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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 existance 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 Entebbe. The contract at Entebbe 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 demonstrate the existance 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 man hours per operation, something which apparently is not standard practise.

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-

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(i) A general discussion of these matters is to be found in E.D.R.P. 94.

(ii) Of 13 replies to a question on bottlenecks to an expansion of building activity, 10 cited skilled manpower and supervisory staff.

Book Number

Classification

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 F.H.C. claims to have attempted to apply the method on an army barracks contract at Ibarara 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 E.C.E. (ii) In this paper, attention is devoted to 'on-site' repetition, or to quote the terms of reference of the E.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 alone 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. EDRP 109.
(ii) Cost, Repetition, Maintenance - Related Aspects of Building Prices. E.C.E. ST/ECE/HOU/7; Effect of Repetition on Building Operation and Processes On-Site. E.C.E. ST/ECE/HOU/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 Abramovitz.
(v) Dean, J. Managerical 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, in so 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 organisation 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 increases 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 existance 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 refered to between labour and volume of output. By repeating 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

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(i) Asher, H. Cost Quantity Relationships in the Airframe Industry. Rand. p. 86.

(ii) Pratten, C. et.al. Economics of Large Scale Production in British Industry. Cambridge. p. 14.

(iii) The only study of cost curves in building that I know of, was done by the B.R.S. 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.(i) 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 noteable 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 comment will become clear later in the paper, though strictly Baloff's remarks apply to a somewhat different situation that is being dealt with here.

The second aspect of the volume cost relationship is ommitted 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 diagramatic 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

$$Y = ax^B \qquad (1)$$

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

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(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 refered to as 'debugging', which is dealt with at length in Baloff,N. The Learning Curve. J.I.E. July 1966.
(ii) Baloff, N. ibid. p.276.
(iii) Bulk purchase discounts could be considered here.
(iv) Asher, H. 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. (i)

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

$$y = a\left(x_i^{1+b} - x_{i-1}^{1+b}\right) \qquad (2)$$

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

What is of particular interst, 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 the 'operation 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 familiarly 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 two 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:

$$S = \frac{Y_{2x}}{Y_x}$$
$$= 2^b$$
$$\log S = b \log 2$$
$$= 80\%$$

Thus on 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 slops - 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 manual effort and the less skill and technique required, the less the likely degree of improvement. This being so, 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,

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(i) For other equation forms used in building, see the E.C.E. 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 forsee these relative speeds in order to prevent man hours being wasted when a fast operation cannot proceed to its work station because a slow operation has not completed its task. In addition, a knowledge of the operation curves 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 Asher, who points out that the 'a' and 'b' values of the function have been found to be associated with the degree of preplanning 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 Andress (iii), present an altogether too simple 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 acting to reduce the man hours per unit of output in a series of unco-ordinated steps.

The nature of the management 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 forsee all the problems and opportunities r. 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 effect 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 preplanning period. When this is achieved, the learning curve will then describe the labour learning element which can reasonably be assumed to show definite

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(i) See for example the results of case studies, where manufacturers were encouraged to project a learning curve from the first few observations, in Keachie. This resulted in underestimation of the curve in a number of cases. Keachie,E.C. Manufacturing Cost Reduction..... Univ. of California.

(ii) Asher, H. ibid. p. 25.

(iii) Andress, F.J. The Learning Curve as a Production Tool. H.B.R.

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 contracts) which in the repetitive building of houses appears to be a reasonable assumption.

Thus, the relationship that Asher found between the 'a' and 'b' 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 existance of a stable and consistant relationship, with due regard to the firm's experience. (i)

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 forms: first a progressive lowering of the 'a' value at the start of a sequence of production, and second in the progress curve itself. To the extent that the first 'a' value does not exceed that of man 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 Practise.

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 on particular operations and long runs in the production of a homegeneous 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 detracts 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 East Africa, 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 warrent 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 was the norm on the Entebbe site, and it was a failute to break this practice that ruined the experiment. Specialisation beyond that enforced by a man'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 sufficient managerial control over the production process has received special study in the E.C.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

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(i) E.C.E. p. 20.

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 was met 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 seems to be the failure of the public sector to co-ordinate and programme its building work. The experience of the N.H.C. is that housing is treated as a residual item, undertaken in haste and with 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 condition, it is not surprising that building is haphazard, 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, thereis 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 as well to remember that building differs from industry in general in several important effects: The required continuity and co-ordination of work gangs is more difficult to achieve in the building industry; sites are mobile and display peculiar characteristics of their own; it is the operatives and not the work who must be made to'flow'; and sites display primitive conditions 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 is, of course, labour cost.

First something must be said about the likely slope of the progress curve. In industry generally, an 80% curve can perhaps be taken as the norm. This would mean a reduction of the average labour input to 50% after nine repetitions. The E.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 87 and 92%. 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 recognised 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 effects, 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. What 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, decreases in operational costs due to the more efficient execution of the work manifest in increased productivity, and second, indirect cost saving

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(i) This is a general impression, though quite accurate with regard to the N.H.C.

(ii) Kilby, P. African Labour Productivity Reconsidered. E.J. June, '61. Conclusions and Recommendations of the Uganda International Seminar on the Levels of Productivity.

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 operatives to take advantage of their increased facility at the job and raise output. If a piece rate system is employed, then direct saving 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 these costs will assume a smaller proportion of total costs than in Europe. To judge on this matter a cost breakdown 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 system there are incentive schemes where the effect on labour-costs depends on the ration 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 - via the target rate set, and the proportion of time saved 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 monetary system of incentive will operate on 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 set, 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 arisigg from the introduction of a repetitive system of building will be greater than those recorded in Europe. But very little information exists as to the effect on building costs. In Czechoslavakia, an 18% reduction in average costs per unit was recorded as a result of lengthening the production run from 125 to 2250. In the Netherlands, a saving per unit of 20% resulted over the range 74 to 432, with another 3% if extended to 1,152. It would be rather interesting, however, if this information were given over the whole range of putput, 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.E. 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 Baloff, much needs to be known of this creature of empiricism. (i)

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 Uganda as 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 strictures placed upon innovations by this type of economy. The repetitive process brings about increases in labour productivity without 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 utilised under a repetitive system, a fall in the capital output ration may be experienced.

The introduction of repetitive building requires changes on-site and in the organisation of demand. With regard to the latter, many changes are long overdue. Responsibility for housing requires to be centralised, and the total of this housing commitment 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 important is that this form of building inflates 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 manager of a large joiner works in Kampala has complained of the practice of designing buildings with a whole range of door sizes. This practice only serves to raise the cost of building with no advantage to the eventual occupier.

(i) Baloff. op. cit. p. 282.
(ii) See Danielson, L. Survey of Public Housing Development for Low Income Groups in the Region, for a discussion of these problems.

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