PRODUCTION THEORY AND CONSTRUCTION PRODUCTIVITY

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ABSTRACT

The theory of production applied to the construction industry has been typically based on management theories, and the application of the economic theory of production is less common. The economic theory of production focuses on features of the demand for factors of production (inputs) and output of commodities to develop input and output functions. The issues involved on the input side are concerned with the technical constraint of production processes that determine the cost base, and on the output side with the structure of markets where prices and revenues are determined. This paper focuses on the input side. The purpose of the paper is to discuss properties of construction production technology in the context of the economic theory of production and the production function. The paper then discusses the role of technical progress and shifts in the production function due to the adoption of new techniques which affect the production process or change input/output relationships.

KEY WORDS

Theory of production, Productivity, Production function

INTRODUCTION

This paper attempts to bridge the gap between Koskela's evolving theory of production, that is the basis for lean construction (LC), and the economic theory of production that is the basis for productivity analysis. The motivation for this is found in the conclusion where a research approach is suggested that could help prove the effectiveness of the lean project delivery system (LPDS) as a production control system.

In the evolution of Koskela's ideas since the 1972 publication of 'Application of the New Production Philosophy to Construction' construction specific theory has developed into what is now the Transformation-Flow-Value (TFV) theory (Koskela 2000). This is now a well developed theory that draws on the management literature and its history as its base. As explained by Koskela et. al. (2002):

What is needed is a production theory and related tools that fully integrate the transformation, flow and value concepts. As a first step toward such integration we can conceptualise production simultaneously from these three points of view … however, the ultimate goal should be to create a unified conception of production instead. (Koskela et al. 2002: 214).

The TFV theory combines three points of view and is built on the insight that there are 'three fundamental phenomena in production that should be managed simultaneously'. The ideas of LC started with site operations but have been progressively applied to the supply chain, design and cost management and project delivery. These elements are brought together in the LPDS. The LPDS is detailed by Koskela et. al. (2002), and the LC tools and techniques by Ballard et. al. (2002).

STRUCTURE OF THE PAPER

The paper starts by arguing there is no other theory of production in the construction literature, that what is typically found in is not production theory but management theory applied to construction. There is a short overview of some significant management theories found in the construction literature.

The next section looks at the economic theory of production and the features of that method of

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analysis. That is followed by a discussion of the construction production function. A graph is presented that shows the distribution of the 17 construction trades in Australia based on the output per employee in each the trades. The implications of using the economic theory of production in conjunction with the LC theory of production are then discussed.

MANAGEMENT THEORIES

Outside the LC movement there has been limited interest in a, or indeed any, theory of production as applied to the construction industry. What is found instead are various practice-based approaches, typically based on one of a range of management theories. The influential management theories, such as Porter's five forces (1980) and international competitiveness (1990), Hammer and Champy's process reengineering (1995), also Davenport (1993) on reengineering with information technology, and learning organisations (Argyris 1999) are all regularly found in papers in the building and construction literature addressing issues such as competitiveness, global markets and organisational capability.

One of the most commonly found approaches takes as its starting point the ideas from corporate strategic management. Thus the books by Langford and Male and (2001) and Chinowski and Meredith (2000) have 'strategic management' in their titles, as do journal articles by those authors and others such as Betts and Ofori (1992, with strategic planning), Winch and Schneider (1993) and Veshosky (1994). Variations are 'competitive strategy' (Jennings and Betts 1996, Huovinen 2001) or 'competitive positioning' (Kale and Arditi 2002), and 'core competencies' (Lampel 2001). The report by Hawk (1992) arguably continues to be the clearest application of this approach.

Another widely used approach is to apply marketing theory. Examples are de Haan et. al. (2002) who combine market strategies and core capabilities in their paper, and Journal of Construction Marketing papers such as El-Higzi (2002) and Wang and Yang (2000) on Australian contractors. European markets have had their share of attention from Carrillo and Heavey (2000) and Male and Mitrovic (1999). Market entry and mergers and acquisitions in international construction were analysed by de Valence (2002).

The construction literature has many examples of other management theories being used, usually during a period when they had gained a high profile in other industries. The short time in the spotlight for many management theories was the basis of Shapiro's (1995) book, and described by Abrahamson (1996). Some candidates for management fads in construction might be total quality management (eg. Love et. al 2000), supply chain management (eg. Love et. al. 2002), knowledge management (Anumba, Egbu and Carrillo 2005) and relationship management through partnering (eg. Cheng and Li 2002) or strategic alliances (eg. Pietroforte 1997). Project-based management (see Turner and Keegan 2002) may have already come and gone.

ECONOMIC THEORY OF PRODUCTION

The economic theory of production focuses on the features of the input demand and output supply functions. The issues involved are, firstly, the technical constraint that describes a range of production processes available to a firm, and secondly, the structure of the markets where the firms transactions take place. The substantial literature on the latter is not relevant in this discussion.

The development of the neo-classical theory of production was based on the model of a cost minimising and profit maximising firm, subject to an underlying technology. The main economic concepts are: the level of output, returns to scale, distributive share of inputs, price elasticity, elasticity of substitution of inputs, and disembodied technological change. Technological change includes the rate of technical change, acceleration of technical change over time, and the rate of change of marginal products due to technological change. By imposing specific restrictions across these effects different functional forms of the production function can be obtained (Sato1975). Of all of these economic effects, those associated with returns to scale, degree of substitution among inputs, and the type and nature of technological change have received most attention in the economic literature. These economic effects arise from inherent nature of a specific production process.

THE PRODUCTION FUNCTION

The output of a production process is a function of (is determined by) the flow of inputs used, and this relationship is called a 'production function'. The starting point of production theory is therefore a set of physical technological possibilities represented by a production function that relates the quantity of output to the inputs used. The production function that originated with Cobb and Douglas (1928) has become the traditional approach, and has been widely employed in empirical economic research. The Cobb-Douglas production function was based on a multiple regression of inputs of labour and capital on aggregate net output of the US economy. The form used was:

$$Q = AL^{\alpha}B^{\beta} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

where Q is output, A is a given level of technology and α and β are the elasticities of output with respect to labour and capital services inputs respectively. The restrictive assumptions of the Cobb-Douglas function required that elasticity of substitution between inputs is equal to one. Thus, in Cobb-Douglas if labour input increases by x per cent (where x is very small) then output will increase by αx per cent. These elasticities of output with respect to labour and capital allow the marginal product and marginal productivity to be found (i.e. the effect on total output of the addition of an extra unit of labour or capital). Cobb-Douglas is therefore the starting point for modern productivity analysis (Denison 1993).

There are a number of different forms of the production function, because, depending on assumptions made about the relationships between inputs and outputs, the form of the mathematical function describing these relationships will differ (Fuss, McFadden and Mundlak (1978: 219–68). In the production function of Arrow et. al. (1961) elasticities of substitution are constant, but do not necessarily equal unity. Cobb-Douglas turns out to be a version of their CES function.

TECHNICAL PROGRESS

The bias of technical change is the response of the share of an input in the value of output to a change in the level of technology. Technical progress deals with the effects of shifts in the production function due to the adoption of new techniques which can affect the production process or change input/output relationships. Several definitions of technical progress have been proposed, these include product-augmenting, labour or capital augmenting, and input-decreasing and factor-augmenting. Thus the economic view of technical change does not address specific examples of new products or processes, but is concerned with the observable effects on the quantities of (measurable) outputs and inputs.

According to Hicks (1932) technical change minimises use of a factor whose price has increased and made its relative cost increase. This factor-biased technical change is from Hicks' *The Theory of Wages*: 'A change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind – directing to economising the use of a factor which has become relatively more expensive' (Hicks 1932: 124–125). In other words, a relative higher price of labour (or capital) is thought to lead to labour-saving (or capital–saving) innovations. This substitution mechanism is the basis of the induced technical change theory.

However, using a production function as a method for measuring technical change does not provide an explanation of how changes in outputs and inputs occur. 'Simply labeling these changes as 'technical progress' or 'advance of knowledge' leaves the problem of explaining growth of output unsolved' (Jorgenson and Griliches 1967: 460–61). Output growth is driven by improved productivity.

PRODUCTIVITY

From the production function the level of productivity can be found, which gives the ratio of output to inputs. The most widely used approach for total factor productivity (TFP), using both capital and labour inputs, is the Solow (1957) method, used as the basis for the 'official' TFP series from the BLS in the US and the ABS in Australia. The Solow method of calculating productivity relies on assumptions of perfect competition, no externalities and constant returns to scale. Although these assumptions have been criticised (see Hall 1990 on returns to scale and industry dynamics and Summers 1990 on the externalities of capital investment):

> The Solow formula allowed the separate identification of shifts in the production function from movements around the production function, a calculation that then revealed the surprisingly large fraction of the growth in output that is attributable to growth in the *efficiency* of factor use, rather than to the *quantities* of the factors used. (Baily 1990: 143, author's italics).

It is this 'surprisingly large' efficiency gain that is of interest in the context of the contribution that LC can make to construction productivity. Productivity gains from the increased efficiency that results from better workflow or application of LC tools and techniques is the basis of the claims for improved performance from using LC instead of traditional project management.

THE CONSTRUCTION PRODUCTION FUNCTION

Using data on construction industry output and employment available on the Australian construction industry from the Australian Bureau of Statistics (ABS 1996) a production function can be derived, as in Figure 1. This shows the level of labour productivity by trade class for the Australian industry, measured by output per person.

The idea behind this production function is that it demonstrates that the productivity of particular construction processes can be measured. This is the basis for the suggestions below, where it is argued that stages of the construction process can be measured in a similar way. Also, the production function shows the trades with the lowest and highest levels of labour productivity[2]. The range of productivity levels across the trades suggests the extent of gains that might be made in applying LC to building projects. For example, a ten per cent gain in bricklaying or tiling will not deliver the boost to productivity that a ten per cent gain in structural steel or electrical work will. The suggestion below is that other categories or stages of a project can be used instead of the trade categories used in this example.

PRODUCTIVITY GAINS THROUGH LEAN

The neoclassical view of the firm was described by Coase (1972) as an 'applied price theory' approach featuring the 'firm-as-production-function'. This view gave technology a key role in determining efficiency. However, there is more to the story, because management of the production process determines, to a large extent, the efficiency with which inputs are utilised. Denison (1993: 24) concluded his review of growth accounting and productivity research with comments on the role of management in productivity. He argued that some, probably significant, portion of the productivity slowdown in the 1970s was due to a decline in management effectiveness in American industry. Alternatively, there may have been a slackening in competitive pressures and less innovation in management methods, leading to a slower rate of productivity growth in the 1970s and 1980s compared to the 1960s. Either way, the key role of management in generating ongoing productivity gains is clear.

In a project based industry it is not easy to compare performance, as the limited success of many benchmarking efforts has shown. International comparisons of projects are bedeviled by the problem of exchange rates and purchasing parities. Also, productivity is often mistaken as a cost function, rather than an output function (as in cost per square meter not the quantity of inputs used per square meter). The production function approach addresses these issues.

For the construction industry, the ideas and methods of lean in general and LC in particular offer an opportunity for efficiency gains that have not been unlocked by any of the management theories covered in section one of this paper, or any of the other many management theories around. Why is this so? There are three parts to the answer.

First, LC is the only theory of production to have been developed specifically for the construction industry, as discussed above in this paper. Therefore it provides insights into the range of process that are involved, based on theory, that lead to propositions that can be tested by application to building and construction projects. The many case studies that have been published at the LC conferences over the years are all tests of the theory and practice of LC. These teats now add to a substantial body of evidence for the effectiveness of LC.

Second, the LPDS (Ballard 2000) is the only integrated approach to managing all the participants and stages of a project, from initiation to operation. Other approaches, such as value management, design management and indeed project management, only cover certain stages or a specific stage in the progress from conception to operation of a building, facility or structure. The LPDS is a framework starting from the project life-cycle, not adding bits on to achieve a comprehensive looking project plan.

Thirdly, drawing on LC theory and the LPDS as an application of that theory, the way building and construction projects are managed can be reconceptualised using the tools and techniques of lean. From the new management methods that LC engenders (for example, the activity definition model and set based design), come sustainable efficiency and productivity gains that have proved to be so elusive under traditional project management in the construction industry.

One issue that arises is how to best measure these potentially large efficiency gains from LC. The problem of using traditional project cost and schedule performance is the heterogeneity of projects and difficulty of establishing a common base for these comparisons. Miles and Ballard (1997) used a series of similar projects to argue for improved time performance, but even then this does not measure construction productivity on the projects. Using per cent complete (PPC) performance over time on a project is a good indicator of productivity improvement, but it is hard to make meaningful comparisons between projects using PPC.

2 Note that this industry-wide level of output per person is not a benchmark and cannot realistically be used to set productivity targets for a project. That has to be done using one of the project productivity measurement systems.

MEASURING LABOUR PRODUCTIVITY IMPROVEMENT

The production function approach applied to lean and productivity improvements due to use of LC tools and techniques would provide solid evidence of the effectiveness of the LPDS. How could this be done? The key is the input data for hours or days worked on the project.

The proposal is to make a couple of assumptions in order to establish a model of a project. The first assumption is the labour component (percentage of total cost of the stage) of each of the four LPDS stages: project definition, lean design, lean supply and lean assembly (see Ballard 2000 and Koskela et. al. 2002: 218 for the model). The second assumption is to set a rate per hour worked for each of the stages and use that to estimate the hours worked.

Although this project model is not 100 per cent accurate, that is not intended nor necessary. (The economic model is an analytic device that has proved its usefulness many times, but would never be defended as accurate for any given production process). The model is a simplified, abstracted version of a real project that is designed to produce labour productivity measures. It will work for the purpose, which is to establish the level of labour productivity for a given project. By use of the model projects can be compared and over time productivity gains identified. Further, it can be applied to many projects, and possibly to parts of projects where LC techniques are being applied.

One way the model could work is to estimate the labour content in the cost of the different stages, i.e. to work backward from the cost data. For example, site work (the installation stage) might have around 40 per cent labour component, but the design and detailed engineering drawing stages might have something like 85 per cent labour content. If the cost of the stage is known (from the fees perhaps) the model rate per hour is applied to get a figure for the hours worked. It will not be the right figure for that project, but used across similar projects (with similar cost structures) will produce a productivity series.[3]

Because the LPDS is an integrated production management approach, it would make sense to estimate the labour content of all the stages of the project, from definition to delivery. This can then be reduced to a single index number as the measure of productivity on that project, or for the individual stages of the project. Productivity estimates could be produced for a whole stage or for any of the steps within a stage. For many projects, comparison and ranking is easily done.

CONCLUSION

For the construction industry LC provides a theory of production that is based on the transformation, flow and value concepts found in management research, but extended into an integrated view that contends these production issues should be managed simultaneously. From the lean theory of production has developed the LPDS, an integrated production management approach for all the stages of a building or construction project's life-cycle.

By contrast, the economic theory of production focuses on the range of production processes available to a firm. The development of the neoclassical theory of production was based on a cost minimising, profit maximising firm, with a given level of technology. From the production function the level of productivity can be found, which gives the ratio of output to inputs.

There are potentially large efficiency gains that LC can make to construction productivity. One issue is to measure these gains in such a way as to establish the extent of productivity improvement, and then to show that this improvement is due to the application of LC. A production function for labour productivity in each of the stages of the LPDS would be a powerful way to, firstly, measure productivity under LC, and secondly, compare productivity levels between projects. This is the sort of evidence that is needed to establish the gains from LC as widely achievable, not just one-off results dependent on circumstance.

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3 There may be a number of methods that could be used to generate the data required for measurement of productivity in LC. The method suggested here is done so to open a discussion as much as to promote any specific approach. Until this approach is tried on a project the model cannot be verified.

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