*Discussion on Paper No. 6829**

Economic analysis of engineering projects

by

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The Chairman (Mr J. E. G. Palmer) said that there were two points with which he did not altogether agree. In § 15 it was said that 'The high cost of capital means that large savings on invested capital are common.' It seemed that 'large *gross* savings' was implied later in the same paragraph. In Table 2, the following figures were shown, 'Demand as per cent of forecast, 100. Degree of confidence that demand will be equal to forecast, 50%.' Surely all economists had learned from bitter experience that it usually paid to underestimate future demand, so that when they were wrong everybody was happy, whereas if they overestimated future demand and were then wrong, they would, perhaps, be heavily criticized. Surely it should have read 'Demand as per cent of forecast, 100. Degree of confidence that it will be at least 80% of forecast, say, 150%. Degree of confidence that it will be 110% of forecast, say, 90%.'?

Mr J. D. Gwynn (Chief Civil Engineer, Balfour, Beatty & Co.) said that the Author's 'engineering analysis without tears' had useful applications in regular engineering procedures; in fact economic analysis could reduce and sometimes eliminate the engineering analysis. Everyone would be only too familiar with the necessity of making an estimate for the alternative possibility which would not be adopted as reliable, in addition to the one that would be adopted. The means of analysis outlined in the Paper sometimes enabled one to reject this alternative at an earlier stage.

93. An example of this had occurred within the Author's and his own experience when there was an apparent alternative between hydro-electric development and the discovery of natural gas. This at first sight looked quite a formidable problem and a lot of data had to be acquired. After an economic analysis the economists, who were called in to vet the engineers' work, and the engineers were able to reach agreement without further investigation.

94. The Author had also spoken of the difficulties of evaluating risks. They of course were real, but there was a distinct and quite large category of risk in engineering work which might appear as such to the client but ought not to appear so to an engineer as it ought to be forestalled; for example, Wandsworth Bridge was finished at about the same time as the outbreak of World War II but as a result of the war, had never until the present had a really adequate traffic flow. It had in fact, been underused for the past 25 years. It would have been possible to forestall that risk by constructing access roads at the same time as the bridge itself. There were plenty of other forestallable risks, and it was the duty of engineers to point them out to clients. It was not always enough for the engineer to adhere strictly to his terms of reference and report solely on the matter given to him. He ought sometimes to mention other things that ought or ought not to be done.

95. In thinking about the clients one had to advise from time to time, it was an interesting coincidence that recently the 'investment appraisal' document[11] had been issued by H.M.S.O. under the auspices of the National Economic Development Council (N.E.D.C.), and that the ground it covered was remarkably similar to that covered by the Author. One document was addressed to engineers whereas the other,

* *Proc. Instn civ. Engrs*, 1965, **30** (Jan.), 17–32.

presumably, was aimed at the businessman or the potential client whom the engineer was advising on how best to take his decision. The more one examined the two documents the closer this correlation between them appeared.

96. In the N.E.D.C. document, naturally, the full spectrum of investment was examined, and it could be seen that engineering, particularly civil engineering, lay right at the outer wing of investment, being the long-term type of investment, and it was to that extent non-typical; and one of the conclusions of the N.E.D.C. was that in this sort of operation, value tended to depreciate. But this was not true of a number of examples of typical civil engineering work. The Mersey Tunnel was a familiar example. Who could say that it was less valuable now than when it was commissioned in 1930 or thereabouts? It was carrying much more traffic than it did then. Who was to say, for example, that a hydro-electric power station, which initially had, say, four sets commissioned, and 20 years later had 12 sets, was less valuable today? It was obviously producing a bigger return some considerable time later than at its inception.

97. This rather important conclusion of the N.E.D.C. happened to be false for quite a number of civil engineering investments, and this ought to be borne in mind by engineers and looked at with particular care.

Mr D. J. Bolton (Consultant, Messrs Kennedy & Donkin) said that the Paper was very welcome because the subject was poorly understood by many engineers; it was also opportune, in that in the same week that the Paper was presented, the Government had produced a pamphlet dealing with the assessment of investments using some of the methods described by the Author.

99. The confusion was always made worse by changing terms, and this had happened in this case. For many years the term 'present value' or 'present worth' had been in common use, but then the American term 'cash flow' had been introduced and, apparently, an entirely new process had come into being called 'discounted cash flow'. The Author had accepted this Americanism and had spoken of the *two* different approaches to the problem in § 38. There was not, in Mr Bolton's view, any fundamental difference. The Author had arrived at the same formulae in § 42 and in § 50, so that mathematically they were the same.

100. There was only one fundamental formula in engineering economics, called capitalization, to convert an annual sum into one capitalized value. The same formula, transposed, converted the single sum into a series, and this process could be called annualizing. When the annual sums were equal the formula was fairly simple; it was the formula that the Author used in §§ 42 and 50. When the annual sums were unequal and the rate of return was unknown it might be necessary to use the method of trial and error and a certain amount of interpolation.

101. This fundamental formula had four variables. Considering the formula in § 42, there were four quantities, S, P, r and n, and it followed that if three of them were known the fourth could be found. On arriving at this point, the problem split definitely into two or more branches, according to the unknown variable. Two situations in particular could be distinguished. There was the situation when r was unknown and the situation when the 'cash flow' was unknown. These two situations were typical of the private enterprise or the company problem on the one hand, and the public enterprise problem on the other. The Author did not make a distinction there because he dealt entirely with private enterprise.

102. Taking these four quantities, the business man primarily wanted to know the value of r, the return he would get on a certain investment, in how many years, with how much cash flow, and so on. His decision whether to proceed or not would probably depend on this. The typical public enterprise situation was different because r was known; all the finance was at a fixed interest which was known in advance; therefore it was not necessary to know what the return would be and the interest to be paid was known, so that r was part of the data but not the answer. These were two distinct types of problem, and the Paper did not make this distinction.

103. It could be argued that the distinction was not as important as it really seemed, since the Government's pronouncements in recent years on financial objectives seemed to have shifted thinking on public enterprise nearer to the private enterprise approach; in other words, they have taken the problem away from the cost situation envisaged when the industries were nationalized, and moved it into the cost-plus area which was more familiar to the businessman. While this was true, the 'cost-plus' figure was still known. The 12½%, say, for electricity supply and the smaller figure for gas supply were known in advance. Therefore Mr Bolton still felt that the two problems were different. The particular problem with which the Author had dealt did not usually arise with public enterprise. It was not a matter of choice; it had to be done. If a factory or a housing estate was built it had to be provided with electricity; therefore the rate of return was not needed to decide whether the job should be carried out or not, but only what to charge for the job when it had been done. He differed from the Author here, because the Author's conclusion on the 12½% was that it amounted to a form of capital rationing. This was, of course, what it would be in the private enterprise situation. The businessman, if capital were short or if he had to earn a higher return, would shelve a particular project because of the high rate. The 12½% did not prevent the Electricity or Gas Boards from starting a new enterprise, as they had to keep pace with the load; it merely told them how much they must charge. He maintained, in effect, that the 12½% was only an artificial form of capital rationing in the private situation, not in the public. In the public situation the 12½% was in effect a target put up by the Government for the Area Boards, so that they could charge more than before, for how else could they earn a bigger return?

104. With regard to § 30, he had found this a tantalizingly brief statement. The problem the Author referred to there was very real, and further comment from the Author on this would be most useful.

105. At the end of § 16 the Author stated: 'The real cost of public investment then becomes loan interest, plus cost of risk, plus an allowance for easy investing.' The Author had, in effect, been saying earlier in the paragraph, that ordinary people found it easier to invest in public than in private enterprise and therefore they asked another ½% from private enterprise. Therefore, the Author suggested, ½% should be added to the public rate to find the real cost of the load. Mr Bolton did not believe this to be correct.

Mr Allen Sykes (Group Planning Department, Rio-Tinto Zinc Corporation Ltd) said that the Author had mentioned the fact that capital investment was very critical to Great Britain for two particular reasons. First, Britain was investing significantly less than her main competitors—something like 17% of the gross national product—compared to figures in the mid-twenties for Europe and in the case of Japan, 40%. Second, the quality of British investment left much to be desired. This situation warranted a critical examination at this particular area, and he was very glad to see engineers taking a serious interest in this subject and in the new techniques that were coming along.

107. One of the reasons why sophisticated methods of accounting had taken a long time to come into use in Great Britain was that, in dealing with investment, forecasts about the future were necessarily involved. The solution to this problem depended on applying a method to uncertain data and seeing whether a meaningful result could be achieved. A rational method had only to improve on the performance of the method it was replacing, and it could be shown beyond doubt that to apply rational methods to investment analysis gave results.

108. Mr Bolton had said that this particular method was not new and had been used by engineers for a long time. Mr Sykes thought this was true, in that engineers had certainly used compound interest and sinking fund formulae for at least a century, but what was new about this was its application to a wider sphere than before. He also thought that it was a new development to have realistic costs of capital.

109. He did not claim to have a detailed knowledge of engineering literature, but in regard to cost of capital or loan interest rates he had yet to see a comprehensive account of how to allow for inflation; very seldom had he seen tax allowances taken into account, and certainly in the private sector this was of tremendous importance. Turning to the public sector, and taking tax rates as being roughly 50%, if one were looking for a 6% return gross of tax, that would be something like 3% net of tax. Inflation had been between 3% and 4% nearly every year since the war, so the net of both tax and inflation would give a return between zero and 1%. These had been the standards sought by the nationalized industries for 15 years after the war. They had been changed in 1961 but one had to be careful in considering target rates of return like 12%. This happened to include the sinking fund element for depreciation. Eliminating this factor the figure came down to 7–8%, and taking away inflation it was down to 5%; in other words, the targets given to nationalized industries were by no means comparable targets required in the private sector. Finally there was still a tremendous gap in applying these methods to the average business decision. Maybe civil engineers had been applying these methods to the building of bridges and roads all the time but in business, despite the publicity given to these methods, it was very rare for anything like these sophisticated methods to be applied to the typical investment project. In the typical investment project the net cash flow (the cash benefit derived from doing something) was in his experience anything but constant from year to year, particularly when account was taken of growing output and the incidence of tax allowances, etc.

110. The final point he wished to make was that this new approach to capital budgeting gave tremendous scope to something which was very much neglected in Great Britain—the optimization of capital projects. Too often in the typical capital project put up, an estimate was made and a project recommended. It was very seldom that the variety of ways of carrying out a project and, just as important, the variety of times of commencing new projects were considered. Many an investment which would make a profit this year would be much better if deferred for three years There was tremendous scope for looking at the different ways in which capital projects could be optimized and this was certainly being neglected by most accountants.

Mr B. D. Cullen (Head of Economics Section, Building Research Station) said that he wished to comment briefly on this Paper because at the Building Research Station they had been concerned with the evaluation of alternative investment projects and with publicizing the available techniques. They had had to recognize that the various techniques available for project evaluation were not just more or less efficient ways of getting to the same answer—in some circumstances they did in fact lead to quite different answers.

112. Fig. 1 showed how alternative projects would be subject to a quite different decision if two different methods of assessment were used. One of the methods considered was discounted cash flow, as described by the Author, and the other was what might be called the 'present value index'. The projects under consideration were different ways of spending £4000 initially and getting back a return increasing linearly with time, and averaging £1000 per year. In one case (A in Fig. 1) this average benefit of £1000 per year was received over ten years and in the other case (B) over 40 years. Looking at alternative A, the capitalized net benefit equalled the capital cost at a rate of interest of probably about 17%. This was the discounted cash flow rate of return. On the other hand, the discounted cash flow rate of return for B was about 11%, so that on this criterion project A would be chosen.

113. Looking at the present value assessment of the same project, future payments were capitalized at 5%; on the diagram the dotted line parallel to the horizontal axis indicated the two projects capitalized at 5%. The choice now depended on which of the two offered the greater ratio of benefit to capital cost. Clearly, the 40 year project would be the better choice on this basis, and the choice was therefore different using the two different decision systems.

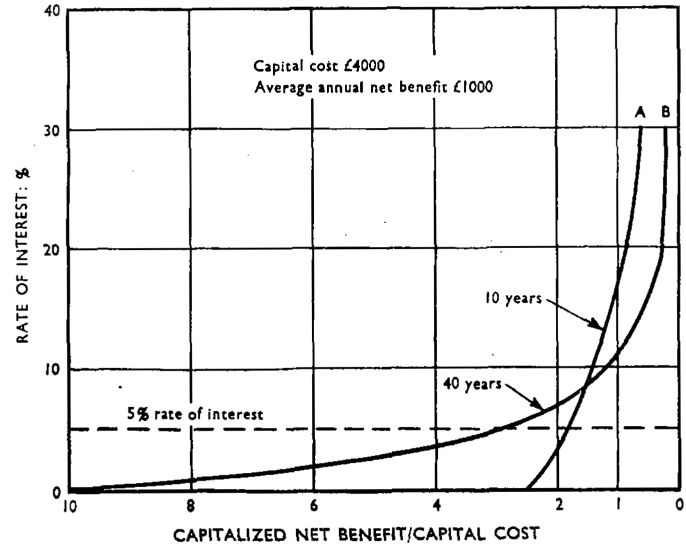

FIG. 1

114. He had quoted this only as an example to show up the possibility of divergence between discounted cash flow and present value decision criteria. In fact, the extensive literature on these matters seemed to lead to the general consensus that the internal rate of return and the present value index frequently gave the same rankings to investment alternatives but that they would only do so invariably if certain very rigorous assumptions were true—namely, that capital markets were perfectly competitive, that investment projects were completely divisible, and that there were no interdependencies between the projects. If these assumptions were not true then the choice of investment decision technique depended on what one was trying to maximize and what were the constraints affecting one's solution to the problem.

115. The technique used at B.R.S. was the present value index, primarily because they felt that this was the most correct criterion to use when public investment policies were in question. Discounted cash flow might well be the correct criterion for the private investor, who was concerned simply, in the words of Ralph Turvey, 'to plough back all surpluses and emerge at the end of the economic horizon with as large a stock of assets as possible'. Present value, which involved the use of a discount rate representing the subjective relative evaluation of current and postponed returns and costs, seemed more appropriate to the public investment decision. At B.R.S. they had used an interest rate of 5%, representing what appeared to be the long-term interst rate which expressed the community's general preparedness to wait for future money on good security. They had ignored inflation which in itself could never affect these problems, except in requiring an adjustment of budgetary policy. What mattered, of course, was not the general rise in costs and prices but their differential movement, and an attempt should certainly be made to predict substantial relative movements.

116. The following tables, both of which related to the economics of factory construction, gave some idea of the way in which they had attempted an optimization decision with what they called 'costs in use' techniques, using the annual equivalent version of the present value index dealt with by Mr Armstrong.

TABLE 3: COMPARATIVE AVERAGE ANNUAL EQUIVALENT COST OF ACQUIRING AN INDUSTRIAL BUILDING

Item	Method of Financing Building			
	£100 000 available from business. Rate of return 15% (£20 000 qualifying as plant for tax purposes)	£100 000 borrowed at 6% (£20 000 qualifying as plant for tax purposes)	Rented for £9000 annually, with initial expenditure on building of £10 000 borrowed at 6%	Rented for £3000 annually, with initial expenditure on building of £10 000 borrowed at 6%
	£	£	£	£
Net cost of forfeiting opportunity for investing £100 000 in the business	8425	—	—	—
Net cost of interest and repayment of loan . .	—	3215	322	322
Rent	—	—	9000	3000
Less annual equivalent tax savings:—				
(*a*) from allowances on capital expenditure	1919*	1967†	162†	162†
(*b*) from relief on rent .	—	—	4838	1613
Net cost	6506	1248	4322	1547

* 15% rate of interest used for obtaining annual equivalents.
† 6% rate of interest used for obtaining annual equivalents.

Notes and assumptions

Taxation: Income Tax at 7*s*. 9*d*. in £; Profits Tax at 15% (3*s*. in £). Except where tax is deducted from payments at source a delay occurs before tax becomes payable, hence the effective rate of tax is reduced. In these cases income tax has been discounted for 1¾ years and profits tax for ¾ year (*vide* Figs 1–4). It has been assumed that rent (lease of 60 years) and interest payments would be subject to deduction of tax at source, and in this case the rate of tax was not discounted.

Repayment of capital: Arranged in the form of equal annual payments of capital plus interest. Tax relief on the declining annual interest payments has been calculated appropriately.

Capital allowances:

	Investment	Initial	Annual
on Building . . .	15%	5%	2%
on Plant	30%	10%	15% Actual (Basic rate 12%)

Life of building taken as 60 years.

Where the building is rented it has been assumed that the tenant is responsible for repairs and renewals. Such expenditure, therefore, would be common to all the alternatives and no allowance is made for it in the calculations.

TABLE 4: COMPARISON OF PREDICTED ANNUAL 'COSTS IN USE' OF VARIOUS TYPES OF WALLS

General specification: Steel frame single storey building: column grid $33\frac{1}{3}$ ft × 40 ft constructed to receive a lightweight roof: glazing 4 ft high in 200 ft long walls from a height of 3 ft: plan area of factory 20 000 sq. ft.

Building element	Type of wall cladding									
	(1) Corrugated asbestos cement sheets		(2)		(3)		(4) 11 in. cavity brickwork		(5) 11 in. cavity brickwork with corrugated asbestos cement sheets and insulated plasterboard above glazing	
	No internal lining		Internal lining of $\frac{3}{8}$ in. plasterboard		Internal lining of $\frac{3}{8}$ in. insulated plasterboard					
	Initial cost	Maintenance cost	Initial cost	Maintenance cost	Initial cost	Maintenance cost	Initial cost	Maintenance cost	Initial cost	Maintenance cost
Foundations	11	—	11	—	11	—	29	—	29	—
External cladding	26	7	25	7	26	7	102	1	66	4
External cladding support	39	—	39	—	39	—	—	—	19	—
External cladding support protection	1	3	neg	—	neg	—	—	—	neg	—
Structure protection	1	3	neg	2	neg	2	neg	2	neg	2
Internal cladding	—	—	4	—	4	—	—	—	2	—
Internal cladding support	—	—	13	1	14	1	—	—	6	neg
Lateral finish	—	—	7	19	7	19	7	19	7	19
Lintol	—	—	—	—	—	—	30	—	—	—
Sub-total	78	13	100	29	101	29	168	22	129	25
Heating	91 431		129 222		130 139		190 112		154 123	
Total	522		351		269		302		277	
Extra over common brickwork for facings	—		—		—		44		30	

Notes: Heating based on calculated heat loss through fabric at 2*s*. per therm inclusive of initial costs and maintenance, for 55 000 degree hours. *Initial cost.* Annual 'cost in use' based on 60 years of life of factory; interest rate 5%. *Maintenance cost* including decoration of walls. All common elements have been omitted.

117. Table 3 dealt with the early planning stage of building and showed the result of adopting four different policies for financing the construction of a factory building. In the first case, funds available within the business were used to pay for construction, and in the second case, borrowed money was used; in the third case the factory was not constructed specifically for the project, but was rented from another party, and in the last case it was also rented but at a lower figure. He quoted the example to show how some important variables had been taken into account. For example, the first policy involved the loss of interest on money removed from the business in order to be used for building. The business was assumed to earn on average a 15% return on capital employed, and Table 3 indicated an allowance for this loss. Such an allowance was inappropriate, of course, where the money had been borrowed (Method 2), but here interest had to be paid though at the much lower rate which would apply to a fairly sound and resaleable investment such as a general-purpose factory building would be.

118. They had also tried to take into account the effect of tax allowances, and in the paper from which this example was taken* there were some fairly detailed nomograms for dealing with the effect of tax allowance.

119. A more detailed example of design costing was shown in Table 4 where a comparison of the costs of various claddings for the walls of a factory building were given. Three alternative types of corrugated asbestos cement cladding were compared with brickwork, and with a design which used both brickwork and asbestos cement. The results showed that the initial costs of the brickwork design were high compared with all the other alterntives, but that the maintenance costs were quite low, though not so low as the unlined asbestos cement. The running costs of the brickwork cladding in terms of heating were very low indeed; so that the total cost of the brickwork cladding was substantially lower than the unlined asbestos cement lined with insulated plasterboard. The comparison of course left room for argument about what one should do, on the basis of, for example, margins of error in the estimates, subjective appraisals of the appearance of the designs, and so on.

120. The examples quoted served to show that they had looked at a wide range of planning and design decisions and had found that it was possible to say something useful about them on the basis of the 'costs in use' technique, using the present value index.

Mr B. Fine (Building Research Station) said that so far most speakers had spoken about how to calculate the rate of return on an investment. In the past he had always considered the inverse problem—given that the organization got a certain rate of return on an investment, how did the engineering achieve this particular rate of return? This was the real function of the engineer.

122. For example, the optimum design for a pipe line with a pump station, with a very low rate of return on the investment, would be a very large diameter pipe with a very small pump, because the accumulated power costs over many years could represent a very large part of the value of the project. If one had a very high rate of return on investment, the optimum design gave one a very small pipe with a very large pump, because the power costs, when looked at now, and discounted by 20% per annum, would be negligible. So that the engineer, when faced with an organization which generally produced a certain rate of return, was faced with the problem of optimization in a complex field.

123. In a typical chemical plant, for example, it was not so very long ago when the fluid velocities based on optimum pipe designs were between 3 and 5 ft/s. In similar plants today, because the rate of return was now expected to be between 30 and 40% per annum, the fluid velocities should be on an optimum basis between 20 and 50 ft/s.

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* Building Research Station Current Papers, Design Series 5, 'Factory Building, Evaluation and Decision', P. A. Stone, Ph.D., M.Sc.

This was an enormous difference in engineering, and the criteria with which they had been trained were not adequate for making simple engineering judgments in the way in which they always used to make them. Any discounted method tended to produce the sort of situation in which one was willing to trade future costs against present capital. The tendency was always to produce something 'cheap and nasty' because future maintenance costs and running costs had to be discounted. He did not want to argue about the merits or demerits of producing this but he would indicate one other situation where engineers might have come to a different conclusion had they been given different terms of reference by their accountants. The power station programme in Great Britain had regularly improved the thermal performance of the stations, yet the financial situation was that if they had built cheaper power stations which were ten years out of date, without teething problems, and without extra capital cost, they would have made more money on power generation.

124. Accountants had often been blamed for being opposed to technical innovation. Looking at this sort of sum one wondered whether perhaps they were justified. He agreed with some of the earlier speakers that accountants did not generally use discounted cash flow techniques or any of these modern techniques. Perhaps this was because they were not pushed into that sort of corner by engineers.

Mr J. D. Storey (R. T. James & Partners) said that he would like to mention some points of detail arising from § 38 on the methods of analysis, principally because he thought this Paper would probably be referred as a supplement to the Institution's pamphlet on engineering economics. He thought that the Author's analysis of making the distinction between two methods was rather confusing; he preferred three: (1) net present value, (2) yield, (3) annual capital charge. Both (1) and (2) were discounted cash flow methods. They all, if properly applied, gave the right answer, and they were all related, as Mr Bolton had suggested, but he disagreed with him that the actual equations were the same.

126. To clarify the situation, the net present value method, Mr Storey thought, was the method where one took the cost of capital and discounted all the cash flows to a certain time, usually the present, and got a certain sum of money. The second method, the yield method, was where one ascertained the rate of interest or the compound interest which reduced the present value to zero; and as Mr Bolton had suggested these two methods were similar in so far as one was trying to find a different term in the same equation. The third method was the annual capital charge, which distinguished between the depreciation charge of the capital and was completely different; and, as Mr Sykes had pointed out, it relied on regular cash flows during the term of the project.

127. In these days of high taxation allowances this was very unlikely to be so. Usually a large engineering project had a phased construction over several years, probably three. In the first year there would be a small cash outflow, the second a large one, and the third a smaller one, and then it would start earning revenue, and then, according to the accounting methods of the company, the investment allowances would probably be 18 months to two years behind, since they were at the beginning of the project they had a tremendous effect on the final result given by the analysis.

128. Of the three methods he favoured either the first or second, both D.F.C. methods. He was very much against the annual capital charge. He thought the reason engineers were so often thrust into this was that they were asked for the depreciation of their project. It was wrong, in his opinion, to treat this from the point of view of an accountant. What engineers were concerned with was assessing a project. They were not really concerned with what the profit and loss account of the company was at the end of the year, and this was what depreciation was concerned with; the depreciation charge was really only required for the assessment of the profit and loss account, in order that taxation could be calculated.

129. Referring to the booklet just issued by N.E.D.C.,[11] he understood that

one of the reasons behind it was the fact that businessmen had not been using these improved methods of analysis and had been neglecting, or not taking into proper account, the effect of investment allowances, and this was why the discounted cash flows were so superior.

130. In relation to his attack on depreciation charges he wished to quote a short paragraph from an article which appeared in a reliable Sunday newspaper at the beginning of 1965 concerned with the new Cunarder. It asked, 'Will the Q4 pay her way?' and the writer stated, 'Since the *France* appeared the average occupancy of the Queens has dropped to 65%. Only their venerable age, which means that they are free of depreciation charges, has allowed the monarchs to make any money at all.' Did the writer mean that if the Queens were a bit younger they would not make money? Surely he was completely wrong? This was typical of the way of thinking of the accountant.

Dr M. E. Beesley (London School of Economics) said that he would like to stress where the public investment analysis would basically differ from that in the Paper. His conclusion was that the implied differences were rather reversed in the Paper compared with the practical problem he faced in the public investment field.

132. Basically the model put up in this Paper was a sort of cost minimization to given demands. There had not been much discussion of estimating demand but this was appropriate for a private firm where there would not be much variance, presumably, in the prices at which it was possible to sell its products. The revenue side was far less complicated than in the public investment field.

133. In assessing a project like the Victoria Line, all the headaches were concerned with the revenue (or 'benefit') side, and, indeed, the distinction between the social and private benefits of the investments arose there, so that all the research effort was put into getting better estimates of such things as time-saving—how to value time in different situations—and so on, the sort of thing which basically did not trouble the Author of this Paper.

134. On the other ('cost') side, he had noticed some false differences between public and private investment. When considering the cost in the public sector he did not think it was true to say (§ 16) 'Public investment is partly free and partly from a risk-subsidized free market.' He believed that the basic problems of the opportunity cost of the investment going into the project—which was really what was being discussed here—were in principle very similar in the public and private sectors. One had to decide exactly what was being sacrificed in order to invest, and this was a very difficult problem. In the Government sector one could perhaps ask, 'What is the particular cost of these funds if applied to railways, or to railways and roads, against health, and so on?' And these problems no doubt had their analogues in private investment. In other words, he was arguing that it was the benefit side which was different when one came to public investment. The cost side had to be treated in more or less the same way. There was no such thing as partly free public investment, or, if there were, it was an indication that society was wasting its capital.

135. He also wished to make two or three minor comments on other parts of the Paper. There was a very interesting discussion of risk (including Table 1). In assessing the prospects of an investment, one had to be clear that the prospect of a return of, say, 9% with 100% probability was not, in general, the same as a return of 100%, with 9% probability. These were clearly not equivalents. If one took the line of weighting expected returns by their expected probabilities, one would need to specify the degree of risk aversion or risk preference of the persons who were making the decision which would enable one to reduce the whole thing to what were called 'certainty equivalents'. A company with a strong cash position for example, might view the prospects as equally acceptable. A company which needed a considerable inflow of cash to keep alive, might well reject the first prospect in favour of the second. In other words, one had to have some kind of risk function at the back of this to

convert these things into equal prospects. This approach was basically the only possible one to take.

136. In § 18 the Author said, 'In dealing with question (x), if risk could be evaluated, it would no longer exist.' The little disquisition he had been giving would tend to argue against that. The point about this was the distinction which economists always made between risk which could be calculated in advance, so that one could define one's position in relation to it by various risk functions, and uncertainty, which in the economist's jargon meant having no basic means with which to set up a probability distribution. In those circumstances, of course, it was true to say, in a sense (re-writing this), '. . . if uncertainty could be evaluated then uncertainty would no longer exist'. It would be turned into a risk. But, in fact, it was very important indeed when one came to compute actual prospects, because some parts of it could be done by turning into risk situations and some of it could not.

137. With regard to § 66, dealing with inflation, he might have misunderstood the Author but it seemed to him that, if the Author increased his return through inflation, and implicitly decreased the acceptable internal rate of return, he would be in great difficulty when he came to renew his assets. In other words, if he really thought of having to renew these assets at inflated prices later on, he would not wish simply to distinguish an inflationary effect on the revenue side. The point about inflation was only important if one had reason to suppose that either some of the revenue terms or some of the cost terms were liable to be inflated at different rates: in other words, that there was a real price change going on. If there was, one would need to take account of this specifically in what one intended to do. If one had to renew later on, then the fact of having inflated revenue was fortunate, but it would all be swallowed up in the renewal. It might not if different price rises applied on each side of the equation.

138. To add a footnote to the question of the internal rate of return, normally this was, admittedly, one version of the discounted cash flow method. The reason why economists had tended to reject this in favour of more straightforward discounted benefits minus discounted costs was simply that it could give ambiguous answers in certain types of investment. Depending on how the positive and negative terms were distributed for revenues and costs over the prospective life of the project, pursuing an internal rate of return it was possible to get a result where, in solving the problem, a rate of return of both 2% and 4% were the answer, in other words, there might be more than one root to the equation. This was why, basically, economists tended to reject this, but in doing so they were only really saying that if one's investments were likely to run into the twin root problem, one had better not use an internal rate of return; but if they typically had time profiles of revenues and costs not running into this difficulty, then one could by all means use it if one wished to.

Mr W. D. C. Murray (Balfour, Beatty & Co., Ltd) said that the point he wished to make concerned allowance for inflation. The Author had allowed for it in § 84 when, having derived the rate of return of 2·9%, he had then increased it by 2% to allow for inflation. As Mr Murray understood it, the 2·9% represented the interest at which one must invest the £96 120 difference in outlay in order to return the cost of running the cheaper of the two schemes. One then decided which scheme was more attractive by saying, 'Since I can invest this capital at more than 2·9% then it will pay for the running of the cheaper scheme; but adding the 2% for inflation makes the cheaper scheme uneconomic because it puts up the 2·9% to 4·9%, which is more than the 3% that the capital will generate.'

140. This reasoning seemed to be valid only when thinking of an alternative investment which returned interest with no capital appreciation. In an investment such as this scheme the value of the real things measured in cash increased. It appeared unreasonable to assume that the alternative investment, the 3%, was necessarily going to have no capital appreciation; and if the alternative investment was of the same type as the scheme itself, one should make no separate allowance for inflation.

The present value was simply a measure of real things in terms of money. It did not matter what the value of the pound would be in the future. All one was concerned with was the value now.

141. On this ground he doubted whether inflation could properly be added as a percentage to the rate of return in making a choice between schemes.

Mr B. Rydz (Messrs Binnie & Partners) said that an anomaly was often apparent when the cost of a job (for instance, an industrial water supply development) could be met either with public or private capital. If the latter, an apparent return of, say, 10% on capital invested might be quite insufficient to justify that use of available capital and a heavy annual expenditure might well be preferred. However, if the same work could be carried out by a statutory water undertaking then its comparatively modest capital charges were easily recovered out of revenue, from water charges perfectly acceptable to the industrialist. For the community as a whole an investment could hardly be sound if undertaken by one body and unsound if undertaken by another.

Dr M. E. Beesley (London School of Economics), referring to the remarks of the previous speaker, said that it could not be denied that there were different themes which might enter into the accounts, and that it might be much more economic for the public to undertake to do something than a private body, and *vice versa*, but the same conceptual problems arose in both cases.

Mr B. Wood (Messrs Merz & McLellan, Esher) thought it was surprising that nobody so far had mentioned life, and that it had been possible to discuss investment at all without deciding what was to be the notional life.

145. Mr Bolton and he had been brought up in the same sort of school and had been using 'discounted cash flow' all their lives without knowing the name of it. Nevertheless, this new interest in D.C.F. had taught them one thing. If one were working for an industrialist who wanted a very big return one found that assumed life hardly mattered because, with a very big yield, profit to come fifteen years hence was worth almost nothing to him. This feature of D.C.F. was very valuable because it made the fixing of a notional life no longer important.

146. With regard to risk, it seemed quite ridiculous to suggest that the risk to a private undertaking did not exist—bankruptcy is still real. On the other hand the risk to the sort of monopoly industry now nationalized in England was negligible, broadly all its investment was safe and the new doctrine that nationalized industry should make a profit was in flat contradiction to all legislation on which monopoly industry had been based for the last 60 years.

147. With regard to inflation, it had been laid down a long time ago that one must discuss what one could do at the time. It was not any use taking a backward look at it and saying that it would have been far better to have spent a lot more money in 1914. Everyone knew it would (except in those ventures which have gone bankrupt and hence one no longer sees). In the 1930's the French electricity supply undertakings were enormously profitable. The simple explanation was that the franc had been inflated to the point where the assets at original cost stood at nothing. Similarly, though in lesser degree, Loch Rannoch station, commissioned 1930 (now nationalized), was still producing energy at a profit which must now be extraordinarily augmented on the 1930 price base.

148. With regard to tax, there again D.C.F. seemed to have brought in something that the accountants apparently thought engineers omitted in their ignorance. In fact this was not an omission, competent engineers knew from other calculations that tax did not matter much. This was true when dealing with nationalized undertakings or public utilities. In England for many years engineers had compared tenders and alternative schemes by orthodox engineering accountancy. The sinking

fund method ordinarily ignored tax both on the earnings of the fund and the main business. This was justified by the side calculation which showed that had tax been taken into account it would have made little difference. Curiously, the same was true of D.C.F. at least on high yields. In fact tax allowances were so generous that very often tax made little or no difference to the return, at least on the short life basis favoured by industrialists. This was perhaps the aim of the Government pamphlet—to show that people should not think that tax was a crippling thing.

149. Finally, engineers were not always just working with two alternatives such as trying to justify spending extra money against a cheaper scheme. Sometimes they might have 10 or 12 tenders or alternatives to compare. They really could not face the complication of using D.C.F. but had to use their old capitalizing of loss process as being the only method which was tractable. Again a D.C.F. side calculation might be made between the two best to show that it would result in the same selection of best alternative.

The Chairman (Mr J. E. G. Palmer) said that his firm had prepared the capital cost estimates for a large harbour development scheme and these were sent in to a newly-created Government body whose job it was to vet all such schemes. They were sent in on figures produced in about July 1965. This scheme had now passed successfully through that particular net and the whole project had taken the next step forward and gone to the Government Departments concerned. In this particular case the benefits were related to demands estimated for the years 1970–1975, so that he did not think he could say that the demand figures ought to be varied, because he imagined that the estimate of demand in 1970 and 1975 would be the same now as last July; but he was sure that his capital estimates ought to be revised. What would be the right thing to do?

The following contributions were received in writing:

Mr R. A. Spottiswoode (Traffic Engineer, Staffordshire County Council) said that the Author had dealt in his excellent Paper with criteria for the economic viability of engineering projects. However, he believed firstly that it was important that it should be clear when it was appropriate to make allowance for the effects of inflation in the calculations and, secondly, that investment criteria for public undertakings must go beyond conventional money accounting and should allow for social benefits in so far as they could be reduced to money terms (as they ought to be if they were to be compared objectively with money costs and returns).

152. With regard to inflation, Mr Spottiswoode suggested that it was correct to allow for its effects when this inflation affected the cash flows accruing to the project, but did not affect the cost of servicing and amortizing the capital. This would be the case where capital was raised at a fixed rate of interest and was repayable on predetermined terms. In most cases, however, capital for private investment was likely to be raised from a source of 'risk' capital, such as the internal savings of a company. In this case the expectation of cash flows would be in 'real' (price adjusted) terms. The proprietors or shareholders expected all their assets to keep their real value irrespective of inflation. In such cases he suggested that it was not appropriate to allow for inflation when making an economic assessment.

153. While it was only reasonable to expect that the assessment of private investment would be in terms of the returns to the investors themselves, this approach could not be appropriate for most public investments. It was here that the cash flow should be assessed in terms of the costs and benefits of the community as a whole. The cash value to be assigned to non-cash benefits could be controversial (how should one, for instance, value savings in travel time outside working hours?) so that decisions on priorities for public investment were often, and inevitably, less objectively assessed than similar decisions for private investment. This was not to deny the need for such assessments, of the type now regularly made for new road projects, but to suggest

that we must guard against the danger of undertaking a too-refined and expensive analysis when our basic assumptions of the values of costs and benefits might be far from accurate. The important thing to keep in mind seemed to be that we should use the same sets of assumptions and values when making assessments to indicate the priority of competing projects in the same field (or would the Author suggest that we could indicate priorities between a hospital, a school, and a road on an economic basis ?).

154. The economic analysis of road projects seemed to run into difficulty when this was attempted on the discounted cash flow method because the benefits from schemes tended to increase faster than they were discounted. The greatest discounted benefits accrued at the end of the life of the works just when conditions were most uncertain. The most important assumption in the analysis hinged on the date when a new road would itself become obsolete: this was anybody's guess and could not be expected to be accurate. In most cases the project would have to be carried out sometime and should, it seemed, be programmed for the year in which the social return on the capital (for that year alone) exceeded that of any other alternative works not programmed for earlier completion. Could the Author express an opinion as to whether he thought that D.C.F. was the right approach under these circumstances ?

Mr G. A. Booker (Senior Engineer, Sheffield Corporation Waterworks) congratulated Mr Armstrong on his contribution to what had been a relatively neglected subject by civil engineers, particularly when considering that a high proportion of public and industrial investment of necessity brought about works of a civil engineering nature.

156. He felt, however, that the Author had not emphasized sufficiently the need to differentiate between public and industrial investment. In recent years only about one quarter of the total investment in Great Britain had taken place in industry, and increasing investment in the industrial sector of the economy had been suggested as a means of accelerating development, since only industry was contributing directly to the gross national product. However, the provision of capital for other purposes was as essential in the long run as industrial investment, for industry could not function without the provision of power, roads, houses, and education. It was characteristic of investment in all countries, and over all periods that the infra structure of the economy made the heaviest demand on investment.

157. The basic difference between industrial and public investment analysis was social benefit. Conventional techniques such as D.C.F. could be used to aid investment decisions with a high degree of success in the industrial sector, and to some extent in the quasi-commercial areas of public activity. However, the responsibility of central and local government was wider than selecting projects on the basis of their ability to cover costs with receipts and earn a surplus. It was to select projects in a way that provided the greatest possible net benefit to society, and selecting projects by applying only commercial criteria that would lead to selections which were less than optimal on cost–benefit criteria.

158. In the industrial field, economic considerations might have to be over-ridden by technical progress and the discovery of new processes and products, and indeed, the investment decision could be said to be primarily influenced by innovation. Careful planning on spread of investment by project timing techniques might be reduced to so much wasted effort due to unforeseen innovation.

159. Project timing if correctly employed would, on a large scale, reap large saving. In development of water supply resources, for instance, over-development or overlapping of development was as much a result of bad planning as under-development which might require consumption to be artificially restricted to supply. Project timing in this field on a local level would bring about 'staging' of investment programmes, which should take into account estimation of the risks involved in planned delaying of investment until the last possible time. At national level there was a duty

to ensure an evening out of investment on a time scale to eliminate booms, with large over capacity between them. The fact that water resources were indivisible meant that they should be efficiently distributed, which fact was a built-in incentive to the growth of distributing undertakings.

160. Once the initial decision had been made to invest to some particular end, economic analysis would revolve around the choice of one of a number of alternative projects achieving that end, which might be an extremely complex operation. This involved investigating the projects as thoroughly as though each one was going to become the selected project and the point made by Mr Armstrong in § 31 was an important one. It was most essential that the engineer should be able to approach an analysis without bias.

161. Mr Booker felt that no economic analysis could be commenced without an appreciation of the concepts of value engineering and planned obsolescence, which might tend to favour one project or immediately eliminate others. These two methods of elimination of unnecessary costs had been relatively widely employed in the United States, and must be allowed to gain recognition in Great Britain, and he thought Mr Armstrong might wish to comment upon the use of these techniques.

162. To compare alternatives completely, a critical path investigation of each project should be employed, in at least outline form. This would allow project costs to be compared by including resource restraints on a fairly elementary level. Obviously, at a later date, full PERT time and PERT cost analysis would be necessary for minimum cost expediting, and these techniques should be regarded as essential on all major programmes. The cost of major construction projects was so high that any shortening of the construction time, and the delaying of the start time to fit in with the latest possible commissioning date, would reap high savings in the form of interest payments.

163. Mr Armstrong outlined the complexities of evaluation and comparison of alternative projects but, in the example given in Appendix 1, simplified the process in order to accentuate the actual D.C.F. calculation. However, Mr Booker contended that comparison of alternatives should be on the basis of either equal investment, when finance for the project had been generated internally, or the cost of long or medium term capital calculated on a sinking fund basis, when finance had to be raised externally. In the case of equal investment, the difference between the highest and lower initial capital costs should be regarded as capital invested to yield a nominal cumulative return.

164. In recent years industry in Great Britain had provided between 50% and 60% of the finance needed for its investment programmes out of retained profits. However, as stated previously, industrial investment had represented only about one quarter of the total investment, thus seven eighths of this total had been provided from capital raised publicly.

165. The effect of the treatment described above on the example given would be to delay the break-even point of Route 1 over Route 2. Break-even analysis was important when risks could not be assessed very far into the future, and also in considering the type of loan terms to offer.

166. A policy of investing in any project which had high risk attachment before the break-even point would need careful consideration. Failure would mean that successive investments would have to contribute to amortization of the investment in the high risk project.

167. Fig. 2 indicated the recovery of total investment in one project, and the break-even point for this project was indicated. A single concern would have a series of successive investment projects contributing to the growth of the concern, and a continuous graphical representation of this type would enable a long term capital investment programme to be formulated.

168. It was sound judgement of the imponderables which allowed a good manager to make a high proportion of the correct decisions, and planned economic analysis,

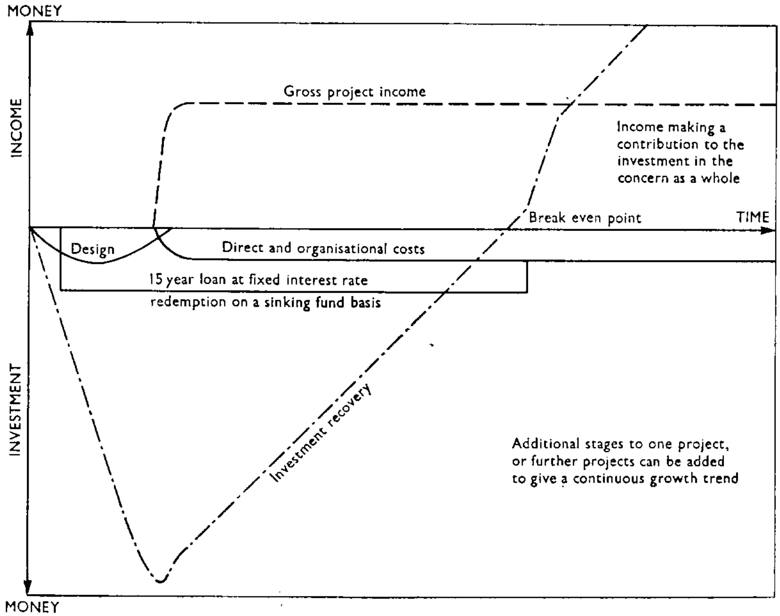

FIG. 2

intelligently applied in relation to other areas of managerial responsibility, would reduce the number of dependent variables, and form a sound base for other techniques of management.

Mr D. P. Griffiths (Design Section Engineer, Heavy Organic Chemicals Division, I.C.I., Ltd) wrote that he was glad to see the Author advocating the use of the discounted cash flow method of economic analysis. However, in its original form this method was used to assess the expected return from a given project having, of course, both expenses ('outflow') and receipts ('inflow'), whereas most of the Author's Paper dealt with comparing *two or more different ways of doing a given job.* In this context, it was surely misleading to talk of cash 'inflows'—in no case was there any inflow, merely differing outflows, i.e. expenditures. This was true in the examples given in Appendix 1 and Appendix 2; Mr Griffiths would describe the calculations outlined in these examples as break-even analyses.

170. He was puzzled by Appendix 2, and could not see that the Author demonstrated a 'breakdown' in the method. He understood that two ways of doing a job were being considered here, i.e. replacing a bridge. Data on the fundamental profitability of having a bridge at all were not given (e.g. reducing traffic delays) but one had to assume this was already proven. The essential economic difference between the alternatives was that Alternative 2 allowed the major item of expenditure (£20 000) to be deferred from Year 1 to Year 3, at the expense of an outlay of £3000 in Year 0. (Delaying the outlay of £20 000 benefited the owner simply on account of his being able to invest this money elsewhere and thus obtaining a return on it.) By discounting the two sets of expenditures to Year 0 at various rates of interest or return, a rate could be found at which *the two alternatives were equally attractive.*

TABLE 5

	Alternative 1		Alternative 2	
	Actual outlay	Outlay discounted to Year 0 @ 9·4%	Actual outlay	Outlay discounted to Year 0 @ 9·4%
Year 0	—	—	£3 000	£3 000
Year 1	£20 000	£18 280	—	—
Year 2	—	—	—	—
Year 3			£20 000	£15 280
Totals	£20 000	£18 280	£23 000	£18 280

This was in effect what the Author had done in the table in Appendix 2, which was reproduced below but re-cast with the two alternatives shown separately.

171. The fact that the totals figures for columns 2 and 4 were the same indicated that the two alternatives broke even (i.e. were equally attractive) when the owner was able to obtain a return of 9·4% by investing his money elsewhere.

172. Supposing now the £3000 in Year 0 for Alternative 2 became £4000, if this higher expenditure in Year 0 was to be justified, it should be because the owner was able to obtain a higher return than 9·4% by investing money elsewhere; (remembering that the advantage of alternative 2 was delaying the outlay of £20 000). A second break-even analysis showed, quite rightly, that this higher return was 13·8%. This was quite different from the conclusion that the Author had apparently drawn—i.e. that 'wastage improves returns'.

173. Mr Griffiths also wished to comment on the Author's treatment of the subject of inflation. He showed how this factor could be introduced into an economic analysis, but Mr Griffiths felt that the Author had begged the question. His 'mathematical' solution might satisfy an accountant but not an economist. The inevitable conclusion to be drawn was apparently that an expectation of inflation increased the attractiveness of the alternative with relatively higher initial costs and lower operating and maintenance costs.

174. Mr Griffiths thought this was untenable. Generally, inflation affected capital and operating costs roughly equally, and the choice of the higher capital scheme as a result of the Author's 'analysis with inflation' would bring with it a day of reckoning should the assets have to be replaced eventually at much higher nominal cost. He suggested that inflation should generally be ignored in these analyses; if 1965 £'s are used in Year 0, they should be used throughout.

175. If there was clear evidence that in future years capital costs were going to change relative to operating or maintenance costs, then inflation should be considered but in this case the analysis was more complex than the Author indicated.

Mr S. C. Roberts (Assistant Hydro-Electric Engineer, Planning Dept., C.E.G.B.) suggested that those who compared the sample discounted cash flow calculation given in Appendix 1 of Mr Armstrong's Paper with the original solution of Example IX given in the Institution's publication 'An Introduction to Engineering Economics',[10] might find it of value to consider the continuation of the discounted cash flow calculation.

177. In taking into account the assumption in the original solution of Example IX of 100% increase of traffic developing on the alternative routes, the increase could have been a fairly early expectation envisaged to take place in ten years.

178. The cash flow difference in the second table of Appendix 1 in Mr Armstrong's Paper could be quickly adapted as follows. The difference of investment was corrected for the cost of finance during construction included in the original solution; the difference of the alternative routes for finance during construction was £5917. Operation and maintenance difference was derived simply by taking the second, fourth, sixth, etc, years of the differences in Mr Armstrong's second table to arrive at full development of 100% traffic increase in 10 years rather than 20 years. The same ratio of residual value to investment was kept. The cash flow difference was then discounted at trial discount rates of 3% and 4%.

TABLE 6

Year	Difference	3% discount	4% discount
0	−96 120 −5 920	−102 040	−102 040
1	2 560	2 480	2 470
2	2 730	2 580	2 530
3	2 920	2 670	2 600
4	3 120	2 770	2 670
5	3 330	2 870	2 740
6	3 550	2 970	2 800
7	3 790	3 080	2 880
8	4 050	3 190	2 960
9	4 320	3 310	3 030
10	4 610	3 420	3 120
11	4 610	3 320	3 000
12	4 610	3 230	2 880
13	4 610	3 140	2 770
14	4 610	3 040	2 660
15	4 610	2 960	2 560
16	4 610	2 880	2 480
17	4 610	2 780	2 360
18	4 610	2 700	2 280
19	4 610	2 620	2 190
20	4 610 90 200	52 600	43 200
	69 240	6 560	−7 960

$$\text{Rate of return} = 3+\frac{6560}{6560+7960}$$
$$= 3{\cdot}45, \text{ say } 3{\cdot}5\% \text{ per annum.}$$

179. This result clearly agreed with the original conclusion of Example IX that the economic advantage of adopting Route 1 was established. The rate of return of 3·5% indicated a good investment with the cost of capital at 3% per annum.

Mr P. P. Rogers (Postgraduate Student, Harvard University) agreed with Mr Armstrong in his plea for greater understanding of the economic issues involved in the planning and design of engineering projects and appreciated his efforts toward widening this understanding. However, he felt that the Author had not made a very clear distinction between the analysis of private investments and of those in the public sector. One was left with the feeling that the problems involved in making these decisions were essentially the same. It was true that the mechanism of present value ranking of investments could be used in both sectors, but the problems to be surmounted before one could reach the stage of 'discounting' with public investment analysis were so significantly different (and more difficult) that it became a qualitatively different problem.

181. The civil engineering profession, in particular, was heavily involved in the planning, design, and construction of public investment projects. Most highways, dams, reservoirs, water supplies, sewage works, etc, were maintained by governments, either local or central. Mr Rogers wanted to show the economic aspects of these sorts of investments which made them different, in the economic sense, from investments in the private sector. The examples he intended to use came from water resource allocation* problems but examples could equally well be drawn from any other activity in the public sector, such as highway engineering.

182. The three properties which distinguished public investments from private investments were as follows.

183. (*a*) *External economies and diseconomies.* An 'external economy' was said to exist when provision of a good or service for one person or group made provision of the same good, or some other good or service, possible at reduced cost to another person or group, with little or no reduction in the quality of the good or service to the first person or group. A diseconomy provided an undesirable good or disservice to the second group for a comparable provision of a good to the first party. Obvious examples from water resource projects were the provision of flood storage in reservoirs as an 'external economy'. The flood storage could be an 'external diseconomy' if it affected downstream users detrimentally. No market process provided an adequate measure of all the gains and losses from the provision of such an external economy. However, public development, by planning for the whole basin, could convert external into internal economies. There was also another type of external economy which resulted from large-scale public investment, namely, market external economies whereby economies were induced in the use of services such as local labour, land, local markets, etc.

184. (*b*) *The collective demand for services.* 'Public goods' generally required collective action if they were to be provided. For example, flood protection could not be parcelled out for sale in separate units only to those who are willing to pay. Hence a conventional market arrangement would not provide it.

185. (*c*) *The social overhead nature of public investment.* Economic development required social overhead capital investments in such things as highways and communication facilities. This requirement was a necessary, but not sufficient, condition for continued economic growth. However, in making its investments the government implied a preferred rate of growth. This was a value judgement which contained an implicit balancing, at the margin, of the government's time discount rate and the social productivity of investment—this was called the social rate of discount.

186. The use of the concept of social rate of discount greatly simplified the computation of the 'real' or the 'opportunity' cost of public investment. The shift of resources (investments) to the public sector was 'socially' desirable only if the present value of benefits per £ of outlay in the public sector exceeded the present value of £ outlay in the private sector—both present values being computed at the social rate of discount. Mr Rogers felt that Mr Armstrong's Paper would mislead its readers into discounting public investments at a lower rate than the rate used for discounting

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* *Standards and criteria for formulating and evaluating federal water resources developments.* Report of Panel of Consultants to the Bureau of the Budget, Washington, D.C., 3 June, 1961.

private investments. Such an error could lead to serious over-investment in the public sector.

187. Much more could be said about the influence of budget constraints and the method of financing on the internal and external 'opportunity' costs, but Mr Rogers wanted to change the emphasis slightly and point to some of the more difficult problems in the analysis of public investment projects. Perhaps of paramount importance was the evaluation of the benefits of the project. In water resource planning, for example, those uses such as hydropower and irrigation which had a convenient market description, were readily taken care of, but those 'common' or 'public' 'goods', such as recreation and flood control had to be measured by much more devious means. The obvious method was to measure the 'willingness to pay'; this was the area under the demand curve, but the construction of demand curves for these commodities was, to say the least, difficult. There was the problem of complementarities between the several purposes which the project had to be designed to handle. Also there was a problem of multiple objectives of the project, e.g. to increase national income and to provide, at the same time, a certain amount of income redistribution within a region (or the nation).

188. Problems of these types were not usually encountered in private investment projects and Mr Armstrong did economic planning an injustice when he did not make the distinction between the two sectors.

Mr B. Severn (Messrs Balfour, Beatty & Co., Ltd) wrote that in § 34 the Author mentioned the target rates of return for nationalized industries. The proper purpose and significance of such targets was not too widely understood and some attempt at elucidation seemed appropriate.

190. The Government White Paper Cmnd 1337[4] laid down principles which should govern the financing of expansion in the nationalized industries. Following these principles, the relationship between the amounts raised internally from revenue, and externally by borrowing, could be derived for any instance.

191. The annual capital needs of an industry were determined by the anticipated rate of expansion and replacement, and by current costs and cost trends for providing new capacity.

192. The minimum aim outlined in the White Paper appeared to be that the burden laid by each nationalized industry on the nation's lending capacity should *not* over the years be an increasing proportion of the total, but should be stabilized (and possibly even reduced). This meant that if the gross national product increased annually by a certain percentage, that percentage was under stable conditions the maximum tolerable rate of net increase in external borrowings by such industries. Incidentally, the gross national product and the said borrowings both being measured in units of money, the fact that this permissible percentage was gross, including the annual percentage rate of inflation, need not be taken into account. The effect of such limitation of borrowing was to require the financing of the balance of the cost of expanding capacity, out of revenue. This determined the required internal rate of return, from appropriate tariffs.

193. The internal rate of return was by definition the annual surplus on revenue account (including depreciation appropriations) expressed as a percentage of the net capital employed, where the latter included depreciated assets to be valued on a replacement cost basis.

194. In the absence of a more detailed definition of this basis of valuation, it was suggested that the value of an asset which would be retired r years hence after a total service life of n years, could in general be properly taken as, $r/n \times$ (Present cost of equivalent asset, new) + (Present worth of prospective residual value, if any).

195. This was independent of historic cost, but future depreciated values could be estimated from the historic cost by extrapolating in the light of cost trends.

196. An example of particular interest was the electricity supply industry, where

the annual rate of increase in capacity was around 9%—well above even the target growth rate of 4% for gross national product. The system capacities for the current year and the next three years would be in the proportion 100, 109, 119, 130. For this expansion the scale of new construction currently in hand for the next three years should be equivalent to undertaking about 10% of present capacity per annum. To this must be added about 1% to replace retirements (assuming 30 years life).

197. On the basis of valuation outlined above, the depreciated value of the entire system in commission at any time would probably be about 58% of the aggregate replacement cost, assuming that recent cost trends continued. The value of partly constructed works would approach half of the 33% expansion in hand, say 15% of present capacity. Accordingly the industry having invested assets worth some 73 units, would need capital worth 11 units, i.e. an annual capital investment rate related to current valuation of 15·1%. If no net increase in borrowings were permissible, this would be the required internal rate of return.

198. Assuming that assets were sufficient to cover liabilities, the present level of external borrowings should be less than the 73 units current valuation, and increase in this level might be permissible at a rate up to that in the gross national product. Taking the target level of 4%, this meant that just under 3 of the 11 units required might be financed by increased borrowing, and the remainder must be raised internally. For this purpose a net internal rate of return of at least 11·1% would therefore be necessary. It may be remarked that the target rate of return presently adopted for the electricity supply industry was in fact slightly higher than this, although the detailed reasoning for such official figures was unpublished.

199. Similar financing considerations would of course apply to other expanding industries.

Mr F. Livesey (Manchester Business School) referred to the example presented in Appendix 1 as an illustration of the use of the discounted cash flow method of evaluating alternative projects. This example concerned the relative costs of constructing and operating two railway lines of identical capacity. Route 1 required the greater initial capital investment, but had the lower operating costs. If these future savings in costs were discounted at 3%, the cost of capital to the company, their present value was exceeded by the additional initial investment required for Route 1 by £2020, and therefore Route 2 was to be preferred. Mr Livesey said that while this example was useful in showing the value of discounting, it would appear to be at best incomplete and at worst misleading.

201. The first point of criticism related to the crediting of Route 1 with a differential residual value in Year 20 of £80 510 (£177 270–£96 760). This residual value was arrived at by applying to the various items of initial expenditure estimated lives varying from 20 years to infinity. However, this procedure was invalid for the following reason.

202. If the projects were to be evaluated over a period of 20 years, one should ask what was to happen to the undertakings thereafter. One possibility was that the line would cease to operate and that the assets would be made available for alternative use. In this case, while some of the assets, such as the permanent way, might have some value, the value of most of the assets was likely to be very small indeed, so that the total value of the assets would be very much less than that postulated by Mr Armstrong.

203. Alternatively operation of the line might continue, either under the existing or under another owner, beyond Year 20. In this case the value of the assets would relate to their future earning capacity, and would again not be related to their original cost in the way suggested.

204. In the main body of his article (§§ 67–70), Mr Armstrong showed that he was aware of these considerations. However, he tended to dismiss them on the grounds that any error which might occur in the estimates for Year 20 would make very little

TABLE 7

Year	A Differential net cash flow Actual value	A Differential net cash flow Present value at 3% discount	B Differential net cash flow Actual value	B Differential net cash flow Present value at 3% discount
0	−96 120	−96 120	−96 120	− 96120
1	7 930	7 700	6 930	6 728
2	7 840	7 391	6 840	6 449
3	7 760	7 101	6 760	6 184
4	7 670	6 814	6 670	5 926
5	7 580	6 539	6 580	5 675
6	7 480	6 265	6 480	5 428
7	7 390	6 009	6 390	5 196
8	7 280	5 746	6 280	4 845
9	7 180	5 501	6 180	4 736
10	7 070	5 261	6 070	4 517
11	6 960	5 029	5 960	4 306
12	6 850	4 804	5 850	4 103
13	6 730	4 582	5 730	3 899
14	6 610	4 370	5 610	3 710
15	6 480	4 160	5 480	3 438
16	6 350	3 958	5 350	3 334
17	6 220	3 763	5 220	3 159
18	6 080	3 572	5 080	2 984
19	5 940	3 388	4 940	2 817
20	5 790	3 206	4 790	2 653
Total		+9 040		−6 030

−Cash outflow, Route 1–Route 2
+Cash inflow, Route 1–Route 2

difference to the overall picture when a discount figure of 10% was being applied. This was true. However, in the appendix example the discount figure was only 3%, so that the very large sum which occurred in Year 20 had a considerable influence on the overall picture. (The present value of £80 510 in Year 20 discounted at 3% was £44 580). Therefore if this sum were ignored, or even drastically reduced as argued above, Route 2 would become considerably, rather than marginally, more attractive.

205. The example dealt only with costs, initial and future, on the grounds that 'other effects such as revenue . . . are assumed to be common and do not need to be taken into account for comparison of these alternatives' (§ 80). But this was not so. To ignore revenue was valid only where no revenue would accrue, i.e. where an undertaking existed purely as a public service.

206. The following example indicated the importance of including revenue. In A, annual revenue was assumed to be £10 400, and the differential net cash flow (D.N.C.F.) for Years 1 to 20 was obtained by subtracting from this figure the differential costs given by Mr Armstrong. In B, annual revenue was assumed to be £9400, and D.N.C.F. was obtained in the same way. For simplicity, the residual values in Year 20 were assumed to be zero, although, as argued above, they were, in practice, likely to be positive.

207. A comparison was now possible, not of costs in Year 0 on the one hand and in Years 1 to 20 on the other, but of costs in Year 0 and (net) revenue in Years 1 to 20. This was, of course, the normal situation as regards commercial undertakings.

208. It could be seen that with the smaller revenue assumed in B, Route 2 was to be preferred. However, when estimated revenue rose to the figure assumed in A, the balance shifted in favour of Route 1. It seemed particularly strange that the importance of possible variations in revenue should be neglected in view of the fact that possible changes in the volume of traffic were considered from the point of view of their effect on operating costs (see, for example, § 83.)

209. The final point related to the effect of inflation, to which Mr Armstrong referred on two occasions. In § 66 he pointed out that 'an inflation effect of $u\%$ per annum increases the cash flow during a period in n years time by $(1+u)^n$', while in § 84 he concluded that 'The foregoing rate of return (i.e. 2·9%) is increased by 2% per annum inflation to 4·9% per annum. This return then makes Route 1 a good investment by comparison with Route 2.'

210. It was not at all clear what Mr Armstrong was saying here. In § 66 he would appear to be referring to the effect of inflation in leading to an increase in revenue. If this was the case it was not valid to allow for inflation in an example in which revenue was assumed to be zero.

211. Alternatively, inflationary tendencies might influence events in that costs might rise in the future. On the assumption that the various categories of cost would all be affected to roughly the same extent, this would mean that the cost difference for Years 1 to 20 would be somewhat greater than in the original example, and this would be to the advantage of Route 1.

212. On the other hand, it was normal to allow for inflation in the cost of capital, i.e. the cost would tend to be higher, and the consequent increase in the appropriate rate of discount would favour Route 2.

213. It was not possible to say what the net effect of these conflicting tendencies would be. It *could* be to increase the relative attractiveness of Route 1. But even if this were so, there was much more to the matter than simply adding together the original (unadjusted) rate of return and the rate of inflation.

The Author, in reply, thanked contributors for a thoughtful and extensive discussion. It had amplified the Paper, giving particular attention to the cost of capital, evaluation of benefits, inflation, methods of analysis, and the target returns of nationalized industries. The Author would use these aspects as headings to try and group the more controversial discussion together coherently; the remaining topics would then come under a sixth heading.

Cost of capital

215. Mr Palmer had interpreted 'large savings' in § 15 correctly; they were in fact large *gross* savings. The inclusion of taxes in these amounts led to wide ranges of costs of capital,[11, 12] because of the uneven effect of tax on investment.

216. Mr Sykes had thought the use of realistic costs of capital was a new development. Mr Bolton had noted that public and private financial objectives were coming closer together. Dr Beesley had regarded the basic problems of opportunity cost as similar in principle for both sectors. Mr Rydz and Mr Rogers had thought that both sectors should have equitable treatment while Mr Booker had warned of the inaccuracies of commercial criteria which did not include social benefits. Mr Wood had stressed the reality of bankruptcy. All these points deserved emphasis.

217. Of controversial interest were the objections of Mr Bolton and Dr Beesley to parts of § 16. These objections were surprising for the following reasons, taking Great Britain as an example.

(*a*) Capital formation exceeded net borrowing and this was evident from Table 8.[13] Therefore it was essential that some borrowing should come

TABLE 8: PUBLIC SECTOR RECEIPTS AND EXPENDITURE, 1964

	Amount %		£ million	
Receipts				
Levies (taxes, rates, national insurance, etc.)		76·0		9 730
Net borrowing				
Central government	2·7		345	
Local authorities	4·8		621	
Public corporations	0·3		41	
		7·8		1 007
Other		16·2		2 069
		100·0		12 806
Expenditure				
Debt interest				
Central government	7·6		967	
Local authorities	2·3		295	
Public corporations	0·8		106	
		10·7		1 368
Capital formation				
Central government	2·2		286	
Local authorities	8·7		1107	
Public corporations	9·3		1197	
		20·2		2 590
Other		69·1		8 848
		100·0		12 806

from public levies. (The other receipts referred to particular commitments and were not relevant.)

(*b*) Public borrowing came from a special market. It excluded the keenest section of private investors and relied instead on those with special demands such as insurance, pensions saving, facilities for investing small amounts, quick withdrawal, easy access and, as explained in (*d*) below, demonstrable security. In the past, public borrowing had benefited from the adverse publicity of private borrowing, but unit trusts[14] had reduced this effect. It met the demands mentioned above collectively through the banking system, insurance companies, and various trust funds. It met individual demands through National Savings, the Post Office and trustee savings banks. For meeting these special demands it payed a lower than average rate of interest, and consequently gained because large scale diversification minimized the costs of meeting them. Finally, public borrowing kept carefully within the limits of these special demands.[15]

(*c*) Public borrowing interest was known whereas private borrowing interest eluded precise determination. The large number and variety of enterprises, the uncertainty of economic forecasting,[16] the secrecy of company activities and the wide range of management skills all frustrated the most accomplished analysts.

(*d*) Public levies exceeded the total amount of interest on borrowing, plus new borrowing by a wide margin. Table 8 showed this as almost 150%.

218. The argument in § 217 led to the conclusion that public borrowing rates of interest did not bear any more distinct relation to public investment cost than was indicated in the last sentence summary of § 16; the Author therefore thought this summary was reasonable. Estimating the public investment cost required the assessment of a multitude of problems which could not all be expressed in terms of money.[17] The Government had recently thought of, and used, a value of 8% per annum as a minimum rate.[18,19]

219. Mr Sykes had indicated that a 6% interest bond (gross of tax) was worth 0–1% to its owner. Since the aforementioned 8% rate excluded inflation and tax, the difference between the two values gave a rate of 7–8%.

220. Mr Sykes also mentioned that some 17% of the gross national product went into capital investment. A small change in consumption could alter this figure, and thereby affect the 8% rate described in § 218. However, the Author did not know what account this rate took of future investment patterns. The National Plan[20] provided for a proportional increase in capital investment in the late 1960's and engineering decisions, like Government ones, often related to capital expenditure extending over several years. The best rate for a project was therefore likely to be a weighted mean of future rates, not the present one.

221. The Author felt that Mr Rogers' statement that readers of the Paper would be tempted to discount investments at the wrong rates was not entirely valid; he hoped that some reconsideration would persuade Mr Rogers to think otherwise. Not only was the Paper neutral on the subject, but such an assertion could only hold if readers had the means of estimating the right rate. Any readers with such means would be able to look up more relevant references.

Evaluation of benefits

222. The Author was particularly indebted to Dr Beesley, Mr Spottiswoode, and Mr Rogers for their contributions on evaluation of benefits. The Paper referred only briefly to this problem in § 28 and had, regrettably, omitted reference to the outstanding Victoria Line exercise[21] in which Dr Beesley was a key participant.

223. The question posed by Mr Spottiswoode on how to indicate priorities between a hospital, a school and a road, was a very small slice of the Government's problem.[17] Engineers could tackle such a problem but they would need to liaise with economists, doctors and teachers to exploit the analysis most effectively. Even then, present knowledge would limit the value of the results to such an extent that the solution would be primarily political. Such a situation, however, should not deter us from seeking an increasing amount of analysis in the future.

224. Mr Rogers' choice of water resource allocation problems as an example was a good one. The solution of these problems often entailed spectacular engineering works and had also, like transportation, attracted economists. Nevertheless, whatever one did with benefit evaluation, the demand forecast exercise was of prime importance. Because the Victoria Line replaced one transportation system with another, errors in future demand affected only some of the benefit estimates. With a river-basin development, all the benefit estimates could depend on the demand forecasts. Furthermore, Mr Rogers had referred to North America where confident water-demand forecasts[22] were attainable. A particular problem nowadays was the incidence of river-basin projects in developing countries where social and economic growth problems made demand forecasting very hazardous indeed. In such cases, an elaborate benefit evaluation, however well conceived, could be wasteful.[23]

225. Dr Beesley and Mr Rogers had identified benefit evaluation with public investment. The Author thought this relationship oversimplified matters, and

reflected what had been accomplished so far.[24] That private investment analysis had not yet evolved any worthwhile benefit evaluation techniques could be true. However, any implication that the private sector did not need to evaluate social benefits was in the Author's opinion wrong. Only the details and the magnitude of the problem differed. An office was part of a company's interests just as transportation was part of the public interest. Its location, size and layout required somewhat similar evaluation criteria.

226. Again, not all public investment required benefit evaluation exercises such as those used for transportation and water resources development. Energy supply was somewhat easier, whereas defence and research were somewhat more difficult.

227. Associated with benefit evaluation was Mr Gwynn's observation that, with larger projects, benefits often increased for a number of years after the date of first use. This made the sizing of projects sensitive to demand and benefit forecasts several years ahead.

Inflation

228. The remarks of Dr Beesley, Mr Murray, Mr Wood, and Mr Spottiswoode about inflation required little comment. The calculation in Appendix 1 depended on a 2% price change difference between capital charges and operation or maintenance costs.

229. Mr Griffiths and Mr Livesey had correctly emphasized that inflation was much more complex than the formula in § 66 indicated. With forecasts, however, one could not tell what complexities would arise. Thus, complicated forecasts were of no more value than simple ones, and the formula applied only to forecasts.

230. An error in line 5 of § 66 required correction. A bracket was omitted from the formula which should read $1/[(1+v)(1+r)]^n$.

231. The answer to Mr Palmer's question in § 150 concerned inflation but could also be linked with Mr Gwynn's remarks in § 96. Assuming costs and benefits were linked with present day prices, two alternatives seemed possible. The whole programme might be put back because of the delay in official approval; then the cost inflation would be matched by benefit inflation. In addition, the initial demand due to growing traffic would be more and thus make a net benefit increase. This would increase the benefit cost ratio and, consequently, the net present value. Alternatively the construction period might be shortened to meet the original completion date. Any inflationary effects would be more than offset by interest during construction savings. The lower cost would again increase the benefit cost ratio.

232. Therefore, Mr Palmer should press on. Presumably he would have to revise the cost estimates for the financiers' benefit but that exercise would not make the project economy any worse or any better than it was before.

Method of analysis

233. Some practical remarks by Mr Gwynn, Mr Sykes and Mr Wood stressed the importance of analysis as a tool and not a master. That clear results sometimes emerged with very little work, that a methodical approach only had to improve on existing practice to give results, and that systematic short-cutting could deal with numerous alternatives efficiently, were points with which the Author readily agreed.

234. The case for using 'discounted cash flow' terminology had strengthened since the Paper had been written. Both the business press[25] and the National Economic Development Council[11] had adopted it. Moreover, it was now customary, as Mr Storey had said, to regard both the rate of return and present value approaches as D.C.F. Like Mr Bolton and Mr Wood, the Author had been left behind.

235. Mr Griffiths had problems with some other terms. His proposal on the term 'break even' conflicted with Mr Booker's use of it. The Paper's reference to differences in outflows as 'inflows' had no particular status, and was descriptive only. While on this topic, a correction to line 3 of § 40 was appropriate: 'initial investment' should read 'differences between the initial investments'.

236. Mr Storey had belaboured the annual capital charge method. However, some engineers used the method correctly by linking it with the present value formula as described in §§ 49 and 50. Mr Cullen's Table 4 was an apt example.

237. Mr Cullen and Dr Beesley preferred the present value approach as simpler and more reliable. Mr Bolton and Mr Cullen thought the rate of approach more appropriate for private investment. The Author maintained his own preference for the rate of return approach because it was more explicit and its defects, because of rarity and easy correction, were unimportant. A project analysis might require months for data collection. Superimposing a rate of return calculation on a present value analysis took only a few minutes which were usually well worthwhile.

238. Dr Beesley was right in emphasizing, in § 135, that any risk analysis must be clearly understood, and that it applied to poor cash positions and cautious management as well as to risky projects. D.C.F. analysis, of course, coped with these situations, and Mr Booker's stress on 'break even' analysis in high risk conditions was mystifying. 'Break even' analysis helped budgeting and cash scheduling; it complemented D.C.F. analysis and this relationship should prevail, regardless of the degree of risk, cash status, and management caution.

239. Mr Griffiths had had a good look at Appendix 2. The Author agreed that the conclusion of 'wastage improves returns' was indefensible and that the difference in results depended on £20 000 being invested at 9·4% in one instance and at 13·8% in the other. However, the £20 000 investment rate would depend on conditions outside the calculation, not inside. The outside condition in Appendix 2 had been represented in § 89 by an owner's cost of capital of 10%.

240. Before leaving methods of analysis, the Author had a qualification to make to the text in Appendix 2. The statement in § 90 that 'the foregoing breakdown will arise only when the summation of cash flows at 0% discount is negative' was not always true. Each D.C.F. equation could be considered a polynominal with n values of r when discounted to zero. Generally these would be irrelevant, i.e. negative or imaginary, except for one usable value. The example in Appendix 2 depicted a rare case of two usable values. Even rarer cases of three or more usable values were possible; such cases could disprove the foregoing statement because an odd number of usable values would have a positive summation of cash flows at 0% discount.

Nationalized industries' target returns

241. Mr Bolton had developed an argument against referring to the electricity supply target return of 12½% on depreciated assets as an 'artificial form of capital rationing'. Yet the Author felt that some of his points contributed to defending this description. An electricity supply to houses and factories became obligatory because it gave more economic and attractive illumination than alternative energy sources. Its other uses, particularly heating, competed with gas and petroleum products. As Mr Bolton said, the target return made the Area Boards charge more than before. The higher charges would divert some customers to heat by gas or oil, the system demand growth would slacken, and less capital would be expended in new works. Thus, capital rationing followed directly from setting the target return. The rationing, as § 34 explained, would become artificial where the target return (amended from a percentage of assets to an interest rate) exceeded the public investment cost of capital.

242. Originally, the Author had thought the target return would also ration capital by requiring correspondingly low initial cost design. Mr Fine had already explained how this happened with pumps and pipes in chemical plant design. However, in power stations, the criteria actually used in design turned out to be interest rates of 5½% and 7½% for cash flows before and after commissioning respectively.[26] Although the Government once related the 7½% to the target return[27] its reasoning lacked conviction. On the other hand, Samuel Brittan[18] described the 12½% electricity target return as an attempt to fix a £200 million ceiling on annual outflow of Treasury funds. As his description is supported by the White Paper's pre-

occupation[4, 9] with self-financing, it seems that the target return has nothing to do with design.

243. Mr Severn's contribution interpreted the White Paper[4] as a self-financing proposal and logically deduced what had to be done within an electricity industry with 9% per annum growth to confine its burden on the Treasury to a slower growth rate. His answer of about 11% compared with the $12\frac{1}{2}\%$ but only arbitrarily. The $12\frac{1}{2}\%$ rate, as explained in § 242, appears to have been more simply derived.

244. Mr Severn's calculation helped to show the weakness of self-financing as a rate of return fixing device. From it followed the situation where a slow growth industry may require a 5% return and a fast one, 20%. The slow growth industry, for maximum profits, wants to put its surpluses in the fast growth industry, but it is not able to do so. It has to reinvest them at its own 5% return. It thus loses the opportunity to maximize returns from its profits and instead, invests them cheaply thereby tending to overproduce at too low prices for too many customers. The fast growth industry, because it has no slow growth industry surplus, raises its prices to obtain new capital. It thus loses customers and its profits drop. The remaining customers pay more and have less to spend on other things. In this way, self financing (and indiscriminate ploughing back of profits) can impoverish the community.

Other topics

245. Mr Palmer's depiction of confidence levels applied when it would be unduly unprofitable or demoralizing to be publicly saddled with the consequences of an over-estimate. The Paper had dealt with a firm's internal expressions only. Public relations were another problem.

246. Mr Sykes' concise summary of Britain's current investment problems reflected the clear exposition set out by Merrett and himself in a steady flow of published work. The Author felt that this work made excellent reading—for engineers as well as businessmen.

247. Dr Beesley preferred 'uncertainty' to 'risk' in the first sentence of § 18. This preference was consistent with a large body of economic thinking. What Dr Beesley considered as a risk was often a 'safety factor' or 'contingency' to the engineer.

248. Mr Bolton asked for more comment on § 30. This paragraph was based on Mr Chapman's finding[7] that paragraph 2 of the MacKenzie Report's Appendix 2[6] was mistaken. It stated that the 'average plant load factor of all the plants throughout their lives' was, for an all thermal system, '$0{\cdot}91 \times$ system load factor'. Such a statement applied only to systems which did not expand. The MacKenzie Report was about an expanding system and Mr Chapman demonstrated that expansion favoured a higher proportion of peak hydro and pumped storage developments than the MacKenzie Report had visualized as potentially economic.

249. Accountancy practice with its emphasis on book value depreciation repelled several contributors. Mr Storey's reference to the mistaken valuation of the Cunarders was a vivid example of this. However, not all accountants had been out of step.[28]

250. Mr Cullen's description of some Building Research Station studies was welcome. Table 3 presumably exemplified the tied low-interest loan situation described in § 65, and Table 4 set out a neat comparison where equal annual costs dominated the study.

251. An endless increase of benefits at higher than discount rates as proposed by Mr Spottiswoode suggested a very high investment cost–initial annual benefit ratio. It was an unusual test for D.C.F. Assuming that benefits more than 20 years ahead were speculative, the study should be limited to that period, while no allowance was made for capital depreciation or obsolescence. Alternatively the rate of return approach of D.C.F. could be used which would discount to 0 at a rate above the increase in benefits rate.

252. Mr Spottiswoode's remarks on timing made sense in putting forward the

best thing to do in an imperfect situation. Ideally, works budgets should vary according to the amount of profitable expenditure attainable, i.e. expenditure which when adjusted for risk, gave an estimated return greater than the cost of capital. Practices of cutting back works when cash ran short or of working to an even rate of expenditure became inefficient when profitable projects were forced back in one year and unprofitable ones brought forward in another. It was preferable to borrow for deficits and invest surpluses, if this was at all feasible.

253. Mr Booker's reference to value engineering and critical path networks deserved particular emphasis. Both practices brought fresh systematic approaches to good engineering concepts. Value engineering contributed directly to economic analysis because it sought the best way to meet a demand. Critical path networks contributed indirectly because they helped the efficient programming necessary for good analysis. The Author thought that there was no need to consider planned obsolescence separately from economic analysis.

254. The critical examination of Appendix 1 by Mr Roberts and Mr Livesey added variations which required little further comment except for Mr Livesey's application of revenues to the calculation. The Author felt that Mr Livesey was surely thinking of differences in revenue, otherwise his application was invalid. On residual values, the estimate in Appendix 1 was a forecast only, and could be correct only as far as one could visualize at the time of forecasting. The uncertainty of its value, as Mr Livesey noted, subjected the results from low discount rates to the risk of serious errors.

255. In conclusion, the Author wished to acknowledge points raised by the following people who did not take part in the discussion but who helped him to correct or amplify the Paper in the reply. They were Mr R. Turvey of the Electricity Council, England, Mr J. A. Polson of B.C. Hydro and Power Authority, Vancouver, Canada, and Mr H. I. Schwartz of the University of the Witwatersrand, Johannesburg, South Africa.

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