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REPETITIVE BUILDING - APPLICATION OF THE LEARNING CURVE TO THE BUILDING INDUSTRY.

Two aspects of the building market give rise to concern: first the large expansion in building activity required over the plan period to 1970 and beyond, and second the high, and probably rapidly rising, level of building costs in Uganda. Consideration has therefore to be given to increasing the capacity of the industry and improving its efficiency. (i)

Capacity may be expanded in two ways - through an increase in the resources devoted to construction activity, and an improvement in the efficiency of the resources already so employed. As it seems likely that a shortage of skilled manpower will arise during the plan period (ii), methods aimed at increasing the efficiency of labour use must be urgently considered.

One of the methods of achieving this objective is through the exploitation of the 'learning effect' derived from the repetition of an operation, which leads to steadily rising labour productivity. The implementation of this innovation, however, is likely to have considerable multiplier effects such as to raise efficiency over and above that attributable to repetition, since the conditions to be met include strict control over the labour input, the preplanning and scheduling of work and the introduction to the wage structure of a system of incentive payments.

It was hoped in this paper to present results of research into the existence of a learning effect on a building site in Uganda. In April of this year, agreement was reached with the National Housing Corporation and the then Ministry of Housing and Labour, to conduct an experiment in repetitive building on a N.H.C. site at Kireka. The contract at Kireka was for five houses and from what will be said below it is clear that a run of five is almost a contradiction in terms of repetition. Nevertheless, the purpose of this project was to determine the existence of a learning effect and to tackle some of the problems which would arise when, as it was hoped, a larger site could be dealt with. As it was, the multiplier effects quickly showed themselves in that the N.H.C. had to design a form to record men hours per operation, something which apparently is not standard practice.

Unfortunately, the experiment was a failure, and after three months full time on the site, the project had to be abandoned with nothing achieved. From the standpoint of research there is nothing to report - even the reasons for failure would be abundantly clear to anyone experienced in work of this nature. The project did, however, succeed in arousing a considerable amount of interest in the applic-

(i) A general discussion of these matters is to be found in E.R.F. 34.
(ii) Of 15 replies to a question on bottlenecks to an expansion of building activity, 10 cited skilled manpower and supervisory staff.
ation of repetitive building. In working papers being prepared in the Ministry of Works, Communications and Housing, the importance of the potential of the repetitive effect is being cited as a reason for the need to create a coherent and programmed housing policy. Furthermore, the M.O.H. claims to have attempted to apply the method on an army barracks contract at Liverpool with 'most encouraging results'. Unfortunately, they have not kept records of operation man hours on this site.

It is perhaps therefore opportune to present a paper discussing the basis of repetition, its implementation, and the problems likely to be encountered in its application. Much of what is said is necessarily derived from publications and not personal research experience.

It is of interest that the implementation of repetitive building is being widely investigated in Europe, where similar problems of expanding output with shortages of skilled manpower exist. Its application to a developing country is an example of a 'modern' innovation that does not require the input of capital to raise productivity. (i)

A point of clarification must be made in relation to the scope of this paper. Two categories of repetitive building may be distinguished, repetition within the building materials factory and repetition on-site. Both these aspects of repetition have been documented by B.C.E. (ii) In this paper, attention is devoted to on-site repetition, or to quote the words of reference of the B.C.E. study, to assess

"the influence on labour productivity and building costs of the scale of production and the degree of repetition of operations carried out on-site" (iii)

The Theory of Costs.

The effect of repetition on building operations is the progressive reduction of time required to execute identical, and necessarily specialised, operations, which are carried out repeatedly and in succession (i.e. from one house to the next). Thus repetitive building means long runs of a homogeneous product and specialisation by the labour force. The source of the reduction in labour input is the implicit training of labour as it repeats an operation time and again.

Thus labour costs, and perhaps some other categories of cost, are stated to be a function of the volume of output. Consideration of the traditional theory of costs, however, shows that, like most theories, it is narrowly based. (iv) Joel Dean (v) presents a lengthy discussion of this, and points out that

"..... in economic analysis the cost function usually refers to the relationship between cost and rate of output, and thus assumes that all of the other independent variables are kept constant. " (vi)

(i) See Green, R. Wage Levels, Employment, Productivity and Consumption. E.C.R.F. 103.
(ii) Cost, Repetition, Maintenance - Related Aspects of Building Prices. B.C.E. 54/E/2/05/1/7; Effect of Repetition on Building Operation and Processes On-Site. B.C.E. 54/E/2/05/14.
(iii) Ibid. p.2.
(iv) In Theoretical work, A. Alchian has attempted to overcome this. See his chapter 'Costs & Output' in The Allocation of Economic Resources, edited by Abromavitz.
(v) Dean, J. Managerial Economics.
(vi) Ibid. p. 274.
Among the other independent variables, he cites volume of production, lot size, and variety of production. He goes on to point out that empirical measurement of cost curves is done in such a way as to represent the theoretical formulation and to eliminate other 'irrelevant cost forces'.

This choice of variables is of course quite acceptable from a theoretical point of view, if the most decisive influence in cost determination has been picked upon. From a practical point of view, however, if we regulating volume as a determining variable, it is possible to hide its influence altogether, for at least in building its exploitation requires appropriate changes in the usual methods of work organization and the pattern of demand, without which a learning effect may not exist or otherwise be of little significance.

It is perhaps interesting to note in this connection that in the field where the repetitive effect was first studied, the airframe industry, while

"most writers..... are agreed that rate of production does have an influence on..... unit costs... It is felt to be of minor importance, within a certain range of production, and definitely subordinate to the effect of cumulative production." (i)

The importance of this relationship is also explicitly recognised in a recent study on economics of scale, where the authors point out that unit costs of a given technique must be observed at different points in time so as to take account of the learning effect.(ii)

There are clearly important interconnections between rate and volume which increase the difficulty of specifying the optimum position when both rate and volume are taken into account. But given what has been said above, and empirical cost studies in a number of industries showing constant marginal costs over a range of output (iii) it is perhaps permissible while noting the existence of the two forces in cost determination, and more important their interconnections, to ignore rate of output and concentrate on the other variable of which relatively little is known.

Nature of the Volume-Cost Relationship.

The best documented aspect of the learning process is that already referred to between labour and volume of output. By reporting an operation time and again, an operative gains in what may be termed 'technical knowledge' and reduces the time taken to complete an operation.

But as the labour force becomes more knowledgeable and skilled, it has been found that wastage of materials decreases, and so gives rise to another aspect of the volume-cost relationship.

The third source of this relationship is concerned with complexities in the production process. In traditional analysis, changes in factor proportions and size and type of plant are included, but nothing is said of the complexities of work organisation, work

(i) Asher, N. Cost Quantity Relationships in the Airframe Industry. Rand, p. 86.
(iii) The only study of cost curves in building that I know of, was done by the B.E.C. in the early 1950's with respect to house building. I believe that their conclusion was that no important economies of scale were to be found.
methods, tool and gang co-ordination, organisation of the work place and solution of engineering problems, within a given technique of production. These problems arise and can only be solved after management has acquired technical knowledge of the production process as a result of experience of operation.

Finally, as volume increases and jobs are repeated, tools in the hands of workers undergo adaptation and improvement, increasing their efficiency.

In this paper, only the first and third are explicitly treated, the two clearly associated in that the contribution of indirect labour manifests itself in the labour input per unit of output. With regard to this contribution of management learning, it is as well to draw attention to criticisms of learning curve literature that have recently been made:

"... with a few notable exceptions, the role played by engineers and indirect labour personnel in facilitating these increases in productivity has not been adequately recognised." (ii)

The importance of this concept will become clear later in the paper, though strictly Beloff's remarks apply to a somewhat different situation that is being dealt with here.

The second aspect of the volume cost relationship is omitted since it is in any case a direct function of the rate of learning, and because it is felt that any saving will be a small proportion of the total materials cost of a building. (iii) The final factor is ignored since it would seem from empirical work to make only a small contribution to the overall learning effect, and furthermore, it is perhaps inappropriate to talk of the introduction of sophisticated hand tools into the Ugandan building industry.

Thus it has been said that learning curve analysis makes two contributions to conventional cost analysis: the inclusion of volume along with rate as an independent variable, and the acceptance of changes in technical knowledge as being an inherent reason for declining unit costs. (iv)

The Progress Curve.

The Progress Curve is the diagrammatic representation of the relationship between man hours input and the volume of production. It has been found in a number of fields that the decline in man hours attributable to the learning effect is sufficiently consistent to be approximated by a single mathematical curve. The exact equation differs according to industry, and other circumstances, but most of those fitted are related to the form

\[ Y = ax^b \] (1)

This is the curve fitted to airframe data by the pioneer of work on the learning process - T.P. Wright. The main objection to this equation is, of course, that it has zero as its limit. But what is

(i) This statement is true only in terms of a labour intensive technology, and should not be taken to mean that an independent management learning process does not exist in a capital intensive technology. The latter is referred to as 'debugging', which is dealt with at length in Beloff, H. The Learning Curve. J.I.E. July 1966.


(iii) Bulk purchase discounts could be considered here.

(iv) Asher, R. ibid. p. 12.
more important is that not only Wright's but many subsequent studies have found man-hours to continue to decrease over a very wide range of observations. This curve has been fitted to data derived from the building industry, (1)

The equation above relates average direct man-hours to volume of output, i.e., after 'e' repetitions, the average labour input per unit equals 'y' for the 'ith' unit and those preceding it. A corresponding 'unit curve' is associated with equation (1), showing the input of labour at each level of output:

\[ y = ax^{1+b} - x^{1-b} \]  \hspace{1cm} (2)

where in both these equations 'a' refers to the man hours expended on unit one.

What is of particular interest, with this equation form and the others that have been used, is the general pattern of the relationship. At the start of a work sequence, labelled 'opposition learning phase', the operative gains the 'know-how' of his job which results in a considerable increase in productivity as he repeats the operation. This is followed by a second phase, the 'routine acquiring phase', during which smaller improvements in performance are achieved through growing familiarity with the job. Though the saving in man hours becomes smaller and smaller, it has been found that a stable operational time is not achieved until very high volumes of output.

The actual improvement recorded is discussed in terms of the slope of the progress curve, but here slope is defined not as the first derivative of the function, but as the ratio of man hours at the different outputs, where the outputs differ by a factor of two. If the value of 'b' in equation (1) is taken as -322, then slope is obtained as follows:

\[ S = \frac{y_2}{y_1} \]

\[ = 2^b \]

\[ \log S = b \log 2 \]

Thus as doubling the number of units produced, the average labour input declines by 20%.

In addition to the progress curve for the total activity, each operation contained therein will have a progress curve of its own, the former being the sum of the latter. While the general shape of these curves will be as described above, their precise shape - equation form and slope - is a function of the nature of the operation considered. Thus, the more complex an operation the slower is likely to be the rise in productivity and vice versa. In addition, the greater the degree of actual effort and the less skill and technique required, the less the likely degree of improvement. Thus being, it is unlikely that any one equation, or perhaps even equation form, will satisfy all operations.

**The Predictability Requirement.**

The need for these curves to be predictable has received very little attention in the literature. But it is one thing being able to fit curves to past data, and quite another to assume that a consistent,

(1) For other equation forms used in building, see the F.C.B. study.
structural relation has been found applicable to subsequent events.

With regard to the curves relating to individual operations it is clearly of importance to be able to predict the path of improvement given that each operation will exhibit features of its own. Under these conditions some operations will be advancing faster than others, and where the sequence of operations is technically determined, it is necessary to foresee these relative stages in order to prevent men hours being wasted than a task operation cannot proceed to its work station because a slow operation has not completed its task. In addition, a knowledge of the operation curve is needed to operate a system of incentive payments. Similarly, the nature of the total progress curve is required for delivery scheduling, pricing and the ordering of materials. Even if it can be assumed that the total curve approximates the form of equation (1), the actual slope is a matter of conjecture. (i)

The problem of predictability arises because at least two elements of the shape of the curve, 'a' and 'b', depend on circumstances which are not constant. It is also possible that these circumstances will alter the equation form.

This problem has been touched upon by Ashor, who points out that the 'a' and 'b' values of the function have been found to be associated with the degree of pre-planning of production. He also points out that one of the vexing problems that faces those working with progress curves is to estimate curves for aircraft not yet built. (ii) Other writers, and particularly Andrews (iii), present in altogether too simple a view of this by insisting that the pattern of improvement is regular enough to be predictable.

It will be recalled that two major factors influence the shapes of the progress curves - labour and managerial learning. Of the latter, a number of things can be said: its influence, in building, is probably relatively small as compared to the effect of labour learning; its influence on the progress curve is proportional to the amount of pre-planning, and that its effect will be erratic owing to reduce the man hours per unit of output in a series of uncoordinated steps.

The nature of the managerial contribution is such as to affect the long run validity of the progress curve. A contractor engaged for the first time on a repetitive sequence will find it difficult in the pre-planning period to foresee all the problems and opportunities resulting from this form of organisation. As a result, many changes will be introduced during the production run. The effect of this will be to make the slope of the function greater than that to be expected on subsequent production runs - and indeed it may even affect the stability of the equation form. This results from the fact that in subsequent runs many of the influences incorporated within the first progress curve will now be taken over into the production planning period.

Consequently, a consistent and predictable relationship between man hours and volume cannot be expected until the managerial contribution to the learning curve has been absorbed into the pre-planning period. When this is achieved, the learning curve will then describe the labour learning element which can reasonably be assumed to show definintions.

(i) See for example the results of case studies, where manufacturers were encouraged to project a learning curve from the first few observations, in Memphis. This resulted in underestimation of the curve in a number of cases. Memoble, E.C. Manufacturing Cost Reduction...... Univ. of California.
(ii) Ashor, H. Ibid. p. 25.
(iii) Andrews, F.J. The Learning Curve as a Production Tool. A.B.B.
and consistent characteristics dependent upon the nature of the operation. This assumes that techniques of production remain constant, and that the same managerial solutions will apply from one production run to another (that is different constructs) which in the repetitive building of houses appears to be a reasonable assumption.

Thus, the relationship that Asher found between the \( t' \) and \( t'' \) values and the experience of the firm and the extent of preplanning can be explained in the above terms. As a result empirical derivations of the progress curve must be treated with caution, and what is required is research that attempts to seek out the existence of a stable and consistent relationship, with due regard to the firm's experience. (1)

Given that the above analysis is correct, and indeed from the relationship observed by Asher, then the benefits of the learning process are going to be summed in two terms: first a progressive lowering of the \( t' \) value at the start of a sequence of production, and second in the progress curve itself. To the extent that the first \( t' \) value does not exceed that of men hours input without repetitive organisation, then the sum of these two factors will represent the total benefits attributable to the learning process.

Repetition and Current Practice.

The conditions of work organisation necessary to achieve a learning effect are quite obvious, but nevertheless rarely met in building. They are, specialisation by operatives or particular operations, and long runs in the production of a homogeneous product.

A peculiar feature of the building industry is that specialisation is craft based, and far from meeting the requirements of the learning effect it distorts from it. This can be seen at two levels. First, within any one of the usual craft divisions there are numerous distinct operations that its members may be required to carry out. For example, in bricklaying, a mason is considered trained to erect brick and blockwork and to execute the plastering of walls. Second, even if specialisation is operation-based, some operations on a building site are so complex as to warrant sub-division; if a maximum learning effect is to be achieved. A good example of this is bricklaying in Europe, which is carried out by operatives trained in little else. But so complex is the wall structure of most buildings that considerable savings from the learning effect have been recorded following the breakdown of this operation into parts.

The basis of the learning effect is specialisation on a single job repeated over and over again, without interruption. However, a haphazard allocation of labour into the norm on the Beetham site, and it was a failure to break this practice that ruined the experiment. Specialisation beyond that enforced by a craft's training appears to be completely alien. The problems of planning work such that continuity could be maintained by each work gang were never tackled.

In addition, operational discontinuities must be avoided. The effect of the lack of efficient managerial control over the production process has received special study in the B.O.E. report. Where discontinuities arise, they are reflected in an upward kink in the progress curve, which represents wasted labour. The conditions to be met include an adequate and continuous supply of materials.
on site, maintenance of operation form, maintenance of gang composition, avoidance of breaks in a supply of services to the site, and so on. None of these conditions were on the Entebbe site.

Length of run is generally not determined by the building firm, and in fact the market displays features which militate against long runs. The most relevant of these in Uganda appears to be the failure of the public sector to co-ordinate and programme its building work. The experience of the U.C.E. in that housing is treated as a residual item, undertaken in bursts and with no co-ordination if surplus funds exist at the end of the financial year. This is further reflected in the lack of a housing programme, or policy, associated with the present five-year plan. Given these conditions, it is not surprising that building in Uganda contracts generally small and therefore length of run small. The cost of this lack of programming is only in part the opportunities foregone of cost reduction through repetition.

Clearly, there is considerable scope for the modification of the traditional building process, both with regard to the conditions for repetition and efficiency in general. With regard to the former, however, it is not well to remember that building differs from industry in general in several important respects. The required continuity and coordination of work gangs is more difficult to achieve in the building industry since the work is mobile and displays peculiar characteristics of their own; it is the operatives and not the work which must be made to flow, the sites display a primitive condition for work being subject to restricted movement and external influences.

The Economics of Repetition.

So far attention has been devoted to labour hours reduction, but the important variable in, of course, labour cost.

First something must be said about the likely slope of the progress curve. In theory, generally, an 80% curve can perhaps be taken as the norm. This would mean a reduction of the average labour input to 80% after nine repetitions. The U.C.E. has suggested that as a result of the factors discussed at the end of the last section, the norm in the building industry is likely to be somewhat lower. They have in fact found the slope, in a limited range of studies, to lie between 60% and 90%. In considering the situation in Uganda, there are a number of reasons for thinking that the likely improvement will be greater than this.

Levels of productivity in the industry in Uganda are generally recognized to be very low, and the degree of management is probably a contributory factor to this in that little or no control is exercised over the labour input. (i) The introduction of a repetitive system will, in itself, and through the multiplier effect, probably lead to quite significant advances in labour productivity. Furthermore, recent analysis of African labour productivity has switched attention away from the quality of the individual to the quality of management. While it is more significant is that two sources have cited the aptitude of African workers for repetitive work. (ii)

Cost savings can be grouped under two headings: first, decrease in operational costs due to the more efficient execution of the work, manifest in increased productivity, and second, indirect cost saving.

(1) This is a general impression, though quite accurate with regard to the U.C.E.
resulting from a reduction in construction time.

The influence of improved productivity on building costs depends primarily on the system of remuneration employed. If the hourly, or daily, system of payment is used, then any gain in productivity would be reflected in building costs. But under this system of payment there is no incentive for the operative to take advantage of their increased facility at the job and raise output. If a piece rate system is employed, then direct savings in labour costs will be small, while indirect savings are likely to be substantial.

With regard to the piece rate system, it may be argued that the indirect cost saving in Uganda is likely to be small since those costs will assume a smaller proportion of total costs than in Europe. To judge on this matter a cost break-down would be required, and it would be very interesting to know what the proportion of indirect costs to total costs is for an organisation like the N.H.C.

Between the hourly and piece rate systems there are incentive schemes where the effect on labour costs depends on the action between the incentive that has to be offered and a given increase in the level of productivity. In a European 'high wage' economy, it is likely that the incentive offered - viz. the target rate set, and the proportion of this rate paid to the operative - will be higher than required in a 'low wage' economy. This is based on the assumption that operatives judge the fruits of their extra efforts in terms of the proportional addition to the basic wage. (i) Assuming that a productivity system of incentive will operate as a full working day, then this system of incentives involves the replacement of that at present generally operated - a leisure incentive system. The greater the returns that can be earned from productive leisure time activities, the more incentive is likely to be required under this system.

But if leisure productive activities are so remunerative, then it should be possible to operate a leisure incentive system, with a progressive raising of the daily target rate, in accordance with the slope of the progress curve. Under this system, the benefits of repetition will be reflected in wage costs.

Thus there are grounds for thinking that the savings in labour costs arising from the introduction of a repetitive system of building will be greater than those recorded in Europe. But very little information exists on the effect on building costs. In Poole, 14% reduction in average costs per unit was recorded over a unit of lengthening the production run from 125 to 2250. In the Netherlands, a saving per unit of 20% resulted over the range 74 to 452, with another 3% if extended to 1,152. It would be rather interesting, however, if this information were given over the whole range of output, from unit one. (ii)

Conclusions.

This paper has attempted to introduce the basic ideas of the learning curve, its potential in a Ugandan situation, and some of the problems that its application would raise. As such it reads more like a research outline than the conclusion to a piece of research.

(i) Steps in the marginal tax rate will also affect this, again operating in Uganda's favour.

(ii) E.C.B. op.cit. p. 86.
An important problem area has been pointed to which does not seem to have received much attention in the literature—the predictability of the curve. The conclusion reached in this paper was that in a labour intensive operation a stable and consistent progress curve was not possible while important managerial innovations were being introduced during the production process—and thus empirical progress curves must be derived in relation to the circumstances of the firm. What the literature does do is to criticise the unqualified application of the 80% curve, based on one equation. This has been shown to be very hazardous when tested on progress curves derived for the building of various aircraft in the war period. Clearly, the shape of the curve will depend on the model and the firm. While in building model changes will not be important, it still leaves one factor unresolved. Thus, as summed up by Beloff, each needs to be known of this creature of empiricism. (1)

This said, however, some very impressive reductions in cost have been recorded as a result of the application of this idea. For this reason, and because of the situation confronting the industry in the future—outlined in the first few paragraphs, it would seem to be a worthwhile exercise to attempt to apply the idea here. In addition, while it is what might be described as a modern innovation, it fits into the structure placed upon industry by this type of economy. The repetitive process brings about increases in labour productivity with-put the injection of capital, though it is likely that the capital labour ratio per unit of output will rise, but as a consequence of a more efficient use of labour. In addition, to the extent that capital is better utilized under a repetitive system, a fall in the capital output ratio may be experienced.

The introduction of repetitive building requires changes on-site and in the organization of design. With regard to the latter, many changes are long overdue. Responsibility for housing requires to be centralised, and the total of this housing component fitted into a programmed housing policy over the plan period. At present sites are generally small, as that at Entebbe. This implication of this for cost saving from repetition are obvious, but what is perhaps as im-portant is that this form of building lumps the cost of providing basic services to the units. (ii)

Finally, the repetitive effect in the materials section of the industry should not be ignored. The merger of a large joiner/export is essential has culminated in the practice of designing buildings with a whole range of door sizes. This practice only serves to raise the cost of building with no advantages to the eventual occupier.

(i) Beloff, op. cit. p. 282.
(ii) Sue Donelson, A. Survey of Public Housing Development for Low Income Groups in the Region, for a discussion of these problems.
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