# Projecting Dynamic Behaviour in the Absence of a Model: Results of a Survey

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**Abstract**

One of the advantages commonly put forward in support of the system dynamics method is that managers find it difficult to trace the dynamic consequences of cause and effect relationships even in simple systems. While this may be intuitively appealing as one of the justifications for the existence of system dynamics, there is a need to accumulate a body of evidence which results from putting this assertion to the test. The paper reports the findings from a questionnaire which has been administered to over one hundred undergraduates and postgraduates covering a range of business management specialisms. Respondents were asked to decide between two manufacturing technologies, exhibiting quite dissimilar cost structures, with a view as to their future profitability under four different demand scenarios. The questionnaires were administered twice with a three month gap between during which the answers to the first one were revealed, and on the second occasion the rubric was altered to incorporate feedback into the situation described. The competing technologies and their associated cost structures reflect very real policy choices and so the outcome of the exercise has a message for manufacturing industry as well as the system dynamics community.

# Projecting Dynamic Behaviour in the Absence of the Model Results of a Survey

## Introduction

In recent years, the system dynamics community has devoted increasing attention to the concept of learning. This focus of research has been timely in view of the need to disseminate more fully exactly how a system dynamics model features in the particular managerial process which is perhaps best described as strategic policy formulation. The notion of a model as an aid to learning about the behaviour of complex, non-linear management systems is a valid one; models cannot be devised which will provide 'answers' to what can be quite opaque 'issues' at the strategic level. (Morecroft 1992; DeGeus 1992).

In order to scientifically demonstrate the power and utility of using system dynamics to shed light on a strategic issue, we would ideally require a real-life situation where, firstly, the management team intervened without the aid of a model and then did so again supposedly equipped with a higher level of understanding arising from experiences with the model. A comparison of the two outcomes could be attempted. Unfortunately, unlike the physical sciences, social science does not embrace the concept of the replicated experiment and one could not be certain that the circumstances surrounding the strategic issue being analysed were being held constant from one intervention to the next. In any case, management systems are notoriously stiff; some time constants may control outcomes over many years whereas others do so merely over a span of months. How long a horizon should be put on the evaluation?

If experiences with a model have not yet been scientifically tested as to their added-value to a management team's stock of knowledge and insight, then an alternative approach is to test a logical deduction from the original hypothesis: we should begin to build up a body of evidence concerning a measure of how well individuals perform *without* the aid of a model. Moreover, this kind of experimentation can be undertaken in a laboratory situation. We can describe an issue and request that subjects analyse it without any modelling input. This mimics the activities which senior managers embroiled in strategic issues engage in almost routinely. Whilst the system dynamics community might hope that some scientific model-based sword was attacking the cloak of complexity which shrouds every strategic matter, the reality is that the vast majority of strategic policy choices in organisations emerge merely from a series of meetings and discussions of variable quality amongst a given body of people. Almost certainly this style of strategic management is changing, but the system dynamics community must expect that this change can be accelerated.

In his classic paper on how formal models can be adopted in order to accelerate the learning process, DeGeus (1988) describes a common mental model people hold on the price-elasticity of the oil market. He asserts that people cannot project this model *dynamically* unless it is programmed and the results reviewed. His statement is, however, nothing more than an assertion. While most of those who engage in system dynamics modelling would be prepared to believe it, there is a lack of genuine evidence in the form of a controlled experiment.

The reports on misperceptions of feedback, evaluated via business games of, firstly, a multi-echelon inventory and ordering system (Sterman, 1989) and, secondly, the marketing of a new product (Paich and Sterman, 1993), are sources of evidence which cannot be ignored. Clearly, in the management of ongoing systems, the dynamic consequences of feedback are not adequately comprehended, even when there is opportunity for learning through repeated exposure to the same conditions. Strategic management action, without the aid of a feedback model, is shown to result in underperformance.

**Description of the Experiment**

As a contribution to the studies which have assessed people's ability to comprehend and project dynamic behaviour, an experiment has been conducted which sought to evaluate respondents' perceptions of profitability under different demand scenarios. Specifically, a large sample, consisting of both undergraduate and postgraduate students covering a range of business studies specialisms, was presented with a questionnaire in which was described how a firm needed to make a choice between two competing technologies. Thus, the orientation was that of a one-off, capital investment type of decision, in contrast to business game based studies requiring sequential decisions.

The framing of the choice between the two technologies was done via the presentation of two break-even charts, that for Technology 'A' reflecting a high fixed cost yet low variable cost option and that for Technology 'B' exactly the opposite. The values for fixed cost and unit variable cost were chosen in such a way that *both* options resulted in break-even at the *same* volume of plant throughput. This was 10,000 units per annum. Revenue per unit was the same in each case (£200 per unit) and hence each technology broke even at total annual cost equals total annual revenue equals £2 million.

Respondents were required to assume they were to attend a meeting in the role of consultants assisting the directors decide which technology to adopt. The performance criterion to be used was cumulative profit over a twelve year time horizon. The questionnaire then posed just four questions, each one offering the same set of possible recommendations but in the context of four different demand scenarios. These scenarios were (i) a stable rising trend in demand with a slope of 800 units per year (ii) a stable falling trend in demand exhibiting the same slope (iii) a cyclical but stationary demand pattern governed by a pure sine wave with an amplitude of 2,000 units per year and a period of 4.5 years and (iv) the same cyclical pattern as in (iii) but with a revised amplitude of 4,000 units per year. Each scenario commenced with demand at the break-even point of 10,000 units per annum. The four possible recommendations were: support for one of Technology 'A' or Technology 'B', that there was no difference between the two technologies and, finally, an option was presented which allowed a respondent to state that they were unable to advise the firm in the circumstances presented.

The variety in demand scenarios was deliberate. All too often it appears that capital investment decisions are taken based on demand projections exhibiting monotonicity; the fluctuating dynamic behaviour exhibited in the real world (and represented by the sine wave scenarios with a period approximating the typical business cycle) seems rarely to be acknowledged and is certainly not planned for. Yet this can have a serious impact on profitability during recessions and this is especially the case with operations involving high fixed costs. For the technology exhibiting high fixed costs (Technology 'A') the demand cycle with the larger amplitude was such that, for approximately eighteen months in every recession, throughput could not accrue sufficient revenue to even cover fixed costs.

The situation in which the respondents were initially asked to imagine they were involved was one where demand was devoid of any effect emanating from within the firm. In short, there was no feedback effect on demand. In order to gauge the respondents' ability to project dynamic behaviour without the aid of a model, and in a way which allowed comparison between feedback and no feedback influences, the rubric of the questionnaire was altered to include the passage reproduced below. For the students, there was a gap of some three months between being asked to respond to the original and amended questionnaires and during this period the answers to the original questionnaire were revealed. The amended questionnaire stated:

> *The demand scenarios illustrated in each of the four questions now relate to potential demand, not actual. You are to assume that the actual (realised) demand is affected by the size of the order backlog which is reflected in the delay in receiving the goods. Customers, on perceiving a higher delivery delay, refrain from translating potential demand into firm orders and take their business elsewhere. You can assume that this*

*effect is proportional to the extent of the increase in the backlog, so that an order backlog of twice the normal size will result in the demand rate being halved. An order backlog smaller than normal has no effect on demand.*

*Normally, the order backlog is for 6000 product units and you can assume this is the situation prevailing at the start of each scenario for potential demand. The firm's policy on plant throughput is to set it proportional to the size of the current order backlog and they aim to completely eradicate any backlog over a full year's operations.*

It was not possible to ensure a perfect match between the sample of students who completed the original questionnaire and those responding to the amended one. However, the same three classes were visited on each occasion and so there was consistency between the populations from which the samples were drawn. The aggregate attendance was down by 24 when the second questionnaire was administered, although the total number involved was still in excess of one hundred. Respondents completed the questionnaires in a 20-25 minute period towards the end of a lecture class and submitted their responses anonymously. Time pressure did not appear to be a factor affecting questionnaire completion. Conferring was not allowed and the selection of a choice by guesswork similarly ruled out. A check was possible on this latter point because respondents were requested to explain very briefly the basis for their particular recommendation in each case.

**Outcome and Results for the Situation without Feedback**

The graphs emanating from runs of a model which incorporates the no feedback situation are shown below. Figure 1(i) - (iv) gives the cumulative profit graphs as a set of co-plots depicting the high fixed and low variable cost option together with its (opposite) alternative, each for the four demand scenarios: steadily growing; steadily declining; cyclical; highly cyclical. Although a system dynamics model was used, in the absence of feedback this particular evaluation could easily have been performed using a spreadsheet.

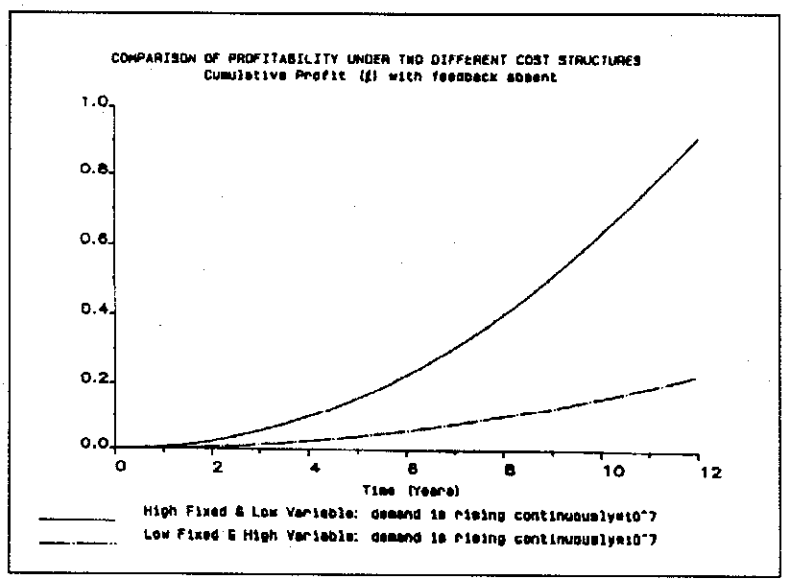


Figure 1(i) Cumulative profit graphs; no feedback; demand is growing steadily

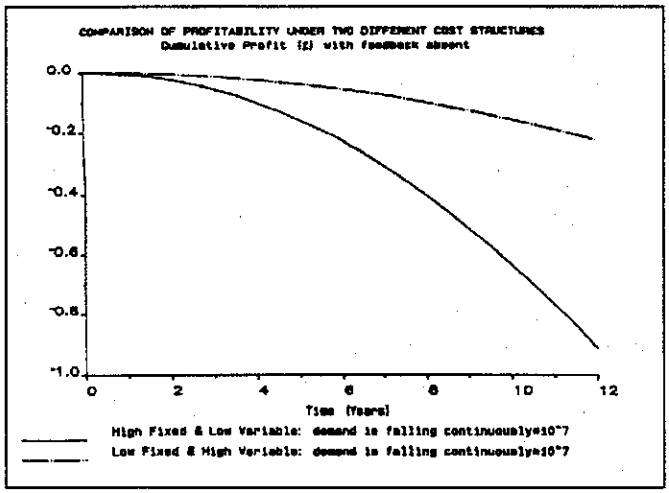


Figure 1(ii) Cumulative profit graphs; no feedback; demand is falling steadily

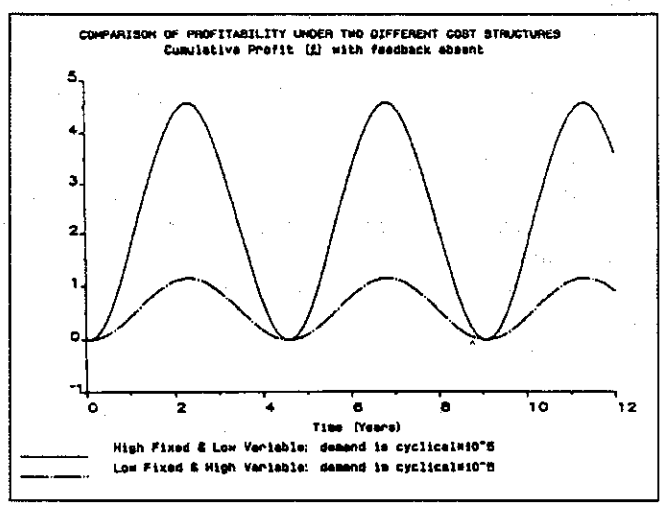


Figure 1(iii) Cumulative profit graphs; no feedback; demand is cyclical

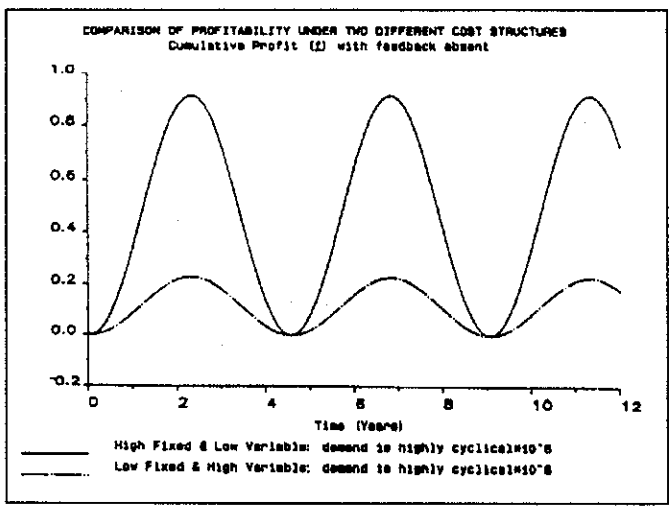


Figure 1(iv) Cumulative profit graphs; no feedback; demand is highly cyclical

When demand is rising steadily, technology 'A' involving high fixed and low variable costs will always be more profitable. This would be an ideal demand scenario for such an operation. On the other hand, if demand is continuously falling, a high fixed cost operation is a millstone. Each year large losses are incurred and these accelerate sharply if the demand drops below that throughput which just covers fixed costs.

The profit repercussions arising from the cyclical demand scenarios are quite interesting. At the completion of each demand cycle, the cumulative profit falls to zero for *both* technology options. There could clearly be a dispute as to which technology offers the superior performance here, so it was decided to allow either that there was no difference between the two technologies or that technology 'B' (with low fixed costs) was the best. For the final question (demand scenario) it was felt that the enormous variation in cumulative profit arising from technology 'A' could well mean that the firm would not survive the severity of the downturns and hence technology 'B' was to be preferred here.

In the 'no-feedback' situation, 134 students completed the questionnaire comprising 52 final year undergraduates studying Business & Management Studies, 49 final year Finance & Accounting students and 33 postgraduates. The latter all had a first degree (or equivalent) qualification in Business Studies/Accountancy; a small proportion had had full-time working experience.

It was clear that respondents had most difficulty in tackling the projections involved in questions 3 and 4 where the demand scenarios were cyclical. The oscillatory behaviour, which is often a feature of real-world business dynamics, clearly leads to more significant difficulties in perception. Table 1 reveals the extent of the difficulty as evidenced by the responses.

**TABLE 1**

| Question No. | 1 (%) | 2 (%) | 3 (%) | 4 (%) |
|---|---|---|---|---|
| Correct answer and plausible explanation | 90 (67) | 84 (63) | 37 (28) | 18 (13) |
| Incorrect answer or correct answer with implausible/no explanation or unable to advise | 44 (33) | 50 (37) | 97 (72) | 116 (87) |

Whereas two-thirds of the respondents for question 1 (steadily increasing demand) had no difficulty in projecting the correct result, only 13% of those responding to question 4 (highly cyclical demand) could do so. A chi-square test led to the rejection of the hypothesis that the numbers with both a correct answer and a plausible explanation were equal across all demand scenarios ($p < 0.01$). The numbers achieving just the correct answers were higher across all questions, but a proportion of these were transferred to the second row of table 1 because of a failure to provide any explanation or an incorrect explanation for their choice. This was done deliberately to rule out a choice by guesswork.

Disaggregation by student group revealed only one important finding: that a significantly higher proportion of Finance undergraduates (45/49) than Business Studies undergraduates (39/52) correctly answered question 1 (with or without a plausible explanation, $p = 0.02$). This would appear to confirm

the belief that in the training of accountants it is a straight line, increasing demand trend which is most commonly employed in examples of capital investment decisions.

Using a probability model which allowed for the two correct answers permitted in question 3, the expected total numbers of correct answers arising purely by chance were computed and compared with the actual numbers for n = 0,1....4. Both with and without an accompanying plausible explanation, the hypothesis that all respondents chose their answers purely by chance was rejected emphatically ($p < 0.01$).

**Outcome and Results for the Situation with Feedback**

Compared with figure 1, the outcome in the situation where order backlog affects realised demand is stark. In each case, the low fixed cost technology results in the best cumulative profit performance. Figure 2 depicts the results for each of the two technologies, the co-plots (i) to (iv) covering the outcomes from the four demand scenarios.

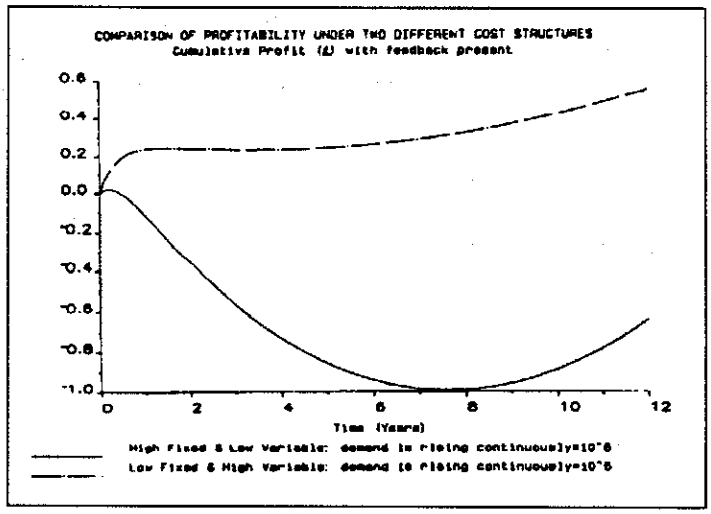


Fig 2(i) Cumulative profit graphs; feedback; demand is growing steadily

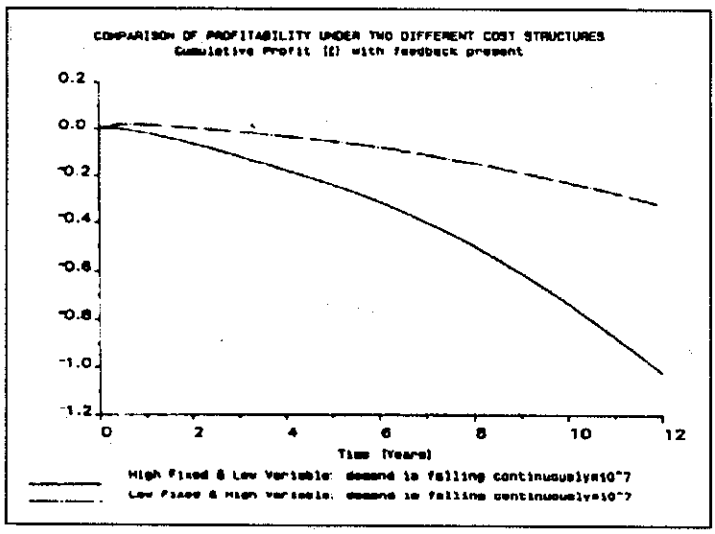


Fig 2(ii) Cumulative profit graphs; feedback; demand is falling steadily

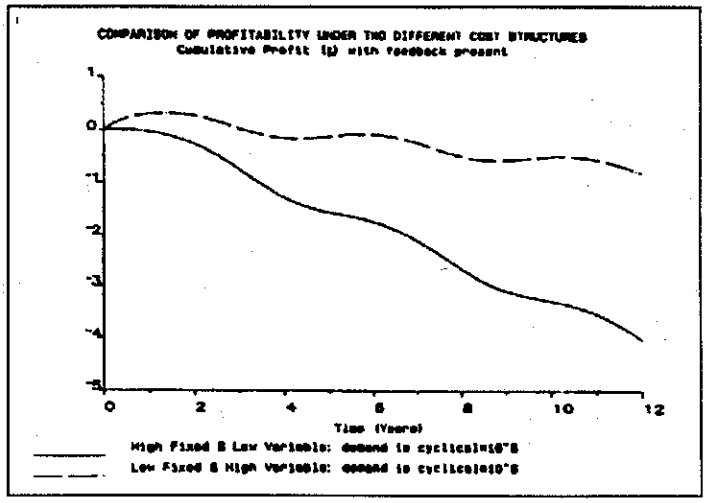


Fig 2(iii) Cumulative profit graphs; feedback; demand is cyclical

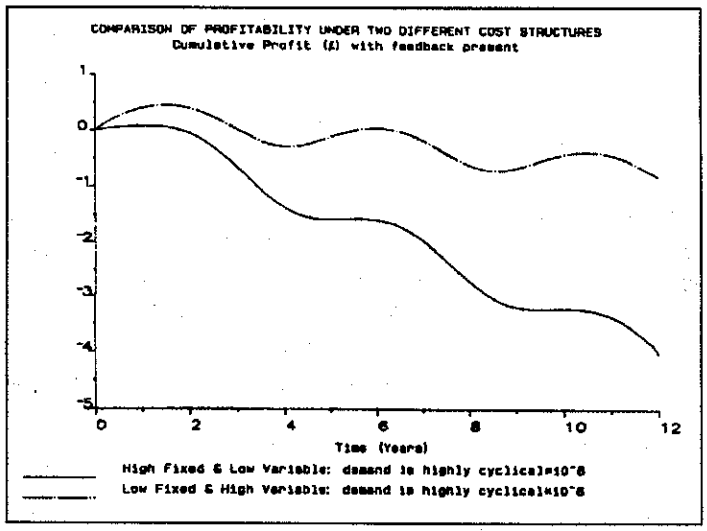


Fig 2(iv) Cumulative profit graphs; feedback; demand is highly cyclical

For the scenario of steadily increasing demand, the consequences for lost demand are the worst because the backlog has the capacity to increase continuously. In this case, actual demand suffers badly at the beginning because of the high backlog. It revives to in excess of the 10,000 units per annum break-even point only after the 8th year (not shown) and then the high fixed cost option begins to make significant profits. In the period covered by the planning horizon stipulated, the low fixed cost technology is clearly the preferred option. A high fixed cost technology would be associated with the firm's output slowly adjusting to the rising backlog and annual profit becomes superior to the low fixed cost technology at year 10 (cumulative profit does not do so until much later than this). However, the policy precept here must be that it is inadvisable to go for a high fixed cost technology if demand is affected by delivery delays and the technology cannot respond with increased output quickly enough in a sharply rising market. This is certainly the case where steel is produced in large integrated works configured with the primary aim of reaping economies of scale (Dangerfield 1993).

In the scenario where demand is falling continuously there is little difference in the cumulative profit comparison because there is little difference in the effect that the backlog has on realised demand. This effect is brief and is confined to the early years. Following that, the path of realised demand in this case

is no different from that in the no feedback case and the consequences for cumulative profit do not materially differ: technology 'B' clearly keeps the losses to a minimum.

Once again the results for the two cyclical demand scenarios are interesting. The backlog effect on demand results in a much reduced fluctuation in realised demand as opposed to potential demand. The characteristic of the reduced amplitude of the fluctuations is that more demand is lost in a boom period than in a slump. The changing amount of lost demand over the course of a cycle is such that, for the highly cyclical scenario, realised demand is only slightly lower than that for the cyclical scenario in a slump, but considerably lower than that for the cyclical scenario in a boom. There is thus a levelling down in the respective paths of realised demand. Moreover, the fluctuations in realised demand are such that, even in an upswing, there is a failure in both cases to ever attain the break-even demand volume of 10,000 units per annum. The implications of all this for cumulative profit can be seen in graphs (iii) and (iv) in figure 2. It again reinforces the precept that a low fixed cost operation is more robust than one with high fixed costs.

An additional comment concerns a comparison between the fluctuations in profit across the two cyclical demand scenarios. Because of the levelling down effect on realised demand, the highly cyclical scenario results in only a slightly increased profit fluctuation as compared with the considerably increased fluctuation (doubled amplitude) of the respective potential demand scenarios.

The second questionnaire was administered to a total of 110 students of which 42 were final year Business and Management students, 40 were final year Finance and Accounting students and 28 were postgraduate Management students. Compared to the first questionnaire, it was quite clear that the presence of feedback was far too much of a challenge to the perception of the respondents. Yet the challenge was only a two-stage one. It was, firstly, necessary to assess how the backlog effect might impinge on realised demand and then to make a projection, the same as that done in the no feedback situation, in order to tease out the implications for cumulative profits. There was deemed to be no feedback between profits and demand, only between order backlog and demand. Despite the description of the circumstances in which the feedback operated being highlighted by thick double lines in the margin of the questionnaire rubric (and the verbal instruction that they must take careful note of the passage which was the only change from the first questionnaire) very few respondents managed a correct answer *together with* a plausible explanation.

Considering correct answers regardless of whether they were accompanied by a plausible explanation, it is possible to discern a pattern to the responses as compared to those given in the no feedback situation. For question 1, 74 respondents (67%) thought (wrongly) the correct answer was technology 'A' as it had been in the first questionnaire. While this was significantly less than the proportion offering the same answer in the earlier questionnaire (80%, $p = 0.03$), the high fixed cost technology was clearly the most popular answer in the second questionnaire. For questions 2 and 4 the correct answer was technology 'B' in each case and because these were the same answers as in the first questionnaire, it was possible to give the correct answer without considering the effect of feedback at all. Questions 2 and 4 were answered equally well in both questionnaires.

It would not be unreasonable to infer, from a comparison between the responses to questions 1, 2 and 4 on the two questionnaires, that people cope with feedback by reducing the problem to one without feedback. This phenomenon is not so easily demonstrated with question 3 because, although a significantly smaller proportion answered this question correctly in the second questionnaire, an answer of *either* of the two technologies was deemed correct in the first questionnaire whereas only technology 'B' was accepted in the second.

It is not surprising, therefore, to find that an analysis of the numbers of correct answers overall showed the second questionnaire to be far more poorly answered. There were significantly more who had 3 or 4 questions correct (out of 4) in the first questionnaire than in the second, 74/134 compared with 17/110; p

< 0.01. Moreover, significantly fewer had none or only one correct answer in the first questionnaire than in the second, 22/134 compared with 67/110; $p < 0.01$. As with the first questionnaire a check was made as to whether answers had been chosen by chance. A binomial model was used to compute the expected numbers obtaining 0,1 ... 4 correct answers. Again the hypothesis that all respondents chose answers purely by chance was rejected, albeit at a lower significance level ($p = 0.07$).

Finally, in comparing the results of the first and second questionnaires, an analysis was conducted of the numbers selecting the option 'unable to advise the firm in these circumstances'. The outcome is revealed in Table 2 and it shows, quite clearly, that a significantly higher proportion of the respondents were unable to advise the firm in the situation where feedback was prevalent than where it was not. This finding was the same over all types of demand scenario, $p < 0.01$ in all cases.

**TABLE 2**

| | Questionnaire 1 (%) | | Questionnaire 2 (%) | |
|---|---|---|---|---|
| Question 1 | 2 | (1) | 14 | (13) |
| 2 | 7 | (5) | 18 | (16) |
| 3 | 22 | (16) | 35 | (32) |
| 4 | 22 | (16) | 40 | (36) |

**Discussion**

This study supports the contention that, in the absence of a model, people experience some difficulty in articulating likely future system behaviour. Even in respect of very simple situations where no feedback effects were imposed, it was clear that the behaviour of the driving variable (demand) imparted a degree of difficulty onto the problem whenever that behaviour was more complicated than linear growth or decline. Yet planning groups in industry ought to consider how their polices will fare in recessionary as well as boom conditions.

Layering a feedback effect onto the original situation resulted not so much underperformance as no performance. Temporal reasoning powers in situations possessing feedback effects have been shown to be negligible, at least as far as this sample of respondents was concerned. However, it would be interesting to repeat the experiment with a group of practising managers, perhaps attending a post-experience course.

The sort of experimental conditions described can also be extended to evaluate any improvement observed in responses if the participants are confronted with the same questions after they have acquired system dynamics modelling skills. For instance, the questions might be posed at the beginning and then towards the end of a course on system dynamics when the respondents would be free to devise their own models to assist in determination of their advice. This may have an advantage over a similar strategy using a business game exercise, because there it is not possible to gauge the improvement effect arising from bringing a model into play without 'giving the game away'.

For real-world capital investment decisions in manufacturing industry the research does convey a message that low fixed costs are a desirable goal. This contrasts with much of the received economic wisdom that economies of scale, almost always implying high fixed cost regimes, are desirable. The situation described in the questionnaire may have been deficient in that nothing was introduced concerning the cost of construction of the plants, only their fixed and variable operating costs. But, on

the other hand, focus upon factors which determine whether an operation, once built, has the potential to survive or not is far more relevant for both the management and the workforce involved.

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