the index is saved from "obliteration". Denison is also in favour of such an approach. Input measures should not be adjusted for quality change because "it seems wise to deal with measures that do not eliminate changes in productivity by definition" (4).

#### The Data

The above methodology will be applied to the measurement of the variables to be used in the analysis, namely, labour, capital, raw materials and output. This task can now be undertaken.

##### (i) Labour Input

Labour can be conveniently measured in physical units, but two problems have to be resolved. Firstly, a choice has to be made between various alternative measures of labour, namely, the total number of individuals engaged in production (in service); the total number of individuals at work; or the total number of mandays, manshifts, or manhours worked. The most popular measure amongst researchers

performing productivity studies has been manhours, but examples of the use of the other measures can be readily found. Secondly, whichever alternative is chosen can be related either to the whole industry or to only a segment of the total number of workers in the industry. An example of the former is provided in the 1944 study of Barger and Schurr (5) who use mandays over the whole industry, whilst an example of the latter is provided in the study of Lomax (6) who uses manshifts worked at the coalface.

The measure of labour input adopted in this thesis is that of total employment in service covering the entire workforce over the whole industry - blue-collar and white-collar workers, surface and underground, black and white. These choices must now be justified.

In the first place, the justification for encompassing the whole workforce is that final sales tonnage of coal reflects the activities of all individuals involved in the production and distribution processes. Complete coverage of labour input is, therefore, appropriate. It makes no sense to concentrate on, say, face workers or underground workers, thus involving a completely unjustified amputation of the remaining personnel in the industry. For instance, an uneconomic expansion of surface workers, *ceteris paribus*, should rightly be reflected in a declining productivity measure, but this would not be revealed if the labour-input measure encompassed only underground personnel.

In the second place, it is often contended that the use of total employment "in service" is an inferior measure of labour input in that it conveys a poor impression of the amount of human effort consumed. For instance, if over an extended time period an unchanged labour force produces an unchanged level of output, *ceteris paribus*, this would be reflected in a constant productivity term. However, if the length of the working day has gradually been reduced over this period then productivity should have been reflected on an upward trend since the unchanged output is being produced by less labour input measured in terms of manhours. Accordingly, total employment "in service" could be progressively improved upon by employing either total employment "at work", mandays worked, manshifts worked, or manhours worked. There is, therefore, a need to justify the use of the chosen measure.

Firstly, the data is readily available on a consistent basis from 1920, and the degree of accuracy is presumably high. However, data relating to the more-"superior" measures are not readily available, on a consistent basis, for the entire workforce over the whole industry, over an extended time-series. This amounts, therefore, to a practical consideration. The data is published by the Department of Statistics and is defined as "the average daily number of persons in service for the year in question". These figures have previously been presented as table 5.1 in chapter 5. However, from 1976 onwards the Department has introduced an inconsistency in that the published annual figure changes from "average for the year" to "average in June". Accordingly, post-1976 figures are not consistent with those of the pre-1976 period. This has been remedied by re-calculating the offending annual figures since 1976 from the monthly figures for the whole year published by the Department. These changes are incorporated in table 5.1 which is now fully consistent over the whole period. However, in order for these figures to be comparable with the input data for capital and raw materials, the labour forces for Duvha, Rietspruit, and Grootegeluk collieries for the period 1978-80 must be omitted. These are new collieries, non-members of the Chamber of Mines and a full explanation for this exclusion is contained in the Appendices to this chapter. The magnitude of these labour forces is shown in the following table.

TABLE 9.1 DUVHA, RIETSPRUIT, AND GROOTEGELUK COLLIERIES:  
LABOUR IN SERVICE: 1978-80

<u>COLLIERY YEAR</u>	<u>1978</u>	<u>1979</u>	<u>1980</u>
DUVHA	147	420	646
RIETSPRUIT	779	988	1108
GROOTEGELUK	<u>600</u>	<u>935</u>	<u>1480</u>
TOTAL	<u>1526</u>	<u>2343</u>	<u>3234</u>

Source: obtained directly from individual colliery concerned.

Table 9.2 shows the magnitude of the "in service" labour force for the coal mining industry for the period 1950-80 once the totals in table 9.1 above have been subtracted. This data is converted to an index with 1950 base alongside.

TABLE 9.2 TOTAL EMPLOYMENT IN S.A. COAL MINING INDUSTRY:  
1950-80 (in thousands)

<u>YEAR</u>	<u>TOTAL EMPLOYMENT</u>	<u>INDEX: 1950=100</u>
1950	54,8	100,0
1951	54,8	100,0
1952	56,9	103,8
1953	56,0	102,2
1954	56,5	103,1
1955	59,4	108,4
1956	59,7	108,9
1957	62,4	113,9
1958	65,8	120,1
1959	67,0	122,3
1960	66,3	121,0
1961	70,3	128,3
1962	72,1	131,6
1963	72,8	132,8
1964	76,4	139,4
1965	80,9	147,6
1966	82,2	150,0
1967	78,4	143,1
1968	79,1	144,3
1969	76,1	138,9
1970	74,7	136,3
1971	76,6	139,8
1972	75,7	138,1
1973	73,3	133,8
1974	74,0	135,0
1975	76,8	140,1
1976	83,9	153,1
1977	92,0	167,9
1978	92,8	169,3
1979	91,7	167,3
1980	90,7	165,5

Secondly, even if published data relating to more-"superior" measures was available, its accuracy could be subject to question. Denison (7) argues that output per manhour, for instance, cannot be estimated as accurately as output per person in service, and that for short-period comparisons the difference in accuracy is likely to be substantial. He considered that the error introduced by using manhours was "several times" the error introduced by using total employment. What is ideally required for productivity purposes is labour input which is actually "at work". Thus, all forms of absenteeism should be excluded, for instance, vacations, sickness, loafing, poor timekeeping, coffee and meal breaks, standby time, travelling time, and so on. Account should be taken only of the time spent working at the place of employment. However, these "ideal" figures are not available because individual companies do not keep records of labour physically present and working in the workplace from one hour to the next. Indeed to attempt to do so would involve a monumental effort, necessitating detailed scrutiny of individual clock cards or time sheets. This would provide reasonably accurate figures for hourly-paid workers but not for salaried staff, most of whom are not required to clock in and out. In practice, therefore, accurate compilation of such "ideal" figures is an impossibility, even if it were to be attempted.

In the absence of the ideal, government statisticians and individual researchers have to resort to a "manufactured" set of data for manhours worked, either for the economy as a whole or individual sectors or industries. Various methods are available. For instance, sample data can be taken from various enterprises in order to estimate the population figure. A popular method is to estimate "average hours worked" from representative sample data and multiply these by the total number of individuals in service. The estimated figure for average hours worked would take into account changes in the number of working weeks per year, and changes in the length of the working week. Other methods make use of "paid manhours", figures for which are more-readily available from individual organisations. These figures are, however, not useful as they stand as they are over-estimates of "manhours worked" since they include vacations, sickness, accidents, standby time, and so on, for which workers are paid whilst being absent from the workplace. They must, therefore, be corrected. In the USA, Denison reports that

correction from hours paid to hours worked is "attempted on the basis of scattered information" (8) and then multiplied by the total number of individuals in service. He complains that data is obtained on a sample basis collected by many different organisations and "fragmentary sources" so that accuracy and consistency must be questioned.

The third and final justification for using total employment in service is that the variability of this series is unlikely to differ markedly from the (unknown) series for manhours worked. This is because hours worked in the South African coal mining industry have hardly changed since 1950. The length of the working week has remained static at 48 hours for several decades. In addition, there is no evidence to suggest that absenteeism patterns have changed. The captive nature of the workforce has generally ensured that loafing and bad timekeeping are continually kept to a minimum. Annual vacations for black workers have not changed in the sense that with migrant labour the annual holiday is taken at the end of the contract and since there is a revolving pool of labour, a worker is replaced immediately he leaves for his home. However, leave provisions for white workers have become progressively more generous. This slight tendency towards a reduction in manhours worked can be expected to be offset by a tendency towards reduced absenteeism resulting from the adoption of more-mechanised methods of extraction as reported in chapter 5. Work has become safer and less physically tedious resulting in less accidents and sickness, and the quality and skill of the men retained by individual mines is of a higher standard. In view of these considerations the time-series for total employment in service and manhours worked can be expected to display a remarkably similar variability, so that the former can be regarded as an accurate proxy variable for the latter.

The methodology adopted in developing the labour-input measure assumes that all labour units are homogeneous and additive. This, therefore, avoids the complication of qualitative differences between different individuals and the weighting procedure which such an approach necessitates. Changes in the composition of the workforce towards more highly-skilled operatives, as in the coal mining industry, are, therefore, left to be captured in the productivity residual, and not defined away through an amendment to the magnitude of labour input in the manner explained at the end of chapter 8.

(ii) Capital Input

The details of the compilation of a fixed-capital-stock series for the South African coal mining industry over the period 1950-80 are dealt with in Appendix A at the conclusion of this chapter. At this stage a general discussion will be undertaken of the major conceptual difficulties inherent in a capital-stock measure and how they have been resolved for the purposes of this thesis.

Both theoretical and practical problems are involved in the issue of how to construct a time-series of capital in real terms, and its place in an aggregate production function. The fundamental question to be answered is whether it is possible to construct a single, reliable time-series for all capital goods, regardless of differences in vintage, technological complexity, and diverse patterns of depreciation of capital goods, and the changes over time in the nature of capital goods themselves.

Disquiet over the measurement of capital in the aggregate production function and particularly the problem of aggregation (which is analysed later) has led economists to react in various ways. Kennedy and Thirlwall (9) note that apart from abandoning the entire notion of an aggregate production function, some economists have suggested that it could be possible to express capital in terms of other factors; Joan Robinson, in her classic article (10), suggested labour time. Solow (11) suggested an approach to capital and production theory through the concept of the rate of return, avoiding the measure of capital and making irrelevant the debate over the assumptions of malleability and smooth substitutability. Samuelson (12) developed the concept of the surrogate ("as-if") production function, and surrogate capital, to rationalise the existence of a single entity called "capital" which, together with labour, produces output in a single production function.

Other economists have attempted to overcome the worries surrounding the measurement of capital by avoiding them entirely through the employment of alternative or proxy measures. Klein (13) notes that some studies use direct physical estimates such as the horsepower ratings of equipment "but these are not representative for all capital", or measures of capacity, "but the conceptual problems underlying such measures are fully as difficult as those for capital stock". Coal-

mining studies in particular have tended to utilise such alternative capital measures as evidenced by the research work of Maddala (14), Lomax (15), and Williamson (16).

However, it is not the intention of this thesis to adopt such an "avoidance" approach. The only alternative is to meet the problem head-on by attempting, through various means, to construct a time-series of the stock of fixed capital.

Usher (17) introduces the situation where problems with capital measurement do not exist. This is where all capital goods are constructed from uniform and indestructible blocks, like children's play blocks, where the quantity of capital per unit of each type of capital good is the number of blocks it contains, and where capital goods can be costlessly assembled or disassembled. The quantity of capital is simply the total number of blocks. Specifically, if  $n$  distinct types of capital goods existed; if each type,  $i$ , of capital good consisted of  $P_i^0$  blocks; and if there were  $K_i^t$  units of the  $i$  type of capital good in the economy in a certain year  $t$ ; then the total capital stock  $K^t$  in that year is simply measured as

$$K^t = P_1^0 K_1^t + P_2^0 K_2^t + \dots + P_n^0 K_n^t. \quad (i)$$

Many problems exist when it is realised that this ideal measurement has to meet the complexities of the real world. These difficulties can be examined systematically.

#### Index Numbers and Aggregation

It is now necessary to examine the premise that capital in real terms can be measured in accordance with equation (i). Several questions pose themselves. Can time-series of quantities of capital goods be combined into a single number that may be interpreted as "the" measure of real capital in the aggregate economy? Can it be said that the capital stock in one industry is greater than in another? Is an adequate representation of real capital provided by equation (i)? Can a better index number be devised?

The conventional approach to measuring capital adopts the working assumption that as an indicator of long-run productive capacity, capital

can be adequately represented by the Laspeyres index of equation (i). This assumption requires careful scrutiny. It is necessary to investigate the accuracy of the Laspeyres index as an indicator of the size of the capital stock. Other alternative index-number formulas need to be considered. The query needs to be raised as to whether it is reasonable to postulate an aggregate production function to represent what is, in effect, the interaction of many production processes in which many capital goods are employed. Such tasks have occupied the attention of analysts for some time. Two more-recent, and comprehensive, attempts belong to Brown (18) and Diewert (19).

Problems in this area are basically two-fold. Firstly, there are those concerning index numbers, having to do with the measurability of capital with the available data, and, secondly, there are aggregation problems having to do with the existence of summary measures of the capital stock.

Diewert systematically studies the properties of several alternatives to the Laspeyres index of equation (i), including Fisher's ideal index, Divisia index, Vartia index, and a class of indices he calls "superlative".

In regard to the aggregation problem, both Brown and Diewert discuss this in great depth, concluding that aggregation is not normally possible except by stringent and unrealistic restrictions on the form of the production function or on the organisation of the market, as has already been mentioned in chapters 7 and 8. The importance of the capital-aggregation problem is difficult to assess. In essence, it is no different from the aggregation problem in deriving a community demand curve from individual demand curves. All models falsify reality to some extent and inevitable discrepancies must be accepted if one is to attempt to describe the economy at all. One can never reproduce the richness and complexity of reality. However, it is argued that if the aggregation problem cannot be solved and if it is not possible to imagine a variable in a function that statistics of capital are intended to represent, then all sense is lost of what it is that is supposedly being measured, there is no basis for choosing among alternative measures of capital, and there is no knowledge of what, if anything, the resulting time-series of capital tells us about the economy.

### Pricing of Capital Goods

Usher (20) considers that the pricing of capital goods may prove to be the Achilles' heel in the measurement of capital in real terms. The working definition of real capital represented in equation (i) contains the terms  $K_i^t$ , where it is implicitly assumed that the nature of each type  $i$  of capital good persists unchanged through time. The equivalence of new and old types of capital goods is a major problem. One hardly needs reminding that the composition and physical nature of capital changes constantly. Any measure of its aggregate must surely, therefore, become increasingly arbitrary as time goes on. Denison (21) puts the whole issue into a nutshell. He observes that largely because of technological progress (but also for several other reasons) the form that capital goods take is constantly changing. Machines and buildings that are made today are not the same as those that were built a decade or two ago. In view of this he poses the obvious question, "how are these capital goods, built at different times, at different costs, and with different performance characteristics equated in the construction of a time-series for the value of the capital stock?" Boulding (22) raises the issue by pointing to pertinent examples: "how can horses be compared with tractors, abacuses with IBM computers, cotton plants with nylon spinners?" The example which interests Usher is the conversion into amounts of a single type of capital: the old Marchant calculator and the modern computing facilities which are available.

As noted in chapter 8, there are two main schools of thought on this issue. The earlier school, pioneered by Denison (23), would measure real capital on the supply side, comparing new and old machines according to their cost of production and thereby excluding costless improvements in capital goods from the measure of the size of the capital stock. Thus, the working premise is adopted that the object in measuring capital is to construct a capital measure in accordance with equation (i), where the  $P_i^0$  are interpreted not as numbers of blocks, but as prices of capital goods in some chosen base year. The more-modern school, of which Gordon (24) is the most recent and comprehensive contributor, would measure real capital on the demand side, comparing new and old machines according to their usefulness as assessed by performance characteristics. Thus, for instance, automobiles would stress characteristics such as speed, size and safety; whereas with calculators, the number of additions per second is stressed. This

debate over the choice of a price index for capital goods reminds Usher of the question often posed in the capital-theory debate, "in what units is capital to be measured?" Using the example of the Marchant calculator, Denison's answer would be "in Marchant calculators according to their cost of production"; whereas Gordon's answer would be "in additions per second and other characteristics evaluated at prices in a base year" (25).

Empirically the difference between the two schools of thought is extremely important. Demand-side measurement shows a much faster growth rate of real investment than supply-side measurement. However, conceptually and theoretically there are major problems with each and there is no general consensus among economists and statisticians on which concept of the price index is preferable.

The views of Government national-income statisticians (of which Young and Musgrave (26) represent the United States' opinion) is that for purposes of determining industrial capacity, or for analysing the determinants of investment or production, cost-based measures of capital are not appropriate because identical amounts of real capital will represent different capacities to produce goods and services. For these purposes, therefore, capital should be measured in terms of its ability to contribute to production. A major problem, however, is that of measuring the contribution of different types of capital to production, so that it has been difficult to implement such measures statistically.

However, for the purpose of measuring productivity, the concept of capital defined and measured on the basis of cost is most useful. Measured by its cost, capital provides a basis for determining if the use of factors of production is becoming more or less efficient over time. As noted in chapter 8 this approach captures quality change in the residual productivity term instead of in the capital measure. On a practical level, it is much simpler to implement this measure statistically. In view of this, the approach adopted in this thesis is to measure capital by its cost, following the lead pioneered by Denison and implemented by Government statistical departments.

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### Definition and Scope of Real Capital

The definition of capital is a contentious issue. The scope of the concept depends upon whether a narrow or broad definition of capital is adopted. It could be narrowly defined as all "produced means of production", or more-broadly defined to include all, or a large part, of the factors of production in the economy. Thus, for instance, Kendrick (27) extends the definition of capital to include land, consumer durables, human capital, and expenditure on research and development, in an attempt to correlate growth in real output per head to the growth of real capital per head. By including human capital in real capital, the size of the technological-change residual is reduced but not eliminated. Clearly, if human capital is an important element it must be accounted for, but Kendrick's incorporation of such factors into the capital measure is an example of the explanation approach and not the measurement approach which is the objective of this thesis. On another front, Soladay (28) considers the question of the stock of sub-soil assets in the measure of capital, especially in view of the concern over the depletion of natural resources. He, therefore, adds an imputation for stocks of oil and gas in the United States.

On the other hand, Government statisticians, responsible for the compilation of national accounts, tend to adopt a narrower definition. Thus, for instance, the Economics Department of the South African Reserve Bank which is responsible for collecting and compiling statistics on gross capital expenditure and the fixed capital stock for the South African economy, defines capital as "physical objects which have been produced by the economic system and which are, in turn, used for the production of other commodities and services" (29). Fixed capital assets include all man-made durable objects in private and public enterprises. The Bank recognises five types of fixed capital assets, namely, residential buildings, non-residential buildings, construction works, transport equipment, and machinery and other equipment. Military installations are excluded. The objective is not to provide estimates of national wealth. Accordingly, no attempt is made to estimate the value of non-reproducible capital assets such as mineral deposits, land and other natural assets. For the same reason, the value of consumer durable goods and other household assets are also excluded from the value of the fixed capital stock. Expenditure on repairs, maintenance, and spare parts which keeps a capital asset

functioning with the same degree of efficiency is not regarded as capital expenditure. However, when modifications, additions, or improvements are undertaken which improve an asset's services, such expenditures are capitalised. A certain arbitrariness may be inherent in the distinction between capital assets and other goods which are bought for the purposes of production. Generally, the main criterion is the length of life, sometimes modified in the light of business practices and experience.

What applies to the South African national accounts tends also to apply, with some differences in details, to the national accounts of Western capitalist countries. Detailed discussion of the method of estimation of fixed capital stock, together with an analysis of the concepts and definitions of capital formation, is provided for South Africa by de Jager (30), for the United Kingdom by Feinstein (31), and for the United States by Young and Musgrave (32).

In view of the extensive problems of measurement entailed in the broader concept of capital, and since the objective of this thesis is to pursue a "measurement" and not an "explanation" approach to productivity, the narrow definition of capital as employed by the South African Reserve Bank is adopted here.

#### Building Up a Capital-Stock Series

The usual method of building up capital-stock figures is by the "perpetual-inventory" system, the classic statement of which derives from Goldsmith (33). By this method a time-series of capital stock is built up step by step, year after year, from data on the dollar values of new investment. It involves the accumulation of real net fixed investment figures, i.e. gross fixed investment at constant prices minus provision for depreciation at constant prices. The basic information required for the application of this method is, (a) annual statistics of gross fixed investment by type of asset in current prices, (b) price index numbers for fixed investment by type of asset, and (c) estimates of the average economic life of capital assets. The method involves the accumulation of measures of prior investment by year, adjusted to prices of a common year. Each annual investment stream is depreciated over time and is finally reduced to zero at the end of the estimated useful life of the asset. The measures of capital stocks for each year are then obtained by summing the remaining values of past investment streams

- either the gross undepreciated values to derive gross-stock measures, or the depreciated values to derive net-stock measures. As explained by the South African Reserve Bank, this is equivalent to the process of commencing with a "start-up" figure for capital stock for a certain year obtained by accumulating the annual real gross fixed investment figures, backwards, for a period equal to the economic life of the particular type of asset and deducting the accumulated provision for depreciation (if any). Capital stock for subsequent years is then obtained by adding the annual real net fixed investment figures to the capital stock of the preceding year.

The perpetual-inventory method is extremely popular mainly because of the apparent ease with which time-series of real capital stock can be compiled. It does, however, contain a myriad of problems and general conceptual worries. Klein (34) reminds us that "we are still faced with the problem of quality change and the fact that all the different vintages combined in this formula are of heterogeneous quality". Klein could have gone further. Most of the difficulties with the measurement of capital pertain to some extent to the perpetual-inventory method - quality, weighting, aggregation, index numbers, depreciation, utilisation, deflation, and so on. Usher (35), however, takes a "critical and sceptical stance" towards the method from a broader viewpoint. He considers two general issues to be worth considering. The first is that the method is "very theoretical in the pejorative sense of the term". At no point in the method is it necessary to compare quantities of capital goods directly, say year 0 with year  $t$ , and to decide which inventory constitutes the larger capital stock. This decision is avoided by treating the total stock each year as the sum of the increments in every preceding year. Even the increments are not quantities that are directly comparable from year to year. They are ratios of values and prices, and any errors in the data reverberate throughout the time-series, as, indeed, do any misjudgements, for there is no unambiguous way of deciding which price index is appropriate. The second difficulty is that the method never fails to yield a time-series of real capital (being the reverse side, as it were, of its principal advantage) no matter how long the series in question or how radically the technology and the nature of capital goods have changed. All that is needed to make the method work is appropriate data on gross investment, price indices, and depreciation. "There is no red light

that flashes, no internal check that tells us when the whole process becomes absurd".

Faucett (36), in turn, lists four major problems with the perpetual-inventory procedure; there are few satisfactory estimates of the lives of plant and equipment; there is shifting over time of the industrial classification of establishments holding the stocks; investment data before 1947 (in the United States) are "woefully lacking"; and transfers of assets between industries are extremely difficult to identify and properly value.

In view of these difficulties, an alternative method to the perpetual-inventory procedure for estimating stocks of fixed capital would be useful. Such a method would comprise a direct measurement of such stocks. There are several possible alternatives, for instance, estimates could be attempted from book values of companies, insurance records, or direct surveys of capital goods in existence. Book values of assets are generally only available at the company level and considerable difficulty would be involved in obtaining detailed information by type of asset, industry, and geographic area. In order to avoid the problems of deficient early investment data, Feinstein (37) calculated the initial capital stock for an industry by "grossing up" a sample of companies in an industry according to their reported balance-sheet book value of capital assets in a certain year, and applying the perpetual-inventory method subsequently to obtain annual stock figures thereafter. Unfortunately, this approach is subject to all the limitations inherent in book valuation, including the likelihood that different companies have used different methods of valuation and revaluation in arriving at their balance-sheet values, as well as all the limitations inherent in the grossing-up procedure. On the other hand, time-series of real capital can be constructed from statistics of fire insurance, as suggested by Barna (38), but problems arise in connection with the compatibility and reliability of the data. Census and survey methods centre on the need for detailed, periodic censuses of tangible wealth, involving a periodic counting and valuing of all assets in the stock, updated by sample surveys. The most amenable types of assets to this method are housing and transportation equipment (automobiles, trucks, buses, aircraft, ships, and railway equipment). However, an all-encompassing survey of all types of assets, as has been attempted in the Soviet Union, meets the problem not only of

considerable expenditure of time, money and effort, but involves complex problems of classifying the different types of capital goods into standard categories.

In this thesis a time-series of capital stock is constructed using the perpetual-inventory method. The objections to this procedure, noted above, are not particularly evident in relation to a study of one particular industry, namely coal mining, or else can be overcome fairly conveniently. Any direct-measurement procedure involves far more complications and conceptual worries than the perpetual-inventory approach which proves to be a straightforward method once the data-measurement problems have been successfully resolved. Young and Musgrave (39) explain the dominance of the perpetual-inventory method in the United States as compared with the limited use made of direct measurement on the grounds that "the existing data are incomplete and because there are problems in valuation of the assets in the stock. Extending the coverage and obtaining the information needed to assign the desired valuation to assets would require a substantial statistical programme". They consider that the usefulness of direct-measurement methods lies in the need to supplement and serve as a check on the perpetual-inventory estimates; in other words, to provide Usher's "red light that flashes" when the whole process becomes absurd.

#### Deflation and Price Indices

Gross capital expenditure recorded in current prices must be reduced to constant prices measured in terms of a common base year through deflation by means of a relevant price index. The price indices employed by Government national-accounting statisticians invariably do not make allowance for quality changes in capital assets, and this is the approach adopted in this thesis. In almost all cases the price indices reflect only the changes in the cost of the inputs of labour and materials required to construct the capital goods. The price deflators used by the South African Reserve Bank are either obtained from the Department of Statistics, or compiled by the Bank from information supplied by the Department. Only indices and information are received by the Bank on pure price components but these are subsequently adjusted for measurable changes in labour productivity.

The indices compiled and employed by the Reserve Bank are also used for deflation of investment in this thesis. The method of their derivation is explained in the Appendix.

### Depreciation

The problem of depreciation, as recognised by Usher (40), is to decide what proportion of capital placed into employment in a given year is deemed to be still available  $t$  years later. He believes that there are four elements to consider: (i) part of the capital stock has been retired, in the sense that it has been withdrawn from the stock entirely, (ii) some of the remaining capital stock may have deteriorated, in the sense that its marginal product from a physical point of view is less than when it was new, or it requires more maintenance and repair, (iii) the capital stock is older, in the sense that it has fewer years of service left than when it was new, (iv) it has become obsolete, in the sense that its marginal value product is less than when it was new because of the availability of more-efficient capital goods, changing tastes, or increases in the rents of co-operating factors of production. Brown (41) explains that the reason why obsolescence enters depreciation calculations is that the quality and quantity of existing facilities declines in relation to the services of new and technically-superior capital goods even though the quality and quantity of the services of the existing facilities do not decline in absolute terms. Hence the appearance on the market of technically-superior capital items implies an increase in the cost of operating existing equipment, and it is this increase in opportunity cost that is represented in the obsolescence component of depreciation charges.

Thus depreciation is the process of converting gross capital stocks into net capital stocks. It represents the rate of attrition of the value of capital items intended to approximate the rate of reduction in economic usefulness of capital facilities as a result of their use in production which has made them older, more worn, and increasingly obsolete.

Depreciation analysis is bound up with the process of making sure that items of cost are properly valued. The practice of deducting annual depreciation charges on fixed capital assets is a sound accounting concept so that producers, for financial reasons and in order to derive a meaningful profit, amortize a fixed asset over its estimated

life. Depreciation, therefore, is regarded as a financial expense which is charged against the current year's production to compensate for the fact that an asset originally charged to the capital account has become older, more worn, and increasingly obsolete during the year. In this way, durable capital equipment is treated on the same basis as, say, fuel, materials, and other running expenses which are invariably used in the same period as they are bought and are, therefore, a direct charge to the current-year's production. But durable capital equipment, although employed and, therefore, used up continuously in the production process, is only purchased at discrete periods of time and it would, accordingly, be quite misleading to charge the full cost of this equipment against the revenue of the year in which it was purchased. It is, therefore, in the first instance charged to the capital account and only the amount estimated to correspond to the use of the period is entered in the year's production account. As a result, the cost of using up durable equipment is charged, as far as possible, against the years in which this utilisation takes place.

This generally-accepted procedure enables goods bought for productive purposes to be divided into two categories, namely, those charged directly against the function of production, and those charged in the first place to the capital account and subsequently written off by means of depreciation charges against the proceeds of production. There is an essential arbitrariness in deciding where to draw the line between these two categories. Generally speaking, the main criterion is the length of life of the asset. The use of durable equipment, of course, involves expenses for repairs and maintenance which are normally treated as direct current costs and not as capital expenditure. By definition, repairs and maintenance merely keep the asset functioning and do not add to its original value or alter the services it provides, so no attempt is made to add such costs to the stock of fixed assets and then write them off through depreciation. This is in contrast to the treatment of major alterations and improvements to assets which are included as part of gross investment. However, to distinguish in practice between ordinary repairs and capital improvements is not always an easy procedure.

Depreciation, therefore, is a sound and universally-accepted financial-accounting concept. Problems arise, however, in its measurement. Economists have never fully agreed on a single definition

of depreciation for allocating the cost of the asset over its service life. Ideally, observations are required of the actual physical using up of an asset during the year, which, together with an allowance for obsolescence, acts as the depreciation charge. Unfortunately, this is not possible in practice and analysts have to make do with an inferior substitute for actual depreciation, defined by Feinstein (42) as the amount which it "seems" right to charge to allow for the fact that capital has become older, more worn, and increasingly obsolete. There are various ways in which this might be measured. However, they are all inherently arbitrary and consequently subject to error. Denison (43) considers that "the measurement of capital consumption is among the most difficult and frustrating of subjects", in view of the fact that "it is not possible to measure what actually takes place. Available information confines us, for the most part, to a choice among a few simple conventional techniques of measurement, with the choice itself based upon the flimsiest of evidence". National-accounting statisticians would tend to agree. Both South Africa and the United States, for example, use the simplest possible measure (straight-line depreciation). "They recognise that this is less than ideal as a measure of depreciation, but they argue that our information about true economic depreciation is so skimpy and imprecise that one cannot do better in practice" (44).

The two customary methods of measuring depreciation are the straight-line method and the reducing-balance method. In the former the asset is depreciated by a constant amount over the estimated life of the asset, so that it is entirely "written off the books" at the end of its estimated life. In the latter a constant percentage of the remaining book value of the asset is charged as depreciation in any one year. This means that in absolute terms the depreciation charge declines steadily every year and theoretically it implies that the asset will never be entirely written off the books until it ceases its productive activity when sold or scrapped. A third method has also proved popular in the past, finding favour amongst public utilities such as the railways (in the United Kingdom), and the mining industry, including coal, in South Africa. This is the renewals method whereby no depreciation is charged in any year until an old asset is replaced by a new one and the entire cost of the renewal is then charged as depreciation in a lump sum in that particular year. Other methods of

depreciation are available. Brown (45) notes that the "sum-of-the-year's-digits" and the "annuity" formulas are frequently-used methods. Young and Musgrave (46) mention the double-declining-balance formula (which assumes an annual percentage rate of depreciation that is equal to twice the first-year straight-line rate) and the discounted-value approach (whereby depreciation is regarded as the decline in the value of the sum of the remaining anticipated services discounted to the present). Goldsmith and Kaitz (47) provide a comprehensive exposition of the use of various alternative depreciation formulas in the construction of capital-stock measures.

It will be appreciated that the actual estimates of depreciation are considerably affected by the choice of depreciation formula. Thus, for instance, whereas the straight-line method writes off the same amount each year, the reducing-balance method writes off progressively smaller amounts each year. If the same effective life is assumed, the reducing-balance method, with its higher depreciation charges in the earlier years, leads to a lower depreciated value for the capital stock than the straight-line method.

More-recent analysts have tended to reject the older-established methods of measuring depreciation in favour of a discounted-value approach on the grounds of failure to reflect the time pattern of the fall in the market value of capital equipment as its ages, in other words, a failure to reflect "economic depreciation". They argue that all sources of decline in present value should be accounted for. Faucett (48) contends that economic depreciation should be calculated with a discount factor, that is, it should involve a calculation of the present value of the future stream of services from the capital assets. Economic depreciation is calculated as the loss in the value of the stock during a specified time period, usually one year. The value of the stock by definition is the sum of the time-discounted values of its future flow of services. Thus, each year it loses one year of remaining life, that is, the final year, which is distant and, therefore, worth less than the current year's service because of the discount factor. Economic depreciation increases steadily over the life of the stock under the assumption of no decline in productive services over its life.

Differences between accounting and economic depreciation cause a divergence between book values of stocks and market values, the latter

reflecting economic depreciation whilst the former reflect accounting depreciation methods that are often arbitrary and are not good approximations to economic depreciation, which reflects the loss in the current and future service value of the stock which, by definition, affects the price a purchaser is willing to pay for the stock - the market value. As a stock ages, its current service value may decrease because of physical deterioration, rendering it less efficient in production. Its future service value also declines with age because its remaining life, or stored-up value, is reduced. There is no reason why the sum of these two effects should be linear (straight-line depreciation) or exponential (reducing-balance depreciation).

In regard to the estimation of economic depreciation, two recent studies have attempted to achieve this from two quite different sorts of data. Hulten and Wykoff (49) base their estimates on a United States' Treasury sample of prices of new and used structures. Coen (50), however, attempts to infer the rate of economic depreciation from time-series of investment.

Regardless of the practical difficulty of measuring depreciation, Mark (51) argues that there can be no argument on conceptual grounds to the practice of deducting depreciation in the sense that "studies have shown that the output capacity of various types of equipment tends to fall with age, which would imply that a net measure would be preferable to a gross measure". (Gross-stock estimates are derived by retaining assets at their full first-cost deflated value until they are retired from use.) Such factors as creeping obsolescence, a shortening of the remaining service life, a reduced ability to contribute to gross output through physical deterioration caused by usage and/or age, larger maintenance and repair costs, increased downtime, less-intensive utilisation perhaps as reserve equipment, usage in less-productive activities, and so on, are all factors which potentially justify the practice of depreciation. Although they would appear to present extensive problems of isolation and measurement, such complexities are brushed aside by Kendrick on the grounds that "empirical and theoretical considerations suggest that these effects may be assumed to occur gradually over the lifetime of groups of capital equipment" (52).

Terborgh (53), in a classic 1949 study, still extensively quoted today, coined the term "functional degradation" of capital assets. The debasement of function over the life of a capital good may be either

quantitative or qualitative. That is to say, there may be a decrease in the amount of service rendered as the unit ages or a deterioration in the quality of the service, or both.

Quantitative degradation can be of two kinds. Firstly, a reduction may occur in the amount of output produced per given time period; for instance, a machine capable of stamping out 100 widgets per hour when new may degenerate to 50 widgets per hour when five years old. Secondly, a decline may occur in the intensity of use of the asset, measured in terms of hours worked or kilometres run per year, for example. Terborgh showed examples of the decline of service intensity with age for eight items of capital assets - locomotives, agricultural implements, tractors, buses, passenger cars, trucks, tractors, and trailers. Thus, typically, for items of transport equipment, less kilometres per year are run as the asset ages, and is shifted to tasks of lower continuity and intensity. Thus, new locomotives, trucks, and buses are used for long-distance work initially, but progressively are demoted to short hauls, branch lines, suburban routes, feeder routes, shunting, peak-hour work, emergency standby, and so on. This decline of service intensity with age is a reflection or manifestation of the growing qualitative superiority of the service offered by available substitutes or alternatives for the existing asset. This superiority may reflect an actual deterioration in the service of the ageing facility, or merely an improvement in the currently-available alternatives without such deterioration.

Qualitative degradation refers to the fact that output of a poorer quality may be produced by a capital asset as it ages. Thus, a machine tool may lose some of its original precision and may gravitate towards assignments for which the requirements are less exacting. Likewise, as a bus ages it loses its initial comfort and luxury and may be downgraded from prestige long-distance runs to shorter routes. Often, this demotion into lower-quality work is accompanied by reduced intensity of use, but sometimes it is not. Qualitative and quantitative degradation may proceed together or one without the other. Thus, in the case of housing there is rarely any marked reduction of service intensity, as measured by occupancy ratios, but there is normally a quality deterioration as evidenced by the drop in rental value. Qualitative downgrading results not merely from a worsening of the service as compared with what it was when the asset was new, but also a

worsening relative to the service obtainable from a newer-vintage asset. Modern facilities may not only perform the same service as an ageing asset in a superior or cheaper manner, but often provide a superior function.

Terborgh considers that a combination of quantitative and qualitative degradation characterises most kinds of movable productive equipment, whereas qualitative degradation predominates for buildings and other structures.

An associated concept is that of obsolescence. The obsolescence of an asset must be defined not in terms of age or decrepitude per se, but in terms of its relation to its job. It is obsolete for the job when it is economically replaceable but, obviously, it need not be obsolete for all other jobs and there may be many other tasks in which it can be successful. Obsolescence is thus a matter of relativity, not an attribute of the asset itself.

Terborgh concludes that almost any machine or piece of equipment is subject both to deterioration and obsolescence as time goes on. Deterioration is the decline in operating performance compared with the performance obtainable from a new identical machine. Obsolescence is the growing operating inferiority of such a replica of the existing unit as compared with the best new machine currently available (54).

Despite the logicity of these arguments for deducting depreciation allowances, the fact remains that many capital assets remain both economically and technically usable long after they have been written off. Accounting assumptions employed in estimating depreciation tend to be such that the phenomenon of fully-depreciated assets still in use is quite usual. (It will be recalled that the magnitude of usage will vary, of course, between different situations, from full utilisation at one extreme to stand-by capacity on the other). Thus, estimates of fixed capital stock at depreciated values understate the stock of assets actually in use, especially in industries with a low rate of technological innovation and long-lived assets. Gross estimates are not so affected since the full value remains until scrapping, except that the rate of scrapping has also generally to be estimated. On the other hand, an opposite tendency can apply whereby technical innovations shorten the life of an asset by making it obsolete before the original estimated allowances for depreciation have actually

written it off. If scrapped in these circumstances, or sold for less than book value, a capital loss will be incurred and ought to be included in with depreciation. However, this occurrence is far less than, and in no way counterbalances, the prevalence of fully-depreciated assets still in use.

Kennedy and Thirlwall also note that net-capital measures tend to assume that the services derived from capital deteriorate with age much more than they actually do, thus leading to over-depreciation (55). They consider obsolescence rather than physical deterioration to be the dominant feature of depreciation. Capital becomes economically obsolete before it has outlived its physical usefulness,

"but obsolescent equipment is still capable of contributing to production. Thus, the flow of capital services does not decline with age at the rate frequently suggested by allowances for depreciation ... Ideally one would like to have a net measure of capital which makes allowance for physical depreciation but not obsolescence, but the lack of evidence renders this scarcely practicable. In the absence of such a measure there would seem to be a strong case for measuring capital gross".

Denison is of the same opinion that depreciation should not reflect creeping obsolescence. Consistency with the method of measuring capital by its cost requires, according to him, that obsolescence should be deducted from gross capital formation when the good is retired (56). Young and Musgrave, in their official estimates of United States' capital stock, state the same argument that their capital services do not reflect the effect of obsolescence - this being charged when the asset is retired. "The reason for this treatment is that obsolescence has little if any effect on the time pattern of services provided by the asset before retirement, even though it is a determinant of the timing of retirement. The charge for obsolescence at retirement writes off the remainder of the asset as a component of capital consumption and in effect replaces the physical life with the economic service life" (57). Both Denison, and Young and Musgrave, would, therefore, support the contention that depreciation should measure only the reduction in

the services of a capital asset caused through physical factors such as ageing, deterioration, downtime, rising maintenance and repair costs, and so on.

Ruggles and Ruggles, however, go further than this and question the charging of depreciation for any reason (58), thus placing them at the other end of the spectrum from Kendrick. They consider it incongruous that in view of the decision to exclude increases in efficiency from additions to the capital stock, that decreases in such efficiency due to ageing should be taken into account.

"Just as there is logic in saying that improved design of capital goods is not more capital but an increase in its efficiency, so also it is perfectly reasonable to say that the efficiency of capital varies with its age, and that deductions from the quantity of capital to make the productivity of existing capital a constant over its life are not consistent with the desired concept".

They also find difficulty with the obsolescence concept in that charging for such obsolescence against existing capital is allowing for quality changes that have not occurred but are only expected to - those resulting from changes in the technical design of capital goods to be produced in the future. The same technical change that improves the quality of new capital will make the old obsolete.

"Kendrick's treatment of additions to the capital stock does not take into account the quality increase due to technical changes in new equipment, but it does count the reduction in the relative quality of the existing capital stock because of the increased technical efficiency of new capital equipment which could be constructed. Again, therefore, the treatment of new and old capital does not seem to be parallel".

The Ruggles' conclusion is that a more-consistent treatment would require that if efficiency increases are to be eliminated from the measurement of capital stock, then efficiency decreases, whether from physical deterioration or from potential technical obsolescence, must also be eliminated. Capital should not be deducted from the total stock

until its retirement, thus deriving net investment in each period as gross investment minus discards. This is not to question the soundness of the concept of depreciation as a financial-accounting practice but merely to question such a practice in deriving capital stock for productivity-measurement purposes.

The Ruggles are in good company in regarding net investment as gross investment minus discards. Domar (59) employed the same concept in analysing a model relating changes in capital to changes in capacity. He noted that depreciation allowances in the United States had usually provided over one-half of expenditures on gross investment and had been even larger in the United Kingdom. The magnitude of such a fraction was a worrying aspect "while the Russians have managed to get away with a mere fraction of either - disparities which cannot be completely explained by differences in national temperament or by manipulations of Soviet statisticians." Domar discovered that in a growing society, replacement falls far short of depreciation. Hence, investment net of depreciation cannot be identified with investment net of replacement.

Hogan, in reply to Solow's classic article (60), was influenced by this observation. He considered that there were good reasons for thinking that gross rather than net estimates of the capital stock are better suited for analysing the relation between capital and output; "in particular there is the point that annual depreciation and annual replacement are not necessarily the same". Consequently, he employed gross estimates based on the "one-hoss shay" concept - assets are replaced fully when they are retired at the end of an assumed average length of life.

Denison (61) also chooses to work with deflated gross capital stock as a measure of capital input. This choice is based on his conclusion that an index of the gross stock moves more closely with the national income created by structures and equipment than does the net-stock alternative when changes occur in the composition of the stock and its average age.

In view of the above discussion it is the contention of this thesis that the measurement of capital input for productivity purposes net of depreciation contains practical and conceptual problems of a serious nature. From the practical standpoint, since the actual "using up" of capital (reduction in the services actually provided) cannot be

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In view of the above discussion it is the contention of this thesis that the measurement of capital input for productivity purposes net of depreciation contains practical and conceptual problems of a serious nature. From the practical standpoint, since the actual "using up" of capital (reduction in the services actually provided) cannot be

observed, and, hence, cannot be accurately measured, all depreciation measures are contrived, inherently arbitrary, and subject to substantial error. From the conceptual standpoint, all changes in the quality of inputs are intended to be excluded. The inconsistency of depreciation charges in this respect, as observed by Ruggles and Ruggles, is, therefore, noted, whereby reductions in the relative quality of existing capital are taken account of but increases in the quality of additions to capital are not. The overall effect is a tendency towards over-depreciation and the assumption that capital services decline with age far more rapidly than they actually do. This contributes towards an under-estimation of the contribution of capital to growth.

However, it is not necessary to go to the extreme of Ruggles and Ruggles in order to reject the concept of depreciation of capital assets for productivity studies. The same rejection would be achieved by adopting the viewpoints of Denison, Young and Musgrave, and Kennedy and Thirlwall, all of whom, as was seen earlier, dismiss depreciation charges for obsolescence, but would retain them as a valid procedure if they compensated for a genuine reduction in services of a capital asset through physical deterioration resulting in a reduced ability to contribute to gross output (or "functional degradation" - quantitative and qualitative - in Terborgh's terminology). In the words of Faucett, efficiency decline, justifying depreciation, represents either: "the decline in efficiency (in terms of productive service units of the capital) with any uniform level of maintenance over the life of the capital; or the increasing costs of maintenance and repair to maintain 100 per cent efficiency" (62). Any of six factors would appear to be involved in the above arguments, namely: the production of fewer physical units of output, a less-intensive utilisation, usage in less-productive activities, poorer-quality output, increased downtime, or larger maintenance and repair costs.

However, it is the contention of this thesis that none of these factors has been a noticeable feature of capital assets in the South African coal mining industry and that depreciation charges would, therefore, act as an unjustified reduction in the magnitude of the capital stock. In order to justify this contention, some relevant empirical studies (not of the coal mining industry) can be examined together with an analysis of capital assets as employed in the South African coal mining industry.

in regard to empirical studies it has already been seen that Terborgh gave eight examples of items of transport equipment which as they aged were progressively used less intensively and were downgraded to provide poorer-quality service and in less-productive activities. In a wider-ranging study, Coen (63) notes that "little empirical evidence has been advanced to support ... (the) widely-held assumption that the productive capacity of capital goods declines with age." A favourite assumption has been that of geometric (or exponential) decline "at a rate typically, though not necessarily, equal to twice the straight-line depreciation rate". Coen found that in the majority of United States' manufacturing industries he studied, structures suffered no loss in productive capacity over their service lives. In other words, they resembled a "one-hoss shay". However, he found that equipment generally evidenced losses in productive capacity as it aged though not necessarily at a geometric rate. His results indicated that the services provided by about 12 per cent of equipment in manufacturing resembled those of a "one-hoss shay", but, as Young and Musgrave (64) noted, obsolescence was taken account of at a constant rate. Since obsolescence should correctly be excluded for productivity purposes, the service declines estimated by Coen will be overstated.

Snaddon (65) noted that the deterioration of capital assets with age and use can be divided into three categories according to the effect on the overall system. These categories are: those when faults occur which have an insignificant effect upon the system, such as a paint scrape on a shuttle car; those which cause a loss in performance, such as the blunting of the coal picks on a continuous miner; and those which result in a breakdown, such as the seizure of a bearing on a vehicle. The important factor linking the states of deterioration together is time. Several examples are given of the performance loss of assets with age (steam turbines, boilers, pipes, and even windows which lose their efficiency in transmitting light) as well as breakdowns (steam turbines, cars, and bearings). Performance loss often leads inexorably to system breakdown, so that a minor amount of maintenance undertaken at the beginning can often save considerable damage which may result later.

Snaddon defines "maintenance" as work which is undertaken in order to keep or restore an asset to the same standard as when it was acquired or developed. The classification of deterioration into neutral faults, performance loss, and system breakdown allows maintenance to be

classified according to the urgency of repair. Two categories can be distinguished - preventative and breakdown. Whichever is practised still involves downtime and the associated costs of rectifying the actual or potential fault in terms of labour, spare parts, and raw materials.

Snaddon estimated the cost of maintenance in South African industry for the year 1977. In that year the fixed capital stock valued at depreciated original cost was R52 452 million of which maintenance costs were estimated at slightly in excess of R2 000 million, or 4 per cent. This overall percentage varied according to the type of asset. Thus, residential and non-residential buildings incurred the lowest maintenance costs of 0,5 per cent of the asset's value, and vehicles incurred the highest costs at approximately 20 per cent.

Snaddon's study provides an indication of the relative magnitude of maintenance costs in comparison with the value of an asset over a period of time but provides no evidence of the escalation of such costs as the asset ages. This problem can now be addressed. Faucett notes that "there are very few data on the distribution of maintenance and repair costs over the life of assets". However, he then goes on to pontificate that "it is certain that these costs generally increase with the age of the asset, if the productive efficiency of the asset is maintained at 100 per cent" (66), a statement which is not empirically justified in view of his earlier observation. Faucett's views could be regarded as representative of theoretical and logical thinking on this subject. They accord with the findings of Terborgh who discovered that for eight classes of equipment - metal-working machinery, textile machinery, light trucks, inter-city buses, local buses, locomotives, farm implements, and passenger automobiles - repair costs per unit of service generally increased at a decreasing rate in relation to increasing age and accumulated usage (67). Such conclusions, however, do not accord with a study which has recently been conducted by Poole (68). He examined a total of sixty separate pieces of heavy equipment used in the South African civil engineering construction industry. These included excavators, graders, scrapers, traxcavators, bulldozers, and front-end loaders. For each piece of equipment a plot was made of cumulative discounted maintenance cost (as a portion of first cost) against cumulative working hours, and he found no tendency for such costs to increase during the normal working life of the asset.

In examining the characteristics of capital assets in the South African coal mining industry in regard to physical deterioration and increasing maintenance and repair costs, it will be necessary to distinguish between structures and construction works on the one hand; and transport, machinery, and other equipment on the other hand.

A significant contribution to gross investment in the industry has been provided by the combined investments in residential buildings, non-residential buildings, and construction works. These encompass such assets as housing, offices, stores, housing of plant, general amenities, railways, roads, dams, adits, and so on. It is now generally acknowledged (for instance, in Coen's study) that such assets suffer no loss in productive capacity over their service lives and resemble a "one-hoss shay". Terborgh is not so adamant, arguing that buildings and structures suffer from qualitative degradation, but agreeing that they are generally free from quantitative degradation. He even admits that the "one-hoss shay" is often encountered in this category of assets, for instance, a railroad crosstie (69). In addition, downtime is almost non-existent since they seldom malfunction and require minimal maintenance and repair (as evidenced by Snaddon's study). If any reduction in services does occur with increasing age, for instance, old offices being used as storerooms, the magnitude would be too slight to be adequately captured by depreciation methods. Such would act as an unjustifiable over-compensation.

In regard to the other components of gross investment, namely, transport equipment, and machinery and other equipment, it is also contended that depreciation is not justified. Although there appears to be some evidence that the physical capabilities of such assets tend to decline with age (for instance, the studies of Coen and Terborgh), the overall evidence is inconclusive. Even amongst such assets, Coen found some evidence of "one-hoss shays". Terborgh's findings of lower usage intensity with increasing age are confined solely to items of transport equipment (which comprise only a small percentage of total capital assets in the coal mining industry) and which had been downgraded not necessarily because of inferior performance but because of obsolescence and replacement by modern substitutes performing a superior function. Terborgh admits that the magnitude of deterioration "varies widely from case to case . . . . (and) some types of equipment suffer little deterioration" (70).

Since the magnitude of decline depends upon the type of asset, it is contended here that the kind of equipment employed in coal mining is such that loss of physical capability is not likely to be excessive. It is necessary to make a distinction between the old hand-got production methods and the newer mechanised methods introduced mainly during the 1970's. The major components of machinery and equipment in the former method encompassed drills, cutters, underground railway lines, tubs, winding gear, and the various components of surface capital assets, whilst the newer mechanised methods have seen the introduction of loaders, shuttle cars, conveyor belts, longwall machinery, continuous miners, walking draglines, heavy-duty dump trucks, and so on. It is difficult to imagine how such assets can either provide or produce less physical units of output as they age or supply a poorer, inferior, or less-precise service. Thus an old, battered tub can still remove the same tonnage of coal at the same speed as when it was new. Railway lines similarly retain the same efficiency and carrying capacity, as does winding equipment. Likewise, such assets as drills and cutters are capable of drilling and cutting with unchanged capacity if routine maintenance is performed to replace bits, teeth, chains, and so on. (The author personally observed a 50-year-old British-made coalcutter still in permanent use and utilised to the maximum just as efficiently as when new on a hand-got coal mine in the Vereeniging district in 1979). The same argument applies with more-modern equipment. Thus, walking draglines do not develop progressively smaller "bites" with age; nor do shuttle cars or dump trucks carry smaller loads; or conveyor belts transport less coal. As far as the provision of a poorer, inferior, or less-precise service is concerned, in many instances there can be no leniency for such a reduction in services from the safety point of view. If there is any doubt at any stage that, say, a section of railway line or an item of winding equipment has become inferior, the safety aspect would necessitate immediate repair, or scrapping and replacement to achieve the "good-as-new" status quo.

As far as less-intensive usage with increasing age is concerned, as well as downgrading to less-productive activities, these factors also have not been evident for machinery and equipment on South African collieries. At least during the normal life of an asset, and excluding downtime periods, all equipment is normally in operation during the production period of a mine. There has been no noticeable tendency to

consciously make less use of a piece of equipment as it has aged up to its normal life expectancy. This has mainly been due to the low rate of technological innovation on individual collieries so that equipment has been kept continuously working in the same job as it was originally employed. Coal-mining equipment is manufactured for a specific task and, in most cases, downgrading to less-intensive or less-productive activities is not possible, in the same manner that an ageing locomotive is transferred to branch-line duties. Thus, for instance, coal tubs and shuttle cars can only tram, and they tend to perform this duty, shift after shift, until they expire or are replaced. The Marion 2000 dragline at Optimum mine has been utilised with undiminished intensity every year since 1972. Other examples abound. Coal-mining machinery over the study period has not been characterised by regular downgrading of function or partial displacement. Services, generally, have been unimpaired to the end. The demise of a piece of equipment has created a functional vacuum which only a successor replacement can fill. It has never just "faded away without a ripple."

A potentially far more-important factor relates to the possibility of increasing downtime and maintenance and repair costs as equipment ages. Under the old hand-got method this was not a noticeable problem since only relatively small amounts of equipment were employed, and it was also relatively unsophisticated, simply and sturdily constructed. However, it has become a substantial problem with the introduction of sophisticated mechanical-extraction methods. It was shown in Snaddon's study that this equipment incurs proportionately the largest maintenance costs as compared with other capital assets. The introduction of such machinery into the South African coal mining industry has been characterised by extensive breakdowns, long downtime, and high maintenance and repair costs. This situation can largely be explained by "teething problems" and the unfamiliarity of both management and labour in the operation of such equipment. Once more experience has been obtained and the machinery properly "bedded in" into the normal production procedure, the issue should become more settled. Since modern machinery is only obtained at high cost. Because of its cost, stand-by equipment is rarely available. In order to obtain an economic return management must keep this equipment functioning almost continuously and cannot afford long downtime periods. Thus, preventative maintenance techniques are practised, such as non-destructive testing (71), and such

breakdowns as do occur are speedily repaired to reduce downtime to a minimum. There is nothing to suggest that during the period the coal mining industry has utilised more-mechanised methods that downtime and repair and maintenance costs have increased. By 1980 many coal mines had operated such equipment for only a short period of time.

Too much confidence cannot be placed in Terborgh's study which showed generally increasing repair costs with equipment usage. His eight types of capital asset were heavily weighted towards transport equipment and his findings cannot be generalised for all types of productive machinery. Secondly, by his own admission "the results are admittedly very rough" and queries can be placed against his data, several of his assumptions, and the representativeness of his sample(s). Poole's study employs sounder methodology and gives the impression that increasing maintenance costs would not be a feature of such assets during their normal service life and would only commence to increase significantly towards the end of their service life at which point the scrapping of that asset would be necessitated. In fact, once the teething problems have been overcome there would be a tendency for such costs to decline to a more-settled level where maintenance becomes routine and is carried out on a regular basis to replace those working parts which deteriorate most rapidly and fail most frequently, such as tyres, gears, hoses, cutting teeth, and so on.

As is seen later in this chapter, output in this thesis is measured in gross terms thus necessitating an additional variable for raw materials. The cost of spare parts for repairs and maintenance will be reflected in this variable, and the extra labour in the form of electricians, fitters, and so on, for maintenance purposes, is captured in the labour variable.

In view of this discussion there is, therefore, little validity for assuming that capital assets in general in the coal mining industry in South Africa for the period under study have supplied  $X$  rands of services when new in year  $t$ ,  $X-Y$  rands of services in year  $t+1$ ,  $X-2Y$  in year  $t+2$ , and so on. Such a procedure is misleading. Estimates of the stock of fixed assets at depreciated values in the industry would greatly understate the stock of assets actually in full-time productive use. It would, therefore, be more accurate to disregard the problem of depreciation in coal mining and to prepare estimates of the stock of fixed assets by recording the deflated first-cost value of every asset

and assuming that as long as it is not scrapped it remains in the stock at this first-cost value irrespective of its age or condition. This is the approach adopted in this thesis, on the assumption that any over-estimation of the capital-stock magnitude which may be implied introduces a far-smaller error than the under-estimation implied by depreciation procedures. Thus, it is conceptually recognised that an asset continues to provide a stream of constant-value services throughout its life until such time as that asset is retired at the end of an assumed average life span when its services are reduced abruptly to zero. This is the process of "sudden death" or "one-hoss shay". Thus, estimates of the capital stock are built up as follows (assuming constant prices):

First-cost value of stock at beginning of year, plus assets purchased during the year, minus first-cost value of assets scrapped or sold during the year.

#### Scrapping, Service Lives, and Retirement Patterns

Scrapping of assets presents almost as much difficulty as depreciation even at the conceptual level. Feinstein (72) highlights some difficulties by asking the questions "has a machine been scrapped if it is no longer used, but is kept in reserve in the factory for possible emergencies?" and "if an eighteenth-century building which has repeatedly been radically altered is finally scrapped, what is the value of the scrapping at first cost?" Feinstein noted that, in practice, there was virtually no information on this subject, but the problems would still be formidable even if full information on the treatment of old assets was available. In his study he employed the working assumption that assets are scrapped when the writing off of depreciation has reduced their value to 10 per cent of the first cost in the case of most plant, ships, and vehicles, and to zero for all other assets.

In this thesis the perpetual-inventory method is used to measure the stock of fixed capital and, as Young and Musgrave (73) note, the success of this method depends to a large extent on the accuracy of the service lives assigned to different types of assets. In the United States' estimates a total of 62 different types of capital assets are categorised each being assigned its own average service life. 34 are categorised under the heading "fixed non-residential business capital";

7 under "residential capital"; 11 under "consumer durables"; and 10 under "fixed non-residential government-owned capital".

However, underlying the concept of an average service life for a certain type of asset is a distribution of discards. One must always take into account that assets of a given type are discarded at different ages, and not all at the same age. This requires an examination of the pattern of retirements of capital assets. In the United States' estimates the so-called Winfrey retirement patterns are applied to all types of investment. Thus, for fixed non-residential capital the modified S-3 pattern is used so that retirements start at 45 per cent and end at 155 per cent of the average life. By way of illustration, 1,2 per cent of original expenditure is discarded at 45 per cent of the average service life; another 1,2 per cent at 50 per cent of the average service life; another 1,7 per cent at 55 per cent of average life; and so on until 155 per cent of average life. For residential capital the modified S-3 pattern is used so that retirements start at 5 per cent and end at 195 per cent of the average life. For consumer durables the modified L-2 pattern is used so that retirements start at 25 per cent and end at 215 per cent of the average life.

The S-3 curves are bell-shaped distributions centred on the average service life of the asset. The L-2 curve is asymmetrical with heavy discards before the average service life is reached and with a tapering pattern thereafter, which was chosen for consumer durables since it appeared that many of such goods are discarded within a few years, while others remain in use far beyond the average life. The compilers of the official estimates admit that the uniform application of Winfrey retirement patterns to all types of investment undoubtedly introduces an artificial smoothness into the stock statistics, but, nevertheless, is the best procedure available considering the lack of information on actual retirements. They view the Winfrey patterns as representing two different phenomena: within each asset group there are a number of different types of assets with different service lives; and for each type of asset there is a retirement distribution around the average service life.

The Economics Department of the South African Reserve Bank does not take account of retirement patterns in its calculation of capital stock for the South African economy. Instead it operates simply on an estimation of the average economic life of five broad categories of

capital assets - residential buildings, non-residential buildings, construction works, transport equipment, and machinery and other equipment - across a broad spectrum of industrial groupings. The life estimations used by the Bank are based on two factors: the periods allowed for income-tax purposes by the Inland Revenue, and discussions with businessmen and other relevant experts from different industries. It is this method which is employed in the calculation of capital-stock figures in this thesis. Capital-asset service lives in the coal mining industry were supplied to the writer by the Bank.

#### Capital Utilisation

The measure of capital so far constructed relates to that of a stock concept. The capital stock is variously referred to as capital in place, capital in existence, available capital, or potential capital services. However, it is contended that "what belongs in a production function is capital in use, and not capital in place" (74), which measures the annual flow of capital services. Capital in use is the more-relevant variable to the concept of a production function because it compensates for the existence of idle capacity. There are periods when capital assets may stand unemployed or under-employed. For instance, during slack periods of economic contraction, machinery may be operating at less than full capacity; then again, some portion of existing capital may be standby and employed only when other capital is under repair, or during periods of high demand. A flow measure, therefore, reflects differences in usage and how these affect varying levels of output, which, it is claimed, is the basis of productivity estimation (75). Thus, flow measure should indicate the amount of capital employed to produce current output. According to Brown (76), the use of available capital "has long been recognised to be an inadequate measure for the estimation of production functions", because by over-estimating the contribution of the capital input to the production process, it under-estimates capital productivity.

Adjustment of capital-stock data for variations in rates of utilisation is also deemed to be essential if comparability of data on labour and capital input is to be preserved. "Since the labour statistics (especially if manhours are used) do allow for the extent of unemployment in labour, it seems that some allowance should be made for the unemployment of capital also" (77).

For these reasons it has generally been considered necessary to adjust the available capital-stock series for relative utilisation to obtain the actual flow of capital services. Several alternative adjustment procedures are available, but all of them are suspect in one way or another, and subject to wide margins of error. The simplest approach is to assume that capital services are proportional to capital stock for each type of asset, an approach which is not empirically justifiable. An alternative, but barely more-sophisticated method, is to take full employment of labour as a standard for full employment of capital, and to assume that the employment of capital varies *pari passu* with the percentage employment in the labour force. Such is the approach of Solow (78), who admits that "this is undoubtedly wrong", but justifies it on the grounds that "it probably gets closer to the truth than making no correction at all". He acknowledges the fact that this method does not take into account the changing length of the work week. As labour hours of work per year decline, the intensity of use of existing capital decreases, and the stock figures over-estimate the input of capital services. However, labour hours do not necessarily provide a reliable indication of machinery hours. In principle, a 40-hour week for labour can be consistent with 40, 80, or 120 hours a week for a machine, depending on whether 1, 2, or 3, 40-hour shifts are employed. Data on shift work can be used to establish broad levels of capital utilisation among industries; for example, Marris (79) used shift-work data for the United Kingdom for this purpose; and Foss (80) attempted to estimate equipment hours of work in United States' mining and manufacturing using limited information relating to employment by shift. However, shift-work-based analysis presents problems in that data is limited in coverage, of poor quality (in most countries), and is difficult to interpret because of differences between plants. In addition, shift work measures labour utilisation which is a poor proxy for capital utilisation.

Another method of measuring capital utilisation is to equate an output peak with full-capacity utilisation of all factors of production so that any departures from peak production represent capital under-utilisation. A popular method is that deriving from the Wharton School (81), the methodology of which is discussed by Klein and Preston (82). A straight line drawn from peak to peak represents the evolution of full-capacity output over time. Actual output for each of the interpeak

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years is then expressed as a percentage of the relevant trend value for that year, yielding the percentage utilisation of capacity for that year. This method is employed for adjusting capital stock by Lovell (83) and also by Brown (84), despite the fact that the latter details many shortcomings of the method. These include the assumptions that peak output implies full-capacity utilisation; and that a linear interpolation between output peaks is a good approximation of the rate of growth of capacity. In view of such shortcomings, Brown also employs an iterative procedure as an approximation to capacity utilisation. A more-subjective approach has been to survey businessmen to ask how their capacity utilisation in a recently-completed period compared with that of a previous period (85). Such methodology is extremely suspect. Businessmen never react uniformly to the questions asked and responses tend to shift over time. Their definitions of capital differ, as do their perceptions of full utilisation especially related to the problems of shift working and varying lengths of the working week. In a recent major study for the World Bank, Bautista et al (86) collected data on levels of capital utilisation and their determinants for Israel, Colombia, Malaysia, and the Philippines through survey questionnaires sent to selected manufacturing plants. Questions asked related to plant characteristics, number of employees, age of plant, value of fixed assets, value of annual sales and value-added, scale of plant, legal status and nationality, time utilisation, wages, supply characteristics demand characteristics, nature of competition, location, managers' views of causes of excess capacity, and electricity-utilisation rates. Another possible measure relates to the rated capacity of a given piece of equipment, but engineering studies indicate this to be an imperfect guide to its capacity utilisation. For instance, in steel rolling, full-capacity utilisation of a given mill (as defined by the managers in practice) may vary from 80 to 120 per cent of its rated capacity.

The whole concept of capacity and the measurement of capacity utilisation is fraught with difficulties and has given rise to an extensive literature. More-prominent studies are attributed to Cassels (87), Klein (88), the subcommittee on Economic Statistics of the Joint Economic Committee (89), Phillips (90), Klein and Long (91), and Perry (92).

Attempts at measuring changes in hours worked by machinery and equipment seem to offer a practical solution to the measurement of

utilisation over time. In this way, capital utilisation can be measured objectively. Unfortunately, comprehensive data on machine hours for overall manufacturing are lacking, but Foss (93) noted that for the United States statistics were available on power equipment and on electricity consumption that could provide the basis for estimates of hours worked by electric motors, and thus hours worked by machinery driven by such motors. Attention is focused on electric motors because of the dominant position of such equipment as a source of work in United States' manufacturing industry over the period 1929-54. By 1929, electric motors accounted for 80 per cent of all mechanical work done in factories, increasing by 1954 to 88 per cent. The rest was provided by "prime movers" such as steam engines and turbines, gasoline engines, and water wheels. To illustrate the use of machine-hours data, Foss looked at the cotton textile industry. There was a 37 per cent decline in the number of spindles in place from 1929 to 1956, but an 88 per cent increase in hours worked per spindle in place, and thus an 18 per cent increase in the total number of spindle hours worked.

Foss found that for hours worked per annum by equipment in United States' manufacturing between 1929 and 1954, there had been an increase of the order of one-third to one-half in the utilisation rate. He considered this of significance in view of the fact that various studies of productivity (as discussed in chapter 7) have found that total output has risen at a faster rate than has the weighted total of factor inputs, and that the contribution of the growth of fixed capital to the increase in total output has been found to be of relatively small magnitude compared with the importance of the total-factor-productivity residual. However, the rising trend of capital utilisation over the years would signify a larger contribution of capital than indicated by capital in place to long-run output growth and, hence, a correspondingly smaller residual productivity term.

Such a method of measuring capital utilisation is, of course, not without its limitations. Over the study period the assumptions are made that there has been no change in the technical efficiency of motors, and that the proportion of total power consumed by motors has not changed. Another factor that has been ignored, concerns the increased use of measuring, metering, and control instruments which grew more rapidly than machinery generally over the period. Foss' figures also take no account of machinery directly powered by sources other than electric

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motors; and his calculations have ignored completely equipment such as furnaces, ovens, storage bins, furniture, hand tools, and transport equipment. The combined effect of these limitations could result in a substantial bias. Morawetz (94) considers that the use of the electricity measure could lead to a total understatement of actual utilisation, theoretically as high as 90 per cent.

Jorgenson and Griliches in their path-breaking studies on the measure of capital input and the elimination of measurement errors in 1966 (95) and 1967 (96), followed the convention of adjusting the capital-stock measure to transform it into a flow of services. They employ Foss' process of the relative utilisation of electric motors in the manufacturing sector. For their studies they make two important assumptions: firstly, that the relative utilisation of all capital goods is the same (so that data on the relative utilisation of electric motors provides an indicator of the relative utilisation of capital in manufacturing); and, secondly, that the relative utilisation of capital goods in the manufacturing and non-manufacturing sectors is the same (so that the relative utilisation of capital for the United States' private domestic economy can be estimated). In addition to the limitations of the electricity measure and the dubiousness of the two assumptions made by the authors, they also note that since installed-capacity data are available only for certain years, the adjustment allows only for the trend in the relative utilisation of capital, and does not adjust for short-term cyclical variations in capacity utilisation, thus failing to attain complete comparability between labour and capital service-flow measurements. This adjustment for capital utilisation was severely criticised by Denison (97). In later studies in 1969 (98) and 1970 (99), Jorgenson and Christensen still employed Foss' utilisation measure but amended the assumption that the relative utilisation of all capital goods is the same and is thus indicated by the relative utilisation of electric motors in manufacturing; they also amended the trend measure so that a utilisation factor could be obtained for all years over the period 1929-67, so that the utilisation adjustment reflected both cyclical and trend changes in utilisation. In a 1973 study (100) the authors withdrew the measure entirely, and this withdrawal was persisted with by Jorgenson and his new co-author Gollop in a major 1980 study (101) for reasons which are explained later.

It must be stressed that there is far from universal approval of the concept of adjusting capital stock to obtain a flow of capital services. Firstly, the concept and measurement of capacity and its utilisation is so elusive that the accuracy of adjustment processes is open to question. Essentially the whole approach is arbitrary. Walters considers that the choice between alternative adjustment procedures is of little consequence since "with our present rudimentary state of knowledge of the idle time of machines (they are all) just as defensible" (102). This appears to be a negative manner of approaching such procedures. Walters might well have written that they are all just as indefensible. One could certainly question the accuracy of Solow's contention that although he recognises his adjustment method to be "undoubtedly wrong", it gets closer to the truth than making no correction at all, thus implying that any correction which appears reasonable is better than none. Denison's argument against the 1966 and 1967 studies of Jorgenson and Griliches was that they may well have introduced more measurement errors than they eliminated by using a common rate of utilisation for all capital goods; a point subsequently vindicated by Christensen and Jorgenson's 1969 and 1970 studies. All of the measures examined contain inherent limitations, which places a question mark over whether they are accurately representing what is actually occurring. The same comment made in relation to depreciation measures can be repeated here in relation to measures of capital utilisation, namely, that they are contrived, inherently arbitrary, and subject to substantial error. Unless there is certainty that the adjustment represents a move in the correct direction there seems little logic in undertaking the exercise. Denison is one of the advocates of leaving capital stock unadjusted for rates of utilisation on the grounds that "adjustments of capital input based on some approximation of the percentage of capital utilised seem to me to go much too far and I make no such adjustment" (103). In other words, our inherently arbitrary adjustment methods over-compensate for what is actually occurring.

The second point is more conceptual. Even if capital stock could be accurately adjusted for actual utilisation there remains the argument that this could be a conceptually invalid procedure. This relates to the observation that although capital utilisation may depend partly upon unavoidable exogenous swings in demand, it is mainly related to managerial efficiency. Bautista et al (104) note that such efficiency

is connected not only with "initial" decisions concerned with "which product to make, what techniques to use, where to locate a plant", and so on, but also with "subsequent" decisions, related to, for example, "how well a plant is laid out, how efficiently equipment is integrated in the production process, that is, how well operations are matched, how intensively machines are operated, the length and frequency of downtime, the management of maintenance operations, and similar issues" generally referred to as production engineering. These characteristics of production efficiency are given such rubrics as "learning by doing" and "X efficiency". Consequently, in view of this argument, capital in place is a better measure than utilised capital. Changes in capital utilisation should be captured in a residual productivity term and not in the size of the capital-input measure, which would amount to an unjustified quality correction of capital. Kendrick (105) strongly supports this contention;

"in contrast to the human population, the entire living population of capital goods is available for productive use at all times, and involves a per annum cost, regardless of degree of use. The purpose of capital assets is for use in production of current output and income. The degree of capital utilisation reflects the degree of efficiency of enterprises and the social economy generally. Hence, in converting capital stocks into inputs, we do not adjust capital for changes in rates of capacity utilisation and thus these are reflected in changes in the productivity ratios".

Foss (106) also considered that there may be some substance to the argument that a far-better measurement is provided by capital in place and that increasing capital utilisation, as discovered in his study, should not be considered as an increase in capital input. Instead it should be regarded as the result of certain forces that have contributed to a rise in total factor productivity over time, for instance, the advances in management efficiency and knowledge that have grown out of the experience gained from working with machinery and from engineering studies within the plant, so that one of the focal points of management has been the reduction of idle equipment time. One example cited of the long-run importance of the advance in knowledge acquired by management in making more-efficient use of machines has been the efforts

by many firms to smooth out within the year the production peaks which come from seasonal or other short-lived peak loads and which frequently entail the use of standby equipment with relatively low annual utilisation. Foss considered the success of the electric utilities in making more-intensive use of capacity needed for peak loads to have been "outstanding". Citing the diesel locomotive, he also believed that there has probably been a relative reduction in downtime for equipment repairs due to better constructed and more scientifically-designed machinery which has increased the available working time. Production methods have also changed and become more efficient particularly centring around the use of continuous automatic operations in which machines tend to be used with a high degree of intensity. There has additionally been a shift to multiple-shift operations. All these points stress increased efficiency, better knowledge, superior machinery, sounder planning, and so on, which account for higher machine utilisation and should be captured in the total-factor-productivity residual term and not in the capital measure itself.

Thirdly, Denison (107) after pointing out that "in the short run, the intensity of capital utilisation fluctuates with variations in the pressure of demand, but in this respect capital input is not different from land input or labour input", goes on to argue that although the hours that capital is used may also change in the longer run "such changes, if they occur, are merely manifestations of changes in other output determinants that are separately measured so need not be given separate consideration". Denison hounded Jorgenson and Griliches, as previously explained, for their use of energy per unit of capital input employed as a relative-utilisation adjustment. Jorgenson and Gollop explain that this involved the substitution of energy, a component of intermediate input, for capital. This adjustment is, however, dropped in their 1980 study because "this substitution is fully accounted for in our measures of intermediate input ... (and, hence) ... no further adjustment of capital input or intermediate input is required" (108). Their procedure of measuring total factor input in such a way that variations in energy consumption are included in the productivity calculation is considered by Berndt (109) to be "clearly preferable" to the practice whereby capital is adjusted using some type of relative-electricity-capacity index, that not only is confined solely to electricity and raises measurement issues in how one defines "capacity",

but also assumes that the relationship between capital and energy is one of strict proportionality. In contrast the authors now treat "energy just like any other input, and do not make any assumption on whether the relationship between energy and capital is one of substitutability, strict proportionality, or complementarity".

These arguments are particularly persuasive for any study of productivity change, as typified by this thesis, which adopts the "measurement" approach and captures quality change in the residual term; and which also treats energy just like any other input, incorporating substitution among intermediate, capital, and labour inputs. In view of these factors no adjustment of capital input to reflect changing rates of utilisation is attempted in this thesis.

(iii) Raw Materials Input

The details of the compilation of a raw materials-input index for the South African coal mining industry over the period 1950-80 are dealt with in Appendix B at the conclusion of this chapter. At this stage a general discussion will be undertaken of the justification for employing this variable in the study, together with some conceptual problems and difficulties associated with the use of raw materials input.

Justification for Inclusion of Raw Materials

More than two decades ago Christ (110) noted that "most studies of production functions explicitly mention as input only things like labour and capital, ignoring materials and fuels". This, to him, seemed to amount to a "theoretical oversight", and he considered that "surely the better approach is to begin with a production function that explicitly makes gross output depend on labour, capital, and materials inputs". He did observe, of course, that if material input is a stable function of gross output, and if the production function itself is stable, then gross output can be expressed as a stable function of labour and capital input alone. This, however, is a big "if", because materials input need not be a stable function of gross output. If the price of materials changes relative to the price of labour and capital then one can expect a substitution between materials on the one hand, and labour and capital on the other. For instance, a reduction in the relative price of materials could result in a rise in the ratio of gross output to labour

and capital input. Consequently, Christ considers it important to use productivity indices in which attention is given to material input.

Gollop and Jorgenson (111) consider that intermediate materials ought to be included in the measurement of total factor productivity since such an exercise is based on the theory of production behaviour, and to an entrepreneur intermediate inputs are treated symmetrically with all other inputs. Cost-minimising firms choose that combination of labour, capital, and intermediate materials which minimises total cost given output, and for this reason intermediate inputs along with labour and capital should enter in the calculation of total factor productivity.

Mark (112) notes that in recent years increasing interest has been shown in separate measures of energy and raw materials inputs because of the concern about energy and material needs. As with labour and capital, energy and materials inputs should be included by type in terms of their physical units or constant dollars, and differentiated similarly in terms of their impact on productivity.

The primary reason why most researchers have ignored intermediate inputs in empirical work is that most studies are performed at the national level. At this level, according to Klein (113), "we might think of intermediate products, aside from imports, as cancelling out because they appear as inputs for some components of the average and outputs for others". In the case of the United States, for example, the relative magnitude of imports is small. For the aggregate of firms within a nation, output is measured customarily as value-added, that is, as the gross value of output less the value of intermediate goods used up in the production process. For an entire country the appropriate output variable would be the statistics of the Gross National Product measured in constant prices. This series measures value-added. Therefore, one may not find any added statistical significance by including an input variable for intermediate goods in the production function. For this reason, the aggregate production function is expressed as a relation between value-added (in a constant-price system) on the one hand, and labour and capital input on the other. Most empirical work on aggregate production functions has proceeded along these lines.

However, the appropriate output variable for a firm, industry, or industrial sector is the conventional index of industrial production, thus the relevant production function differs from the aggregate production function in that the output variable is not defined in terms of value-added, but rather physical units produced. Now although raw materials and other intermediate goods cancel as inputs and outputs for the economy as a whole, this does not occur within an individual firm, industry, or sector, and, therefore, at these levels, materials, fuels, and other intermediate goods should be included among inputs. This approach was recognised and adopted in empirical work as long ago as the early 1950's, as evidenced by the studies of Ruttan in the United States meat packing industry (114), and farming (115). If output is defined in gross terms a separate intermediate input variable for materials and fuel should be included in the production function. However, many studies at such levels dispense with the necessity of a separate input variable by defining output in value-added terms (gross output less raw materials) in constant prices, and thus limit the explicit significance of intermediate inputs.

#### Value-Added or Gross Output?

Now that the necessity to take account of raw materials input in industry-level studies has been established, a conceptual problem still remains, namely, whether to measure output in value-added terms and, hence, eliminate the need for a separate raw materials input, or to leave output gross and utilise the separate raw materials input. The two approaches are not alternatives.

Klein (116) considers that raw materials, especially of the fuel variety, may not have the fixed relation to output that is implied by the use of the value-added concept whereby raw materials are not treated as a separate factor of production, but as an automatic subtraction from the total value of output. With  $Y$  representing gross output and  $R$  raw materials, the value-added concept in the Cobb-Douglas formulation is

$$(Y-R) = PL^{\alpha} K^{\beta} \quad (ii)$$

or,

$$Y = R + PL^{\alpha} K^{\beta}. \quad (iii)$$

In other words, materials input is not treated in the same way as labour and capital in the production function. But there are persuasive reasons why it should be - at different levels of productive operation there may be economies or diseconomies in the use of materials. Accordingly, the gross output formulation would be

$$Y = PL^\alpha K^\beta R^\gamma \quad (iv)$$

It has been shown several times, although perhaps not sufficiently recognised in empirical work, that a productivity index for a single industry derived from a value-added formulation will generally be greater than such an index derived from a gross-output formulation. The discovery of this inequality relationship is sometimes attributed to Simon (117) but was popularised in two papers in the early 1960's by Domar (118) (119) and again analysed by Star in 1974 (120). The gross-output formulation of equation (iv) above can be replaced by,

$$Y^1 = P^1 L^{\alpha^1} K^{\beta^1} \quad (v)$$

so that with raw materials omitted from both sides of the production equation,  $Y^1$  is an index of value-added in real terms, and  $\alpha^1 = \alpha/1-\gamma$  and  $\beta^1 = \beta/1-\gamma$ . Thus, R is given a weight of zero, and its former weight in (iv) above is assigned to L and K in (v) in proportion to their former weights. However, as far as the productivity index is affected by this exercise it is now obvious that in the general case  $P^1 \neq P$ , and subject to a proper definition of  $Y^1$ ,  $P^1 > P$ .

If the following general production equation is postulated,

$$Y = P(w_0 L + i_0 K + h_0 R) \quad (vi)$$

where  $w_0$ ,  $i_0$ , and  $h_0$  are the real prices of labour, capital, and raw materials respectively in a base year, and L, K, and R are labour, capital, and raw materials respectively in physical units, then the productivity term is represented as,

$$P = \frac{Y}{w_0 L + i_0 K + h_0 R} \quad (\text{vii})$$

By eliminating the cost of materials in constant prices from both sides of the production equation, then expressions (vi) and (vii) are, respectively, transformed into,

$$Y = P^1 (w_0 L + i_0 K) + h_0 R \quad (\text{viii})$$

(which is analogous to (iii) above), and

$$P^1 = \frac{Y - h_0 R}{w_0 L + i_0 K} \quad (\text{ix})$$

Thus, in this transformation it is implicitly assumed that although (when  $P > 1$ ) the marginal products of labour and capital are increased by "other forces" in the same proportion, the marginal product of materials remains constant. It is immediately appreciated that the exclusion of raw materials from the numerator and denominator of (vii), increases  $P$  when  $P > 1$ , and reduces it when  $P < 1$ . Accordingly, the absolute rate of growth of the index is increased.

If the exclusion of raw materials from both sides of the production equation exaggerates the size of the residual productivity term, then clearly a choice must be made between  $P^1$  and  $P$ . Domar is adamant; his preference is for  $P$ . "We are interested in the Residual involved in the production, say, of shoes made from leather by labour and machinery with the help of electric power. The output of such a firm or industry is clearly shoes, familiar physical objects, and not shoes lacking leather and made without power. Leather and power are inputs not less essential than, and not inherently different from, labour or machinery" (121).

Accordingly, the issue seems fairly clear, and for the purpose of this thesis raw material input is treated as a separate variable on the same footing as labour and capital inputs, and related to gross output in the formulation suggested in expression (iv), and also (vi) and (vii).

#### Other Difficulties

Raw materials input is made up of hundreds of different commodities and even within a broad commodity category there are differences in

vintages, design characteristics, performance capabilities, and so on. Ideally, each individual commodity should occupy its own vector in a production equation, but for the sake of convenience and practicality they are all aggregated into a composite raw material input. Some raw materials are directly measurable in physical units; others can only be counted in value terms and deflated to a base year. In other words we are confronted with familiar problems of weighting, aggregation, and deflation, which introduce biases and measurement and specification errors of unknown magnitude. These concepts and difficulties have been analysed previously in this thesis and there is no need to repeat the analysis at this stage.

(iv) Output

Output is measured as a flow of goods and services over an accounting period. For productivity purposes it must be measured in physical or real terms. The concept is one of work done, or the amount of product added in the various enterprises, industries, sectors, or economies. It refers not to activity as such, but to the results of activities.

By far the most usual case is that of a plant, industry, sector, or economy producing many heterogeneous products. Weighted index-number techniques must, therefore, be employed to combine this multitude of separate products into a composite-output measure. Physical-quantity data may be available for many products but others are only satisfactorily calculated in value terms. Accordingly, myriad problems of deflation, aggregation, weighting, and so on, are involved in this exercise, and although the end result may approximate physical flows, the purity of the production function as a technological relation has been lost.

However, in the case of a producing unit which makes one homogeneous commodity, production in physical terms is merely a count of units produced. Tonnes of cement, barrels of oil, bushels of wheat, and so on, provide obvious examples. The coal mining industry can be regarded as producing only one homogeneous commodity. Accordingly, a gross measure of output in physical units is simply formulated in terms of tonnes of saleable coal produced. The purity of a physical-units measure and a true technological relationship is, therefore, preserved. However, for a commodity to be regarded as homogeneous, Mark

(122) states that certain conditions should be fulfilled. The product should be of a specified quality, and it must conform to precise standards of size and volume. Even though the measure of production is a single count, the way of defining the unit of product can have different implications for productivity measurement. Thus, carpeting can be measured either in kilograms or square metres. A change in the density of the carpeting would affect the weight per metre and have a differential impact on labour requirements depending on whether output is measured by the metre or the kilogram.

Walters (123) is of the opinion that coal is only an "apparently homogeneous" commodity in that "different grades of even the same type of coal command quite different prices - and so the composite output has to be weighted." Maddala (124) identified several differences in the quality of coal based on such characteristics as average heating values, average amounts of moisture, volatile matter, fixed carbon, ash, and sulphur. Although this argument is technically correct any attempt to provide for it in an empirical study would raise multitudinous measurement problems, and probably introduce more errors than it eliminated. Certainly, Maddala himself, after raising the issue, considered that it could be ignored in that no significant bias would be involved in the case of the United States' coal mining industry. The only source of bias he considered worthy of correction arose from the fact that coal coming from strip mines is, in general, inferior to that coming from underground mines. This is not a noticeable factor in South African coal mining, but Maddala took care of this difference by introducing the percentage of output coming from underground mines as an additional variable in all his regressions. Lomax (125), in his study of British coal mining, did not consider the matter as worthy of any discussion and employed an index of tonnes of saleable coal produced. Both Barger and Schurr (126) and the International Labour Organisation (127) adopted the same approach, although it must be admitted that these studies were conducted as long ago as 1944 and 1951 respectively.

For the purpose of this thesis the definition of output adopted is tonnes of coal sold, as compiled and published by the Department of Mines (128). These figures have already appeared as table 2.3 in chapter 2. However, in order for this data to be comparable with the

input figures for labour, capital and raw materials, the coal sales from Duvha, Rietspruit, and Grootegeluk for the period 1978-80 must be omitted. The magnitude of these tonnages is shown in the table below.

TABLE 9.3 DUJVA, RIETSPRUIT AND GROOTEGELUK COLLIERIES:  
COAL SALES, 1978-80

(In millions of metric tonnes)

COLLIERY	YEAR		
	1978	1979	1980
DUVHA	NIL	0,4	1,8
RIETSPRUIT	NIL	3,6	4,8
GROOTEGELUK	<u>NIL</u>	<u>NIL</u>	<u>0,2</u>
TOTAL	<u>NIL</u>	<u>4,0</u>	<u>6,8</u>

Source: obtained directly from Department of Mines, Minerals Bureau.

Table 9.4 shows the sales tonnages of coal for the period 1950-80 once the totals in table 9.3 have been subtracted. These are converted to an index with 1950 base alongside. The overwhelming percentage of this coal can be described as bituminous (including coking coal). Over most of the study period sales of anthracite have comprised between 1,2 and 2,5 per cent of total coal sales in volume terms. However, anthracite sales have grown considerably in recent years, mainly due to strong export demand, and by 1980 they accounted for 3,9 per cent of total coal sales. The selling price of anthracite is considerably higher than that of bituminous coal. Sales of coking and blend-coking coal have remained almost constant in recent years and are less than ten per cent of total coal sales. The main growth in coal sales has been provided by the steam-coal sector. The value of coal sales has also increased enormously towards the end of the study period reflecting not only increased output but more-frequent upward revisions in the domestic selling price and the much higher price received on the export market.

The difference between total tonnage mined and total saleable production has already been discussed in chapter 2. The data for actual

sales presented in table 9.4 are fractionally lower than saleable production and this is explained by some, or all, of the following reasons: coal consumed at the collieries, unsold duff, variations in moisture contents, and different reporting times.

TABLE 9.4 COAL SALES, 1950-80  
(in millions of metric tonnes)

<u>YEAR</u>	<u>SALES</u>	<u>INDEX: 1950=100</u>
1950	25,7	100,0
1951	25,8	100,4
1952	27,1	105,4
1953	27,6	107,4
1954	27,9	108,6
1955	30,1	117,1
1956	32,2	125,3
1957	33,7	131,1
1958	36,2	140,9
1959	35,6	138,5
1960	38,1	148,2
1961	40,5	157,6
1962	41,0	159,5
1963	41,9	163,0
1964	44,1	171,6
1965	47,6	185,2
1966	46,9	182,5
1967	48,3	187,9
1968	50,6	196,9
1969	51,2	199,2
1970	53,1	206,3
1971	57,0	221,8
1972	57,0	221,8
1973	61,5	239,3
1974	64,6	251,4
1975	9,1	268,9
1976	75,7	294,6
1977	85,0	330,7
1978	85,7	333,5
1979	94,2	366,5
1980	104,5	406,6

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CHAPTER 9: APPENDIX ADETERMINATION OF CAPITAL INPUTGross Investment in the Coal Mining Industry: 1950-80

Gross capital expenditure is divided into four categories, on the basis determined by the Economics Department of the South African Reserve Bank (1).

- (i) residential buildings
- (ii) non-residential buildings and construction works
- (iii) transport equipment
- (iv) machinery and other equipment.

The Reserve Bank actually distinguishes between expenditure on non-residential buildings and expenditure on construction works, but they are treated as an aggregate in this analysis because of identical average service lives.

Expenditure in each of these categories on an annual basis since 1950 can be deduced from figures published by the Department of Mines (2). The Department collects statistics from each coal mine annually relating to the value of stores consumed. These stores are broken down into fine categories and the value of each category is published on a provincial basis (Transvaal, Natal, and Orange Free State in the case of coal mining). All items of capital expenditure are included in the stores breakdown but are not separately distinguished as such, nor categorised into the divisions above. It was, therefore, necessary to use personal judgement, firstly, in deciding which items of stores should be regarded as gross capital expenditure, and, secondly, the categorisation of such expenditures into the four divisions above. Analysis of capital assets is undertaken in the text. Expenditures on maintenance and repairs (which keep, or restore, the asset to a constant level of services) are not regarded as capital expenditures. However, expenditures which add to the services of an asset are capitalised. The detailed components of each of the four divisions of gross capital

expenditure are shown in worksheet I. Slight changes have been made by the Department of Mines in the format of reporting the various items of stores over the study period. The period 1950-69 can particularly be distinguished from 1970-80. The main change concerns the components of the division on non-residential buildings and construction works. However, with the assistance of the Department's Reference Key (3) the definition of each item of stores was accurately identified, and categorisation facilitated. Most changes were merely in terminology or the grouping or separation of items.

The statistics collected by the Department of Mines are analysed by the Chamber of Mines who also publish in their Annual Report (4) the same detailed breakdown of stores consumed, but only in relation to those coal mines which are members of the Chamber. Natal coal mines only joined the Chamber in 1974. Before this date the Chamber's figures related only to Transvaal and Orange Free State members, but the "total stores" figures for these Provinces were virtually identical to those of the Department of Mines since very few coal mines in these Provinces were not members of the Chamber. With the membership of Natal mines in 1974 the Chamber and Department of Mines figures for "total stores" ran parallel, until 1978. Since that date, however, the Chamber's figures have been substantially lower due to non-membership of the Chamber by several new developing collieries, these being Duvha, Rietspruit, and Grootegeluk.

More-detailed information concerning the source of gross capital expenditure figures is provided below.

<u>YEAR AND SOURCE</u>	<u>COMMENT</u>
1950-56 DEPT. OF MINES' ANNUAL REPORTS	Full coverage provided of breakdown of stores consumed on a Provincial basis.
1957-62 CHAMBER OF MINES' ANNUAL REPORTS	Dept. of Mines ceased publishing breakdown of stores and provided only Provincial totals. However, a breakdown for the Transvaal and Orange Free State mines was obtained from the Chamber of Mines' Annual Reports. The missing Natal figures were estimated by interpolation for each division of capital expenditure, bearing in mind the "total stores" figures for Natal published by the Department of Mines.
1963-65 DEPT. OF MINES' ANNUAL REPORTS	Dept. of Mines re-commenced publication of full coverage of the breakdown of stores consumed on a Provincial basis.
1966-73 CHAMBER OF MINES' ANNUAL REPORTS	Dept. of Mines' Annual Report changed completely in format to report very laconically on most issues. A new publication was created - "Mining Statistics" (5) - which quotes only "total stores" for each Province with no itemised breakdown. However, a breakdown for the Transvaal and Orange Free State mines was obtained from the Chamber of Mines' Annual Reports with the missing Natal figures for each division of capital expenditure being estimated by interpolation, bearing in mind the "total stores" figure for Natal published by the Dept. of Mines.
1974-1977 CHAMBER OF MINES' ANNUAL REPORTS	Natal coal mines now members of Chamber of Mines. Full breakdown and coverage, therefore, provided in their Annual Reports, except for 1974 Natal breakdown which was obtained personally from the Department of Mines, Minerals Bureau.
1978-80 CHAMBER OF MINES' ANNUAL REPORTS	Full coverage and breakdown provided, except for Chamber non-members - Rietspruit, Duvha, and Grootegeluk.

Total gross investment in the coal mining industry for each year over the period 1950-80, broken down according to the type of capital expenditure, is shown in worksheet II.

Gross Investment Before 1950

In order to compile capital-stock figures for the 1950-80 period, it is necessary to take account of pre-1950 gross capital expenditure which would still have productively formed part of the post-1950 capital stock. Capital expenditures on each of the four categories of gross investment have to be traced backwards for the number of years corresponding to the expected average service life of the particular type of capital expenditure. The Economics Department of the South African Reserve Bank has calculated average service lives for different types of capital assets for different industries. The lives below, as relating to the coal mining industry, were supplied to the writer by the Bank:

residential buildings	50 years
non-residential buildings and construction works	30 years
transport equipment	8 years
machinery and other equipment	16 years .

The Department of Mines' breakdown of "stores consumed" for the period 1946-9 is the identical format as that for the post-1950 period. However, the format is fairly substantially different for the year 1945 and all earlier years back to 1911. This presented some problems, none of which were insurmountable. No detailed breakdown of stores was published for the war years 1941-3.

For each category of capital investment it is necessary to first start taking account of expenditure in that year which would exhaust its final year of service in 1950. An annual figure is counted as losing one year of its life in the same year it was incurred. Thus;

- transport equipment commences with capital expenditure incurred in 1943. As noted above, figures for 1946-9 are readily available

from the Department of Mines' Annual Reports' breakdown of "stores consumed". For the years 1944-5 accurate figures for the components of transport equipment can still be obtained despite the changed format of the breakdown. The unpublished War figure for 1943 was obtained by interpolation, which presented little problem since expenditure figures were relatively small at that time;

- machinery and other equipment statistics commence with capital expenditure incurred in 1935. Accurate figures are available for the period 1946-9, and although the format is changed for the period 1935-45, expenditure on the different components of machinery and other equipment can still be accurately and consistently calculated. The unpublished figures for the war years of 1941-3 were obtained by interpolation;
- non-residential buildings and construction works figures commence with capital expenditure incurred in 1921, whilst the starting date for residential buildings is 1901. For both types of investment, accurate figures are available for the period 1946-9, but the changed format for the earlier years provides a formidable problem since no breakdown is given on a separate basis of expenditure on buildings, stores, offices, roads, railways, and so on. These figures, therefore, had to be estimated on the basis of the historical percentage which each of these categories of capital expenditure have comprised of the total value of stores consumed in the coal mining industry. The accumulated inaccuracy introduced by this estimation is not likely to be significant. By 1946, capital expenditure on non-residential buildings and construction works was in the region of R1 million annually, whilst that on residential buildings was approximately R0,5 million annually. For earlier years these expenditures would have soon become insignificant when compared with expenditures in more-recent years.

For the five immediate post-war years of 1946-50 inclusive, capital investment in residential buildings comprised approximately 7 per cent of the total value of stores consumed in the coal mining industry but for the latter and longer and more-stable period of 1951-56, this percentage was remarkably stable between 3 and 4 per cent. It was,

from the Department of Mines' Annual Reports' breakdown of "stores consumed". For the years 1944-5 accurate figures for the components of transport equipment can still be obtained despite the changed format of the breakdown. The unpublished War figure for 1943 was obtained by interpolation, which presented little problem since expenditure figures were relatively small at that time;

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- non-residential buildings and construction works figures commence with capital expenditure incurred in 1921, whilst the starting date for residential buildings is 1901. For both types of investment, accurate figures are available for the period 1946-9, but the changed format for the earlier years provides a formidable problem since no breakdown is given on a separate basis of expenditure on buildings, stores, offices, roads, railways, and so on. These figures, therefore, had to be estimated on the basis of the historical percentage which each of these categories of capital expenditure have comprised of the total value of stores consumed in the coal mining industry. The accumulated inaccuracy introduced by this estimation is not likely to be significant. By 1946, capital expenditure on non-residential buildings and construction works was in the region of R1 million annually, whilst that on residential buildings was approximately R0,5 million annually. For earlier years these expenditures would have soon become insignificant when compared with expenditures in more-recent years.

For the five immediate post-war years of 1946-50 inclusive, capital investment in residential buildings comprised approximately 7 per cent of the total value of stores consumed in the coal mining industry but for the latter and longer and more-stable period of 1951-66, this percentage was remarkably stable between 3 and 4 per cent. It was,

therefore, decided to use a constant percentage of 4,5 per cent of the total value of stores consumed annually as an estimate of capital expenditure in residential buildings for the missing years 1901-45 inclusive. Department of Mines' figures for total stores only commence in 1911 after Union, before which figures were published by the different Provinces.

The same percentages for non-residential buildings and construction works have shown considerably more variability over the period 1946-66, ranging from a low of 6 per cent in 1963 to a high of 24 per cent in 1950. These figures, however, were isolated extremes. The percentages for the eight post-war years of 1946-53 inclusive displayed an average of approximately 17 per cent, whereas those for the latter and longer period of 1954-66 inclusive displayed a lower average of approximately 10 per cent. It was, therefore, decided to use a constant percentage of 13 per cent of the total value of stores consumed annually as an estimate of capital expenditure in non-residential buildings and construction works for the missing years 1921-45 inclusive.

Total gross investment in the coal mining industry as determined by the analysis above for relevant years over the period 1901-50, broken down according to the type of capital expenditure, is shown in worksheet III.

#### Price Deflators

At this stage it is necessary to obtain price indices to act as deflators to convert the current capital expenditures of worksheets II and III into real capital expenditure. Such indices are required for each type of capital expenditure.

The Economics Department of the South African Reserve Bank compiles such indices for the purpose of deflation of investment expenditures, but does not publish them as a special exercise. Nevertheless, they can be derived from the Bank's published estimates of fixed investment at current and constant prices. The price indices for this thesis for the period 1946-80 inclusive were derived from statistics published by the Bank in their publication A Statistical Presentation of South Africa's National Accounts for the Period 1946 to 1980(6). It presents statistics for gross domestic fixed investment according to the type of asset (residential buildings, non-residential buildings, construction

works, transport equipment, and machinery and other equipment) in both current prices (table 18) and constant 1975 prices (table 20). By dividing the latter into the former (i.e. current ÷ constant) for each type of asset, it is possible to obtain the required price indices to be used as deflators, with a 1975 base. These indices, for the five types of capital assets for the period 1946-80 inclusive, are shown in worksheet IV.

For the purpose of this thesis, however, non-residential buildings and construction works are combined into a single aggregate. Correspondingly, a joint deflator is required, not separate deflators. This can be achieved by appropriate weighting. In separate communication with the Reserve Bank they provided the writer with an aggregate price index for residential buildings, non-residential buildings, and construction works combined, and comparing this with the indices in worksheet IV it became clear that the Bank had adopted an average weighting scheme of 1,1 and 2 respectively, by virtue of the historically larger expenditure on construction works. This is also evident in coal mining and, hence, the same weighting scheme is adopted to derive a joint deflator for non-residential buildings and construction works, which is shown in brackets in worksheet IV. In any case the two separate indices closely parallel each other so that any error is not substantial.

Unfortunately, the Reserve Bank's figures only commenced in 1946 and price indices are required to go back much further than that. For transport equipment the starting date is 1943, machinery and other equipment 1935, non-residential buildings and construction works 1921, and residential buildings 1901. The only price indices that the Department of Statistics published in those early days which are remotely relevant are an index of wholesale prices of metals, and an index of wholesale prices of building materials.

The metal index comprised an aggregation of separate indices for: pig iron; steel sections; steel plate; hoop iron; galvanised sheets, corrugated and flat; fencing wire; fencing standards; binding wire; copper sheet; copper wire; lead sheet; lead pipes; tinsplate; quicksilver; and zinc sheet.

The building materials index comprised an aggregation of separate indices for : timber (separate indices for teak, deal, oregon,

pitchpine, flooring boards, ceiling boards, skirting, shelving); doors; windows; cement; lime; bricks; paint; varnish; turpentine; white lead; linseed oil; red oxide; red lead; glue; resin; tar; putty; glass; nails; and brads.

These two indices are presented in worksheet V.

It will be necessary to use the metal index as a proxy for a price index for transport equipment and for machinery and other equipment, and the building materials index as a proxy for a price index for residential buildings and for non-residential buildings and construction works, for the years preceding 1946. However, the indices as they stand in worksheet V are incomplete since they deal only with materials input, and ignore the important aspect of labour costs in the two relevant industries. This aspect must now be considered.

For the engineering and metal working industries, the Official Yearbook of the Union of South Africa (7) annually published statistics relating to the average number of employees, total salaries and wages, and cost of materials used. These are shown in worksheet VI to cover the period from 1946 back to 1934, under the columns numbered 1, 2 and 3 respectively. No statistics were published for the average number of employees for the years 1939-40 to 1944-5, and these had to be obtained by interpolation. From these statistics it is possible to calculate the average earnings per employee, and these are shown in column 4. Column 5 converts this to an index with 1938 base.

For the building and construction industry the Official Yearbook also annually published statistics relating to the average number of employees, total salaries and wages, and cost of materials used. These are shown in worksheet VII but, unfortunately, they only go back to the year 1915-16:

- for the "average number of employees" (column 1) no statistics were published for the years 1918-19, 1925-6, 1930-1, and 1931-2, and had to be interpolated;
- for the "cost of materials used" (column 3) no statistics were published for the same years and also had to be interpolated;
- for "total salaries and wages" (column 2) a figure for the whole Union was published for the years 1915-16 through to 1917-18 inclusive, and for the years 1932-3 through to 1945-6

**Author** Jones R A

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