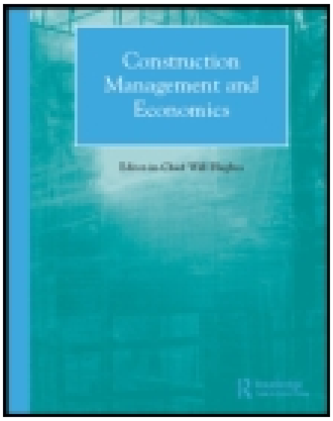

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Does quality assurance deliver higher productivity?

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This paper seeks to assess whether the implementation of formal quality schemes in the construction industry delivers higher productivity when measured at site level. The work reports an experiment in which the resources used by construction contractors to build housing association houses varied in accordance with the level of formal quality certification held by the contractors. It concludes that formally assured organizations use fewer resources to create the same output.

Keywords: Quality assurance, housebuilding, productivity

Introduction

The attainment of acceptable levels of quality in the construction industry has long been a feature of the debate about the future direction of the construction industry. In recent decades, client dissatisfaction with both the products and services delivered by the sector has placed increasing pressure on service providers to improve performance.

At the end of the last century industry began to move from being craft based to one driven by scientific production methods to such an extent that it needed mechanisms by which the quality of the new processes could be controlled. Formerly, the quality of the building produced was governed by craftsmanship; the definition of good quality rested with the master craftsman's expertise and experience. Quality was personalized.

Added to this was the fact that only a limited range of material and techniques had been used up to that time. Designers and craftsmen could communicate through simple drawings. This is illustrated by the fact that the Commonwealth Bank building in Martin Place, Sydney, a six-storey building with some 8000 m^2 of floor area, was fully documented at the turn of the 20th century on a single drawing which showed an elevation, a plan and a section through the building.

As the construction process became more detached from its craft origins and more aligned to modern production methods, the diversity in construction technology complicated the process and the responsibilities for quality management were gradually separated from the physical act of building. This move away from the crafts led to formal quality control procedures by inspection. Inspection was the first formal instrument for quality control (Dale and Plunkett, 1991) and it dominated manufacturing processes in the early 1920s until the start of World War II. Inspection systems were extended by the use of statistical quality control techniques whose use was greatly advocated by Deming (1986). This technique emphasized the sampling of the quality of the output but did little to ensure the quality of the production process itself, a source of much scrap, rework and waste (Feigenbaum, 1986).

In the 1960s, manufacturing organizations sought to introduce the concept of total quality control and redraw the boundaries of the responsibility for quality. No longer was an inspectorate responsible: now the corporate managers were given the overall responsibility for quality. By the 1980s the issue of quality

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began to emerge as a single strategic issue, so that quality was not seen as something engineered into the production process but more as an all embracing management system.

Such systems found themselves formalized by quality assurance schemes. These showed that quality could not be 'inspected in' but rather that it had to be in-built into the design and production process in such a way as to 'provide adequate confidence that a product or service will satisfy a given requirement for quality' (BS4778 Part 2, 1991, first published in 1971). By 1987 the industry had developed its own generic standards for this concept (BS 5750, AS 900) corresponding to ISO 9000 and, in Australia, an industry specific standard, AS2990, was developed for construction.

These QA mechanisms placed great emphasis upon procedures and compliance with pre-set standards. Such standards, in theory, contributed to greater coordination of the many parties involved in a construction project but, as Shammas-Toma *et al.* (1996) argued, the QA systems, and procedures have created considerable dissatisfaction with the quality of work produced under formal QA regimes.

The drive for the implementation of QA initiatives came largely from government and major clients in order to enable the supply chain within construction to be coordinated through sets of interlocking documents which provided a consistent framework. In the UK a BS5750 registered firm of plumbers would subcontract to a registered contractor to fit a BS5750 registered supplier of, say, a toilet bowl which would be fitted by a Level 3 NVQ certified plumber. In Australia, the push to adopt standard based QA processes in construction came from state and federal governments.

Since the late 1980s, this procedure bound model has gradually been giving way to TQM, which has proclaimed itself as a management philosophy rather than an empirical tool. The era of total quality management had arrived. Together with the term 'world's best practice', this movement ushered in an approach that integrated total process quality, product quality and continuous improvement. These ideals were reinforced and institutionalized through national quality awards.

Unfortunately, this approach achieved only limited gains in product quality and only among a limited number of suppliers. Many industry organizations saw quality as a marketing tool. It was demanded by clients and therefore had to be provided. In many instances, quality system development was funded from the marketing budget and little was expected from the implementation. In this environment, quality consultants with little or no knowledge of construction processes were engaged to 'supply' a quality system that would meet the client demands. Initially this process provided cynical service providers with a certificate and a set of quality documents that gave them entry to the client's tender list. Predictably this has led to clients developing a jaundiced view of quality systems. The perception in the Australian construction sector is that while lead organizations have joined their peers in manufacturing and believe that the TQM philosophy is essential to business survival, many still debate whether quality management is worthwhile. A 1996 survey of the Australian construction industry showed that attitudes to quality management varied widely between those practitioners who had experienced the implementation of a quality system on a project and those who had not. Those with experience were committed to the process whereas those with no experience were cynical, seeing the process as no more that a marketing tool.

At the same time Marosszeky (1995) reports that government clients in New South Wales are disillusioned with the results achieved by demanding quality systems of their suppliers. They are turning to a philosophical reliance on measured quality of products procured rather than quality system compliance. The problem is that there is no link in third party quality system certification between system compliance and product quality. The above factors have stimulated a discussion of the efficacy of the QA/TQM paradigm in delivering improved quality standards in construction.

Burati *et al.* (1991), Tyler and Frost (1991) and Kline and Coleman (1992) have argued that although the QA approach has shifted standards upwards, TQM offers greater scope for process improvement. However, Shammas-Toma *et al.* (1996) studied 25 construction projects and found that quality 'generally fell below required standards', despite all contractors having quality control procedures in place and all but two in the study had BS5750 certification. The number of contractors involved is not given.

The question regarding the usefulness of the quality management systems in delivering higher quality remains as a keen point of discussion in the construction industry. Does it, however, deliver other things?

This paper addresses the question of productivity benefits that might arise from the implementation of quality systems. If this is the case, then the discussion regarding the use of formal quality management systems immediately becomes much more important for the industry. In short, does the use of formal quality systems improve site productivity? Before going on to address this question, it is important to identify what is meant by productivity and how it may be measured.

Productivity measurement

Many theorists have struggled to define precisely what is meant by productivity. Perhaps one of the most generalized definitions is offered by Prokopenko (1987). He regards productivity as an effective and efficient utilization of all resources; labour, plant and materials. However, this generalized definition masks the variety of approaches evident in the literature. Four theories of how productivity may be measured can be detected. They are:

1. productivity as a ratio
2. productivity as a rate of return
3. productivity as a form of efficiency
4. productivity as a utilization of resources

Productivity as a ratio

This is one of the most widely used definitions. Talhouni (1990) and Easterfield (1953) both see productivity as a ratio of output to input of materials, labour, energy and capital equipment.

Productivity as a rate of return

Return on investment is seen by many as a valid measure. Hornglen (1965) and Risk (1965) suggest that a measure of productivity can be obtained by comparing the assets used in production with the value of product produced by these assets.

Productivity as a form of efficiency

Although efficiency and productivity are often used interchangeably they are different. Efficiency may be seen as a relative measure of actual output to potential output and so expressed as a percentage. Hence, the concept of efficiency is limited to the utilization of a set combination of equipment, materials and tools. By contrast, productivity is concerned with the effective utilization of various resources which encompass the totality of production.

Productivity as a utilization of resources

This concept sees productivity as a function of 'utilization, performance and method' according to Feiner (1968). By increasing all of these factors one is maximizing productivity. The selection of an appropriate theory for the measurement of productivity at site posed a problem in the research design, and after consideration it was decided to use 'the utilization of resources' theory.

The reasons for this selection were manifold. The work of Bishop (1975) was influential when he defined productivity in the context of construction 'as the optimal use of resources to obtain an acceptable goal'. The resource utilization theory also enabled the researchers to compare the utilization of resources occurring in different sites and comparing the resources used against a fixed output. Consequently, high productivity was considered as occurring when the utilization of labour, materials and capital (plant) was optimized to provide a specific value of construction work.

This view led the researchers to consider how to measure productivity. Five levels of measurement were identified.

International productivity comparisons
National productivity comparisons
Industry productivity comparisons
Company productivity comparisons
Site level productivity comparisons

In our study, it was found that most previous research on site level productivity had concentrated on partial measures of productivity, such as labour productivity measured by output per man-hour. Although ratios were important, it was vital that the mix of inputs to construction be recognized, and that one issue was not to be used as a surrogate for others. Lowe (1987) concludes that 'total factor productivity is the ideal against which other approaches should be judged' when considering productivity measurements in the construction industry.

The total productivity factor was chosen as the appropriate instrument for measuring site productivity for the following reasons.

(i) It is consistent with the working definition of productivity to be used in this study.
(ii) It reflects the methodology chosen for this study which draws on the mixture of resources and which best describes construction productivity.
(iii) It integrates the contribution of all resources used in a construction project: materials, plant and labour.

Methodology development

In short, the task of productivity measurement was assessed by the measurement of the quantity of resources used in achieving a given output. Obviously the difficulty in obtaining a homogeneous output in construction is an obstacle. In this research the output was measured in monetary terms. The inputs on project one were measured as labour (L1), materials (M1), and plant (P1) and these inputs gave an output of £. If another construction company achieved the same output but used fewer total inputs to achieve this output, then it could be said to be more productive.

This approach, however, is not without its problems. Ideally the output measurement should be uniform in character, e.g. widgets produced or bricks laid. In this study the monetary value of the output was taken as a surrogate measure of the physical quantities. This then raised the problem that the heterogeneity of construction work, with different technologies, specifications and ground conditions, etc., make the alignment of monetary values and physical output of construction work difficult.

In order to eliminate as many of these variables as possible a number of issues were considered and assumptions made. First of all, similar construction firms were selected. They were medium size firms specializing in and competing in the medium-density housing market. It was assumed that their buying power for materials and their management structures would be similar. Detailed information regarding management costs on the projects in the sample were not obtained; however, this is a variable that might warrant further study. Second, a uniform construction product (as far as is possible) was selected.

In this case the sample was selected from one client type: housing associations, producing one type of product, housing, in low-rise flats of similar size and construction type, in one geographical area, Glasgow, within a short time frame, namely 1988–1992. In all cases traditional forms of procurement were used. The type of housing selected comprised 3–4 storey slab blocks, 20–30 dwellings in each. Construction was reinforced concrete framed with flat slabs and edge beams with brick infill walls.

Some confidence in the method was gained from the work of Thomas *et al.* (1990), a leading group of construction productivity researchers, who argued that the monetary value of the outputs matches those for inputs and used this assumption to create a model for estimating total factor productivity for construction.

How then were these inputs modelled? Here, the theory of isoquants was found to be useful. An isoquant is a curve connecting points representing different combinations of resource inputs into a construction process. These inputs produce a quantity of output. In construction the inputs were labour and capital (plant). The essence of the methodology is to measure and compare the quantity of the resources used in achieving a certain level of output.

The theory, first suggested by Farrell (1957), is that if a production unit (e.g. a building site) utilizes its resources most efficiently, it must be using the minimum amounts of input required to produce a given level of output. Consequently, one can compare the productivity of two sites producing broadly the same product. Figure 1, drawn from Ruddock (1994), shows seven organizations (A–G) all producing a single output Y with inputs X1 and X2. All seven organizations produce the one type of output. Organizations B, C D, F and G are using resources efficiently; B uses more of X1 than C but less of X2. Similarly, organization D uses more X2 than organization C but less X1. However, there are grounds for believing that organization E is unproductive as it uses more of both inputs X1 and X2 than C and yet produces no more output.

Therefore, for a fixed output, the productivity of projects could be compared from the point of view of resource utilization. A key assumption made by Farrell (1957) for the productive unit isoquant is that the productive isoquant is never upward sloping and is always convex to the origin. Convexity means that if two input bundles can each produce one unit of output, then so can any weighted average of them. In terms of the above diagram it means that an organization could, for example, operate at C or D or anywhere along the line segment CD. These two assumptions allow productive bundles to be separated from non-productive bundles.

Productive bundles are found by picking adjacent pairs of bundles and joining them with a line segment, as seen in Figure 1. If the line segment has a non-positive slope and none of the other bundles on the isoquant map lies between it and the origin, then the chosen bundle may be considered as efficient, in the utilization of resources, and ‘productive’, in the sense of this study. Therefore, bundles B and C, for instance, would be declared productive because line BC has a negative slope and there are no bundles between it and the origin.

The line segments linking all the productive input bundles trace out the productive isoquant. This isoquant envelops all the less-productive organizations which lie to its north-east. As construction techniques become more efficient through technological change, the inputs are reduced and the isoquant moves towards the origin and the plant axis, indicating increasing relative investment in plant and a reduction in labour.

Farrell defined the productive efficiency E_p of any ‘less productive’ unit, say at a point A, relative to a ‘productive’ unit at A′ which has the same ratio of plant and labour inputs and lies on the productive isoquant as:

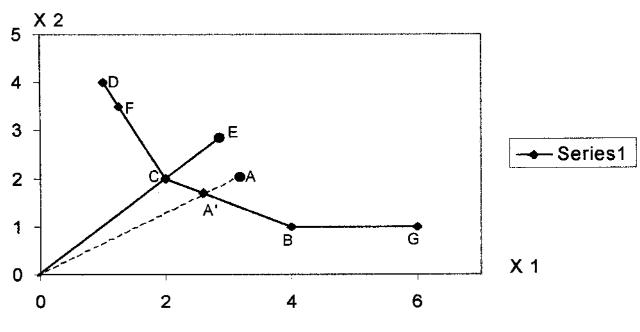

Figure 1 A productive isoquant frontier (Ruddock, 1994)

E_p =OA/OA′

where OA and OA′ are the distances of the points from the origin

As production at unit A becomes more efficient, and as provided that the ratio of inputs remains constant, the point A moves closer to A′ along the line to the origin, and the value of E_p approaches unity. The less efficient a production unit, the greater the value of E_p. The distances OA and OA′ can be calculated mathematically, and hence values for the productive efficiency E_p of all the points in a sample are readily calculated.

While this provides an easily calculated and convenient method for the numerical analysis of relative efficiency, it should be noted that the approach assumes that the ratio of plant to labour inputs remains constant as technological change takes place. While this may hold true in some instances, often, as technology develops, plant investments skew the ratio of inputs. Having defined the theories to be used, our next task was to assess the productivity of a sample of projects. Some 30 organizations were contacted which had completed housing association projects in the Glasgow area in the period 1988–1992, and from these organizations some 24 firms were selected; 12 of them were registered with BS5750 and 12 not registered. Each organization provided a priced Bill of Quantities for a single project.

The procedures used for analysing each Bill of Quantities followed the methodology devised by Horner (1996). This involved five steps.

(i) Identify cost significant items,

(ii) In the Bill of Quantities apply Horner's formula. The cost significant items are defined by Horner as those 20% of Bill items which represent 80% of the total cost. Horner determined that the cost significant items are those which are greater than the mean value of all Bill items. This means that the 20% cost significant items may be readily found by identifying all those items whose value is greater than the average Bill item price. This is expressed by Horner as:

$$A = V1/N \quad \text{and}$$
$$V2 = 100/80 \times V1$$

Where V2 is the total Bill value, V1 is 80% of the total Bill value, N is the number of Bill items, and A is the average value of Bill items. So, any Bill item with a value greater than A was considered to be cost significant.

(iii) Having selected the cost significant items, the costs of plant and labour for each cost significant item is broken out using the Wessex Building Price Data book. The cost of materials is excluded from this calculation as all buildings in the sample were constructed of an in situ concrete frame with brick infill. Thus, materials could be considered as a constant across the sample.

(iv) The total value of labour and plant for each project is aggregated.

(v) The total cost of each resource is divided by the Bill value to obtain the amount of resource input for our £ of construction work. This enables comparisons to be made across the 24 projects.

(vi) The data obtained are then plotted as an isoquant to test the proposition that productivity benefits might arise from the implementation of quality systems.

It was found that construction organizations with formal quality assurance systems use fewer labour and plant resources to obtain the same level of output when compared with those who do not have formal quality assurance systems.

Results

The data obtained for each of the 24 projects are given in Table 1, the construction of which is based on a relative weight of resource. Thus, for example, for project Q1 the figure 0.1483 under the 'plant' column is obtained from the formula:

$$\frac{\text{Cost of plant input}}{\text{Total value of output}} = P_1 \times \frac{1.25}{T} = \text{figure to represent the plant resources used in project Q1}$$

where the aggregated value of plant in all cost significant items in the Bill, P_1, is multiplied by 1.25 to

Table 1 Input ratios for the 12 projects

Quality assured			Non-quality assured		
Project No	Plant	Labour	Project. No	Plant	Labour
Q1	0.15	0.84	N1	0.20	0.62
Q2	0.19	0.68	N2	0.26	0.40
Q3	0.23	0.53	N3	0.36	0.74
Q4	0.26	0.77	N4	0.38	0.56
Q5	0.29	0.41	N5	0.38	0.40
Q6	0.31	0.54	N6	0.40	0.57
Q7	0.32	0.39	N7	0.44	0.57
Q8	0.33	0.33	N8	0.48	0.34
Q9	0.35	0.47	N9	0.50	0.56
Q10	0.37	0.32	N10	0.59	0.39
Q11	0.42	0.62	N11	0.63	0.40
Q12	0.47	0.30	N12	0.64	0.40

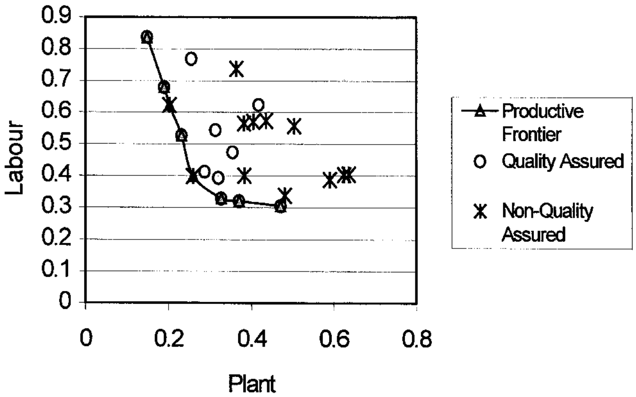

Figure 2 Productive isoquant for the 24 projects in the study

reach to the total cost of plant input as P_1 only represents 80% of the total value (it should be noted that this value excludes overheads and profit), and where T is the total value of the project.

From the data obtained, an isoquant diagram was constructed (Figure 2). As can be seen, the isoquant is formed by eight projects in all, six built by companies which were formally quality assured and two that were not. It is also noticeable that the formally assured contractors are clustered closer to the isoquant whereas the non-assured firms are generally more distant from it. The closer a project is to the frontier the fewer resources it uses to build the same value of work.

In order to test if the bipolar sample of quality assured firms and non-quality assured firms are drawn from similar or different groups a statistical cluster analysis test was applied to the data. In entering the data projects, 1–12 were those firms with quality assurance certificates and 13–24 were those without. Cluster analysis shows that the formally quality assured and the non-assured groups are two distinct clusters of firms. Further evidence of the dissimilarities between the samples can be seen in the curves fitted to the two sets of data in Figure 3. The curve of best fit (polynomial) for the quality assured projects is relatively a much better fit than the curve for the non-quality assured projects with an R^2 of 0.55 compared with a value of 0.26. For the non-assured projects, the data points are much more scattered, reflecting greater disaggregation and this is reflected in the lower R^2 value. The implications of this are discussed in the Conclusions.

Table 2 shows the results of the productive efficiency calculations for the 24 sites examined in the study. The mean E_p for the quality assured sites was 1.124, a low value indicating that on average, sample of projects from quality assured firms were efficient relative to the productive isoquant. By comparison, the non-quality assured sites had a mean E_p of 1.317, indicating that, on average, the projects from the non-quality assured firms were some 17% less efficient. Using this measure of relative productive efficiency, the quality assured sites are significantly more productive.

Table 2 Productive efficiency ratios E_p

QA projects		*Non-QA projects*	
Q1	1.00	N1	1.00
Q2	1.00	N2	1.00
Q3	1.00	N3	1.51
Q4	1.25	N4	1.44
Q5	1.06	N5	1.20
Q6	1.25	N6	1.49
Q7	1.09	N7	1.54
Q8	1.00	N8	1.09
Q9	1.26	N9	1.62
Q10	1.00	N10	1.27
Q11	1.58	N11	1.33
Q12	1.00	N12	1.33
Mean	1.12		1.32
Std Dev	0.18		0.21

Yet another perspective on relative productivity can be drawn from Figure 4, which shows a set of curves parallel to the productive isoquant moving away from the origin and the axes. Projects falling into the band closest to the origin and axes are more productive than those in bands further out. These parallel bands define projects of approximately equivalent productivity. It is noteworthy that within a band of similar productivity different companies may use a wide range of resource combinations from high labour–low plant to the opposite. Companies which fall into the lower productivity bands, further from the origin and the axes, use more resources, though they too range through widely differing combinations of plant and labour.

Conclusions

The main finding of this study would tentatively suggest that formal quality assurance systems make a modest contribution to the improvement of construction productivity where this is measured by using the total productivity factor method. The important question is why may this be the case? In part, the conclusions may be explained by the way in which the process of quality assurance isolates the factors which can be controlled by site managers. These controllable variables are internal to the company and may be said to contain issues such as:

How resources are managed
How information is managed
The management of the organization structure
How well people are managed
How well staff are trained

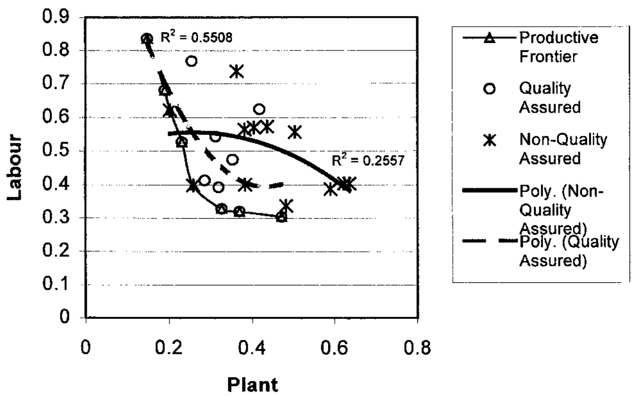

Figure 3 Polynomial regression showing R^2 for quality assured and non-quality assured projects

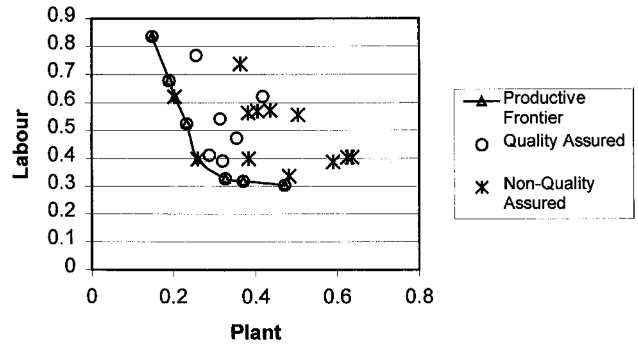

Figure 4 Productive bands parallel to the productive isoquant

In discussion with the site managers of all of the 24 projects, it was determined that formal quality assurance measures crystallize the management of the above variables. By providing a framework for managing quality, other issues concerning management control come to the fore.

Implementation of quality assurance systems leads to better management of the above variables, which influence productivity rather than quality. It would appear that the implementation of quality assurance systems led to better utilization of site based resources; that which had been done previously in an ad hoc way had now become formalized and systematic (and a great deal less fun). As Shammas-Toma *et al.* (1996) point out, the purpose of QA was to increase coordination and information flow. Although their research reports that practitioners find QA wanting, in terms of delivering its stated purpose of higher quality, it still may have benefits which are as yet unrecorded.

The diversity of resource combinations yielding comparable productivity justifies the adoption of the total productivity factor approach. It also indicates, counter to popular belief, that high investments in plant and automation do not necessarily yield the most productive outcomes within any given economy. The finding needs to be put into the perspective of the nature of the sites used in the study. All sites were based upon a simple, well understood technology which had not changed in some 20 years: materials, construction methods and machinery used had remained more or less constant.

The productive frontier for the project contains a wide mix of resource combinations of labour and plant. Although, instinctively, we may believe that highly productive sites are more mechanized, in this sample the low degree of innovation in this type of construction project has meant that conditions where labour is the dominant resource can be as productive as situations where plant is widely used. The result is not so much counter-intuitive as more a function of the nature of the product being built.

The point is reinforced by the fact that the average plant used by QA'd organizations (0.31) is much less than that used by the non-QA'd (0.44). The skew on the productive isoquant (Figure 2) suggests that productive firms use more labour and less plant. This combination would be typical on traditional construction but less likely in settings requiring innovative construction methods.

Comparing the set of points representing the quality assured projects to the non-QA'd, it may be observed that nearly all of the accredited projects lie in the more productive bands closest to the production isoquant. In addition, and more importantly, this demonstrates that the resources utilized by the quality assured contractors are more consistent with each other. The non-QA'd projects are scattered more widely, with as many falling in the less productive bands as in the more productive bands. This reflects greater variability in the use of resources to achieve a given output. The inference from this is that QA may introduce requirements of conformity of procedures, which is their stated purpose, and that this spills into the way projects are analysed and evaluated with respect to their resource requirements. Again, it says little about the delivery of quality, but much about the requirement for assessing and controlling resources.

This study broadly supports that undertaken by Fisher (1992), who considered four Sydney based companies which were embarking on quality assurance programmes in which, productivity data were collected before and after accreditation. Although no objective data were collected, the managers involved were convinced that quality improvements led to productivity benefits.

Finally, several limiting factors need to be mentioned which could impact on the data and also on the analysis. First, the primary data were drawn from priced Bills of Quantities, and so the prices used in the research may not have been the prices used in undertaking the actual work. Negotiations between contractors and with subcontractors, plant suppliers, etc., may be much more aggressive after a bid has been successful. This may distort the data. Second, the pricing strategies implemented will influence the unit rates for various Bill items. Expectations of quantity changes, front-end loading strategies, etc., will all influence the primary data used.

Other issues, such as the mechanism for pricing Bill items, may distort the evenness of the primary data. Some contractors will price common plant items, such as cranes, in the preliminaries, while others will proportion such common costs to each bill item. Further, much of the work will have been undertaken by subcontractors, some of whom may have been accredited while most were not. However, the necessity for accredited contractors to create a quality plan to which subcontractors had to agree provides sufficient delineation between those subcontractors who were used on the quality assurance accredited projects and those who were not. These factors could not be accounted for in our analysis, and are limitations, that need to be acknowledged.

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