A review of the theory and measurement techniques of productivity in the construction industry

Malcolm Abbott and Gerard de Valence

Introduction

The rate of growth of productivity in Australia, the United Kingdom, the United States and other major economies in the OECD became an issue in the late 1960s, when declining output per hour worked and output per person employed became the focus of a large research programme that sought to interpret and analyse the causes of what became known as the productivity slowdown. At this time the construction industry's low productivity growth also attracted attention. The rate of growth of productivity of the construction industry has been poor since the 1960s, even by comparison with a long-run overall industry average in the order of two to three per cent a year.

Despite the efforts made by governments, industry organisations and firms over the past few decades, the rate of measured growth of construction productivity has remained low compared to many other industries. The possible reasons behind this stagnant growth of productivity are various and could include such things as the high labour intensity of the industry, the low economies of scale in the industry, a lack of competition, regulatory impediments, faulty innovation and management practice, poor investment quality and a low levels of skills (Davis, 2007). Alternatively it is possible that the measures to determine the levels of productivity in the industry, themselves, might be faulty, as was argued in the American case when low levels of productivity growth were detected (see for instance Rosenfielde and Mills, 1979; Scriver and Bowlby, 1985).

The purpose of this chapter is to examine some of the issues surrounding the possible stagnation of growth in productivity in the construction industry as well as some of the techniques used in estimating this productivity growth (or possible lack of it). To begin with a description of the manner in which productivity growth in the construction industry has been estimated in the past is given. In addition a review is provided of previous research across five areas that have been suggested as important influences on construction productivity.

The different aspects of construction productivity measurement and performance apply at three distinct levels. Which of these three levels is the most appropriate for productivity analysis of construction will depend on the purpose of the analysis. Firstly at the industry level the focus is on the measurement of output within the national accounting framework, so we firstly look at the industry level of measurement of rates of productivity growth. The second level is the heterogeneous nature of construction products, both in type and location. The chapter collects the limited research on the effects of location and the project based nature of the industry. Generally, each project is designed and built to serve a special need.

Although specific design and construction skills are needed over and over again, the outputs differ in size, configuration, location and complexity. Such uniqueness impacts substantially on construction productivity and the construction process. Thirdly, the site-based nature of construction and project management is discussed. As a subset of these factors the work sampling studies carried out on specific tasks, processes or teams should be included. Finally, there is also another set of factors that are here called institutional, and these include construction industry policy, R&D and innovation, technological progress, regulation, the legal framework and procurement and delivery systems.

Productivity measures

The manner in which productivity of the construction industry has been analysed over the years has been influenced by the manner in which productivity analysis more generally has developed. Structural reform in a variety of industries has encouraged researchers to study the productivity and efficiency performance of these industries. In undertaking these examinations, researchers have used a range of productivity and efficiency measurement techniques. In determining the productivity performance of a firm or industry a range of indicators can be looked at. Utilities and government service providers, such as schools and hospitals, often operate in markets which lack prices and costs determined under competitive conditions. In these cases, the usual market indicators of performance like profitability and rates of return cannot be used to gauge a firm or industry's economic performance accurately. It is possible that these financial indicators might be more an indication of the distortions themselves rather than of the performance of the firm or industry in question. In these circumstances indicators of the level and change of productivity would be a more appropriate indicator of performance. Although the construction industry is a relatively competitive one a number of questions have been raised in the past regarding the degree to which prices and costs in the industry reflect their true economic worth. In these circumstances, therefore, productivity analysis can make a useful contribution to gauging the performance of the industry.

In the past productivity changes over time were first measured using an 'index' approach. This approach involves the construction of index numbers which can be used to indicate the partial or total factor productivity of an industry. Partial productivity measures generally relate a firm's (or industry's) output to a single input factor – for example, the volume of construction activity per employee is a labour-based partial productivity measure (see for example Cassimiatis, 1969; Briscoe, 2006; Cremeans, 1981; Ive and Gruneberg, 2000: Chapter 3; Pearce, 2003: Chapter 5). Total factor productivity measures are generally the ratio of a total aggregate output quantity index to a total aggregate input quantity index (and total factor productivity growth is then the difference between the growth of the output and input quantity indices).

Partial productivity indicators have the advantage of being easy to compute, require only limited data and are intuitively easy to understand. They can, however, be misleading when looking at the change in productivity of a firm or industry. For instance it might be possible for a company to raise productivity with respect to one input at the expense of reducing the productivity of other inputs. Indices of output to labour, for instance, often tend to overstate the growth of total factor productivity (that is the combined productivity of labour, capital and other factors). Further, capital productivity measures are difficult to calculate given the difficulty in measuring capital inputs, and the often very long life of some assets.

Although there are a few studies of industry level total factor productivity in the construction industry the literature is not as extensive as it is in many other industries. Most research on construction industry productivity tends to be concerned more with site level labour productivity, which has a more direct relevance to industry management (see for instance Ganesan, 1984; Lowe, 1987; Maloney, 1983; Allen, 1985; Thomas et al., 1990; Thomas and Sakarcan, 1994).

Total factor productivity indices on the other hand were first developed at the National Bureau of Economic Research in the United States in the late 1940s. The total factor productivity index approach shows the ratio of an index of combined outputs to an index of combined inputs. The index approaches used to combine outputs and inputs that might be used include the Laspeyres, Paasche, or Fisher approaches. A Tornqvist index approach has been used in many total factor productivity studies in recent times.

First of all labour productivity measurements were undertaken for a range of industries (including construction). This was followed by a range of partial productivity measurements for other inputs such as capital and, in the case of agriculture, land and livestock indicators. A range of studies were then undertaken that attempted to combine the various types of inputs together in a similar fashion to the way in which earlier researchers like Simon Kuznets and Colin Clark had for output in determining levels of Gross National Product. In undertaking this work the research by Stigler (1947; 1961), Barton and Cooper (1948); Kendrick and Jones (1951), Schmookler (1952), and Fabricant (1954) were important. Starting with agriculture this work spread to other individual sectors of the economy as well as national wide studies. Schmookler (1952) used national level data to generate nation-wide productivity measurements. By the mid-1950s the National Bureau of Economic Research had published a great deal of work using total factor productivity indices for a range of industries with one of its employees, John W. Kendrick, publishing extensively using these techniques for a number of years (Kendrick 1956a, 1956b, 1961, 1973). Amongst those industries examined was the construction industry.

Total factor productivity indices of the construction industry in the United States, therefore, were the first part of larger attempts to calculate productivity across the whole economy. Other researchers also began to undertake similar studies of this sort in the 1950s; these included those by Schultze (1959), Kendrick (1961), Haber and Levinson (1956) and Alterman and Jacobs (1961). Over the years studies have also been conducted in a range of other countries besides the United States using the index approach They include studies such as those on Hong Kong by Chau (1988), Chau and Lai (1994), Chau and Walker (1990), for Singapore by Tan (2000), the United States by Stokes (1981) and Allmon et al., (2000), the United Kingdom by Briscoe (2006), and New Zealand by Diewert and Lawrence (1999), Black, Guy and McLellan (2003), and Statistics New Zealand (2011). In the studies by Tan

(2000) and Black, Guy and McLellan (2003) a slowdown in productivity growth was detected.

The second approach to determining productivity change is econometric measures which uses the estimation of cost or production functions. The estimated functions can then be used to identify changes in productivity or productive efficiency. The estimation of cost functions has been the most commonly used method of determining the levels of efficiency in the industry, although a number of techniques have been used in estimating these cost functions. This approach is also often referred to as the Growth Accounting Approach. Dacy (1965) was perhaps the first to use an estimated production function for the United States construction industry (1947 to 1963) and found increasing levels of productivity. Later examples of estimated production functions include those by Allen (1985), Stokes (1981), Goodrum and Haas (2004), and Kau and Sirmans (1983). Examples of the use of cost functions estimations include those by Schriver and Bowlby (1985) for the United States, and Chau (1993 and 2009) who found in both cases rising productivity levels in Hong Kong. Additional work has been undertaken in countries like New Zealand using this approach (Orr, 1989; Chapple, 1994; Philpott, 1995; and Mason and Osborne, 2007).

Another approach is data envelopment analysis (DEA). The technique was pioneered by Charnes et al. (1978) based on the work by Farrell (1957) and there are now many texts offering detailed discussion on DEA, including the algorithms used (see, for example, Knox Lovell and Schmidt, 1988; Coelli, Rao and Battese,1998). DEA has been used to extensively in a number of industries to assess productivity and efficiency levels (especially utilities). In the case of the construction industry only a fewer number have been undertaken and these are looked at in the following chapter.

The accuracy and impact of price indices

Most studies that look at the productivity of the construction industry are centred on the industry in the United States. One element some researchers found was that of stagnation or declining productivity in the United States construction industry and these researchers had some difficulty explaining why this might have occurred. These include work by Stokes (1981), Allen (1985) and Schriver and Bowlby (1985). Tan (2000) found a similar decline in productivity in the Singapore construction industry over the period 1980 to 1996.

One of the reasons the measured rate of construction productivity growth may be low is because of the measurement of output as value added (the total value of goods and services produced after deducting the costs in the production process), is adjusted by a deflator for movements in prices. The construction deflator may not fully take these movements into account, and therefore real output is underestimated. Also, the significant role of changes in the quality of construction may not have been rigorously measured and reflected in changes in real value added.

Output of the construction industry is estimated by deflating current price figures by input price indices. A number of researchers have criticised the use of input price indices for deflating construction expenditure, for being unrepresentative of the inputs priced and geographical coverage, and being based on inaccurate weights. The Stigler Report (1961:29) recommended a significant increase in research on construction deflation, and suggested a residential deflator based on the price per square foot of a range of categories of new homes. This led, in 1968, to the adoption of a new, hedonic price index for housing in the United States by the Bureau of Economic Analysis.

A number of alternative deflators have been developed. Allen (1985) used a price per square foot index for deflating non-residential building, assuming that this is a good proxy for output. According to Allen's estimates about half the decline in construction productivity during the 1960s and 1970s was due to the over deflation of construction output. Cassimatis found that price indices cannot provide adequate deflators for construction: 'the feeling persists that construction productivity is greater than the measurements show ... largely due to the fact that there are no adequate price indices that can be used as deflators of the gross product' (Cassimatis, 1969:79-80).

Pieper (1990) also argued that deflation by input price indices does not produce suitable estimates of output at constant prices and, given the extensive use of input price indices as deflators in estimating the constant price of output for the construction industry, productivity measurement for this industry is problematic, to say the least. Pieper concluded that, for the United States: "evidence indicates an over deflation of construction of at least 0.5% per year between 1963 and 1982."

Chau and Lai (1994) developed a system for measuring the relative labour productivity of the Hong Kong construction industry. Their approach used a method of measuring the relative labour productivity of the industry, from national accounts data, and then derived the trend of construction labour productivity. This discussion of relative rates of growth of labour productivity used an implicit price deflator for net output of the construction industry obtained through double deflation, but did not discuss the nature of the price indices used or their applicability. The price indices were based on a construction output price index and a material cost index using the methodology developed by Chau and Walker (1988).

Lowe (1995) described the use of estimation indices by Statistics Canada, using surveys sent to subcontractors. Around 100 different items were priced for five building types and each of five types had its own index. A recent analysis of British building price indices by Yu and Ive (2008) found that these indices measure the price movement of the traditional building trades but almost completely ignore mechanical and electrical services.

Cannon (1994) questioned the accuracy of contractor statistics and Briscoe (2006) asked: "How useful and reliable are construction statistics?" These papers identified a range of problems with data collection and analysis, including defining the scope and coverage of the industry; measuring outputs across different types of activity; identifying construction firms; measuring capital formation and capital stock, and inconsistent employment statistics. Crawford and Vogel (2006) also drew attention to data limitations for productivity analysis.

Regional and sectoral effects on productivity

As well as problems associated with choosing the best possible price indices other hypotheses also exist that attempt to explain the decline in construction productivity. Some common ones include that there has been a decline in the capital-labour ratio in the industry (Blake et al., 2004), changes in the age-sex composition of the labour force (Cremeans, 1981), a shift towards non-union construction (Allen, 1985), an increase in government regulation (Tucker, 1986) or cyclical and business cycle effects. Project characteristics such as the increased size and complexity of projects, resulting communication difficulties, and fast-tracking projects where design and construction phases overlap also affect coordination. There have been a few papers that address the effects of these on productivity (for examples see Table 10.1).

Cremeans (1981) discussed a number of hypotheses that had been proposed to explain the significant decline in construction industry labour productivity in the 1970s. Only one of the hypotheses, the increased proportion of younger, less experienced workers, was supported by the available data. Bowlby and Schriver's (1986) analysis of United States productivity data indicated seven compositional changes in building, and they suggested that these would account for much of the productivity slowdown.

<Table 10.1 here>

Project-based nature of the industry and the role of project management

A large number of papers have recommended that construction productivity could be improved through the use of flexible organisation structures, favourable union attitudes, higher worker motivation, and improved overtime and change order strategies (examples of these studies can be found in Table 10.2). Most of these surveys found that cost control; scheduling, design practices, labour training, and quality control are the functions that are consistently seen as having room for improvement. Often the fragmented nature of the industry is seen a hindrance to improving productivity (Ganesan, 1984). However, Chau and Lai (1994) suggest that productive efficiency is increased by the division of labour.

Borcherding (1976) identified the factors having an adverse effect on construction productivity as union attitudes, worker selection practices and motivation, inflexible bureaucratic organisation structures, overtime, and change orders. Using these factors, Herbsman and Ellis (1990) developed a statistical model of the quantitative relationships between influence factors and productivity rates.

<Table 10.2 here>

Koehn and Brown (1986) argued that construction productivity is affected by a wider range of variables which they divided into the six areas of management, labour, government, contracts, owner characteristics and financing. Koehn and Caplan (1987) focused on small to medium size construction firms rather than large construction firms. Their study concluded that productivity improvement efforts should be concentrated in planning, scheduling, site and labour management functions. Jenkins and Laufer (1982) also focused on the management issues, and discussed them in the context of motivation of workers. They suggested that while motivation does not directly influence the rate of working, motivation directly impacts upon the percentage of working time spent productively.

Arditi and Mochtar's surveys of the top 400 United States contractors in 1979, 1983 and 1993 identified areas with potential for productivity improvement. The functions needing more improvement in 1993 compared with the previous survey were prefabrication, new materials, value engineering, specifications, labour availability, labour training, and quality control, whereas those that were identified as needing less improvement were field inspection and labour contract agreements (Arditi and Mochtar, 2000).

Allmon et al. (2000) presented an approach to long-term productivity trends in the United States construction industry over the past 25–30 years. Means' cost manuals (the main United States source of estimating data) were used to trace the values for tasks undertaken in the process of construction and changes in these values were taken as productivity trends. Unit labour costs in constant dollars and daily output factors were compared over decades for each task. Direct work rate data from 72 projects in Austin, Texas over the last 25 years were also examined. The combined data indicated that productivity had increased in the 1980s and 1990s. Depressed real wages and technological advances appear to be the two biggest reasons for this increase. Their data also indicated that management practices were not a leading contributor to construction productivity changes over time.

Procurement systems and the effectiveness of construction industry policy and intervention

Some researchers have identified institutional factors responsible for construction productivity levels. Labour issues include organised labour, the competencies of project participants, the tendency of site management to spend more time providing information and writing reports than actually managing the project, and the inadequacies of an educational system which produces graduates with excellent skills in analysis and design but with little knowledge of methods to turn designs into realities (Tucker, 1986). Other institutional issues are the tendency of construction firms to become larger and more specialised, legal restrictions on the management of construction projects and the complex regulatory regimes the industry works under (Table 10.3).

<Table 10.3 here>

The limitations of the traditional procurement method have contributed to the poor performance of the construction industry and have prompted the development of alternative procurement strategies designed to facilitate improvements in the way buildings and structures are delivered (Cox and Townsend, 1998). Craig (2000) concluded that the traditional tendering process for building works does not encourage design innovation by tenderers, because tendering rules produce direct price competition for a specified product.

R&D, innovation and productivity

The construction industry has not established an impressive track record in innovation or technical advancement. The main effort in industry development has been concentrated in procurement, planning, and management and design improvements. Nevertheless, there have been some significant advances in construction technology over the last two decades in both the materials used and the application of new construction methods (Fairclough, 2002).

Gann (2003:554) cites Bowley (1960) as showing that construction is an adopter of innovations from other industries, rather than a source of innovation. Bowley's work: 'shows that demand for new types of buildings is usually more important in stimulating radical technical and organizational innovation than the need to erect better and cheaper buildings to accommodate existing functions.' Cassimatis (1969) concluded his study with a chapter on institutional factors, because: 'once the contract is awarded, competitive forces do not always prevail' (Cassimatis, 1969:118). Institutional factors that affect the performance of the industry are its openness to innovation and capturing of economies of scale.

Koch and Moavenzadeh (1979) focused on the role of technology in highway construction, and found there had been substantial gains in both labour and capital productivity over the previous 50 years in the United States. They concluded that future gains in efficiency can be expected to be less than the previous gains, so new means of accomplishing technological change in the construction industry are needed. Arditi (1985) conducted a study of large construction firms to determine potential areas for construction productivity improvement. One of the study's conclusions was that more productive construction technology such as industrialised building processes are important in achieving higher levels of construction productivity.

<Table 10.4 here>

Hobday (2000) and Gann and Salter (2000) argued that the construction industry can, and should, be more innovative. Many papers follow Tatum's (1986) analysis of the industry in terms of advantages and constraints to innovation, and despite the Tatum model of construction innovation being more than two decades old it still captures many of the key features of the discussion raised by more recent efforts such as Reichstein et al. (2005), Fairclough (2002) or Slaughter (1998). Ivory (2005) suggested that clients of builders will not be prepared to pay for innovation.

Conclusion

The rate of growth of productivity in the construction industry in a number of countries has lagged that of other industries for at least five decades, and the earliest studies that identified this problem date from the late 1960s in the United States with Cassimatis' (1969) analysis of labour productivity growth in construction between 1947 and 1967. This is despite there having been a range of technological changes that have occurred in the industry, such as the introduction of new hand held powered tools, improved lifting and moving machinery and new materials and processes.

Two possible explanations for the lack of demonstrable improvement in construction productivity are possible. The first is the importance of measurement and data to the research. This belongs to a broader set of issues about the structure and use of price indices in the national accounting framework, an area where construction economists might have an opportunity to make a contribution. Recently there has been a shift from the use of deflators and their effects on measured output (or more precisely the ratio of output to labour input) to concern over the boundaries of the production system and more accurate measurement of specific factors such as capital inputs adjusted for quality and employment adjusted for firm size.

The second is the diversity of other issues raised that are suggested as affecting productivity. Influences on productivity growth in the construction industry, apart from the nature of the product, can be traced to the nature of the methods used in delivering and managing the processes involved. Construction is a labour intensive industry in comparison with manufacturing industries, but there has been a significant increase in the prefabricated component of construction, which could have been expected to lead to productivity growth. Also, construction methods have tended to become more capital intensive as the number of cranes and the variety of equipment and hand tools used has increased. However the productivity growth that one would expect to observe as a result of these trends has not occurred, according to measurements of productivity growth by the major national statistical agencies and reports like the UK studies by Ive et al. (2004) and Blake et al. (2004).

This paper has reviewed a wide range of previous research addressing a range of factors that could affect productivity. The bringing together of these different literatures on productivity analysis and measurement, project procurement and delivery systems, construction industry policy and intervention, and R&D and innovation allows a broader perspective on the construction industry's productivity performance. In terms of applicability the breadth of management issues raised by researchers points to some possibly serious problems with both the management of projects and the management of workers. After several decades of development of project management techniques the average performance of projects does not appear to have improved greatly, with the more recent research finding problems similar to those found in the early work. Lastly, it is possible that the R&D profile of the industry is as much an artefact of the data as a real problem. Construction is an industry that readily adopts research developments in other industries, the use of computers and the constant flow of new products from manufacturers supplying materials and equipment being good examples. R&D expenditure within the industry will not be very high in this case.

References

Allen, S.G. (1985) 'Why construction industry productivity is declining' *Review of Economic Statistics*, **117** (4), 661-665.

Allmon, E., Haas, C., Borcherding, J. and Goodrum, P. (2000) 'US Construction Labor Productivity Trends 1970-1998' *Journal of Construction Engineering and Management,* ASCE, **126** (2), 97-104.

Alterman, J. and Jacobs, E.E. (1961) 'Estimates of real product in the United States by industrial sector, 1947-1955' *Output, Input and Productivity Measurement*, National Bureau of Economic Research, Princeton University Press.

Arditi, D. (1985) 'Construction productivity improvement' *Journal of Construction Engineering and Management*, ASCE, **111**, 1-14.

Arditi, D. and Mochtar, K. (2000) 'Trends in productivity improvement in the US construction industry' *Construction Management and Economics*, **18** (1), 15-27.

Barton, G.T. and Cooper, M.R. (1948) 'Relation of agricultural production to inputs' *Review of Economics and Statistics*, **30** (7), 117-126.

Black, M., Guy, M. and McLellan, N. (2003) *Productivity in New Zealand 1988 to 2002*, Treasury Working Paper 03/06, The Treasury, Wellington.

Blake, N., Croot, J. and Hastings, J. (2004) *Measuring the Competitiveness of the UK Construction Industry, Vol. 2: Industry Economics and Statistics*, Dept of Trade and Industry, London.

Borcherding, J.D. (1976) 'Improving productivity in industrial construction' *Journal of Construction Division*, ASCE, **102** (C04), 599-614.

Borcherding, J.D. and Oglesby, C.H. (1974) 'Construction productivity and job satisfaction' *Journal of Construction Division*, ASCE, **100** (3), 413-31.

Bowley, M. (1960) *Innovation in Building Materials*, Gerald Duckworth, London.

Briscoe, G. (2006) "How useful and reliable are construction statistics?" *Building Research & Information*, **34** (3), 220-229.

Cannon, J. (1994) 'Lies and construction statistics' *Construction Management and Economics*, **12** (4), 307-312.

Cassimatis, P.J. (1969). *Economics of the Construction Industry*, National Industrial Conference Board, New York.

Chapple, S. (1994) *Searching for the Heffalump? An Exploration into Sectoral Productivity and Growth in New Zealand*, New Zealand Institute of Economic Research Working Paper 99/10, Wellington.

Charnes, A., W.W. Cooper and Rhodes, E. (1978) ;Measuring the efficiency of decision making units' *European Journal of Operational Research*, 2 (**6**), 429–444.

Chau, K.W. (1990) *Total Factor Productivity of the Building Industry of Hong Kong*, Unpublished PhD thesis, University of Hong Kong, Hong Kong.

Chau, K.W. (1993) 'Estimating industry-level productivity trends in the building industry from building cost and price data' *Construction Management and Economics*, **11** (4), 370-383.

Chau, K.W. (2009) 'Explaining total factor productivity trend in building construction: empirical evidence from Hong Kong" *International Journal of Construction Management*, **9** (2), 45-54.

Chau, K. W. and Lai, L. W. C. (1994) 'A comparison between growth in labour productivity in the construction industry and the economy' *Construction Management and Economics*, **12**, 183-185.

Chau, K.W. and Walker, A. (1988) 'The measurement of total factor productivity of the Hong Kong construction industry' *Construction Management and Economics*, **6** (3), 209-224.

Chau, K.W. and Wang, Y.S. (2005) 'An analysis of productivity growth in the construction industry: a non-parametric approach'. In: Khosrowshahi, F. (ed.) *21st Annual ARCOM conference*, 7-9 September 2005, SOAS, University of London, Association of Researchers in Construction Management, 1, 159-69.

Coelli, T., Prasada Rao D.S. and Battese, G. E. (1998) *An Introduction to Efficiency and Productivity Analysis*, Kluwer, Boston.

Cox, A. and Townsend, M. (1998) *Strategic Procurement in Construction*, Thomas Telford Publishing, London.

Craig, R. (2000) 'Competitive advantage through tendering innovation' *Australian Construction Law Newsletter*, 70: March, UTS Design, Architecture and Building.

Crawford, P. and B. Vogel (2006) 'Measuring productivity in the construction industry' *Building Research & Information*, **34** (3), 208-19.

Cremeans, J. E. (1981) ‘Productivity in the construction industry’ *Construction Review*, **27** (5), 4-6.

Dacy, D.C. (1965) ‘Productivity and price trends in construction since 1947’ *Review of Economics and Statistics*, **47** (4), 406-411.

Dai, J., Goodrum, P. M. and Maloney, W. F. (2007) ‘Analysis of craft workers' and foremen's perceptions of the factors affecting construction labour productivity’ *Construction Management and Economics*, **25** (11), 1139-1152.

Davis, N. (2007). *Construction Sector Productivity Scoping Report*. MartinJenkins, Wellington.

Diewert, E. and Lawrence, D. (1999) *Measuring New Zealand’s Productivity*, Treasury Working Paper 99/5, Treasury, Wellington.

Dubois, A. and Gadde, L.-E. (2002) ‘The construction industry as a loosely coupled system: implications for productivity and innovation’ *Construction Management and Economics*, **20** (7), 621-632.

Fabricant, S. (1954) *Economic Progress and Economic Change*, National Bureau of Economic Research, Washington D.C.

Fairclough, J. (2002) *Innovation in the Construction Industry – a Review of Government R&D Policies and Practices*, Department of Trade and Industry, London.

Färe, R., Grosskopf, S.and Margaritis, D. (1996) ‘Productivity growth’ In: Silverstone, B. Bollard, A. and Lattimore, R. (eds) *A Study of Economic Reform: the Case of New Zealand*, Elsevier Science, New York.

Farrell, M. (1957) ‘The measurement of productive efficiency’ *Journal of the Royal Statistical Society*, Series A, CXX, 253-81.

Ganesan, S. (1984) ‘Construction productivity’ *Habitat International*, **8**, 3-4.

Gann, D.M. (1997) ‘Should governments fund construction research?’ *Building Research and Information*, **25**, 257-267.

Gann, D. M. (2003) ‘Guest editorial: innovation in the built environment’ *Construction Management and Economics*, **21**, 553–5.

Gann, D.M. and Salter, A.J. (2000) ‘Innovation in project-based, service enhanced firms: the construction of complex products and systems’ *Research Policy*, **29**, 955-972.

Goodrum, P.M. and Haas, C.T. (2004) ‘Long-term impact of equipment technology on labor productivity in the U.S. construction industry at the activity level’ *Journal of Construction Engineering and Management*, **130** (1), 124-13.

Haber, W. and Levinson, H. (1956) *Labor Relations and Productivity in the Building Trades*, University of Michigan Press, Ann Arbor.

Hague, D. J. (1985) 'Incentives and Motivation in the Construction Industry: A Critique' *Construction Management and Economics*, **3** (2) 163-170

Herbsman, Z. and Ellis, R. (1990) 'Research of Factors Influencing Construction Productivity' *Construction Management and Economics*, **8** (1), 49-61.

Hobday, M. (1998) 'Product complexity, innovation and industrial organisation' *Research Policy*, **26**, 689–710.

Ive, G. and Gruneberg, S. (2000) *The Economics of the Modern Construction Sector*, Palgrave Macmillan, Basingstoke.

Ive, G., Gruneberg, S., Meikle, J. and Crosthwaite, D. (2004). *Measuring the Competitiveness of the UK Construction Industry*, Dept. of Trade and Industry, London.

Ivory, C. (2005) 'The cult of customer responsiveness: is design innovation the price of a client-focused construction industry?' *Construction Management and Economics*, **23**, 861–870.

Kau, J.B. and Sirmans, C.F. (1983) 'Technological change and economic growth in housing' *Journal of Urban Economics*, **13**, 283-95.

Kellogg, J.C., Howell, C.G. and Taylor, D.C. (1981) 'Hierarchy model of construction productivity' *Journal of the Construction Division*, ASCE, **161** (38), 137-52.

Kendrick, J.W. (1956a) *Productivity Trends: Capital and Labor*, Occasional Paper 53, National Bureau of Economic Research, Washington D.C..

Kendrick, J.W. (1956b) *The Meaning and Measurement of National Productivity*, PhD thesis. George Washington University, Washington D.C.

Kendrick, J.W. (1961) *Productivity Trends in the United States*, National Bureau of Economic Research/Princeton University Press, New York.

Kendrick, J.W. (1973) *Postwar Productivity Trends in the United States 1948–1966*, National Bureau of Economic Research, New York.

Kendrick, K.W. and Jones, C.E. (1951) 'Gross National Farm product in constant dollars, 1910-1950' *Survey of Current Business*, **31**, September, 12-19.

Koch, J. A. and Moavenzadeh, F. (1979) 'Productivity and technology in construction' *Journal of the Construction Division*, Proceedings of the American Society of Civil Engineers, 105 (C04), December, 351-366.

Koehn E. and Caplan, S. B. (1987) Work improvement data for small and medium size contractors. *Journal of Construction Engineering and Management*, 113(2), 327-339.

Knox Lovell, C.A. and Schmidt, P. (1988) 'A comparison of alternative approaches to the measurement of productive efficiency' In: Dogramaci A. and Färe, R. (eds) *Applications of Modern Production Theory: Efficiency and Productivity*, Boston, Kluwer, Boston.

Lowe, J.G. (1987) 'The measurement of productivity in the construction industry' *Construction Management and Economics*, **5**, 115-21.

Lowe, P. (1995) 'Labour-productivity growth and relative wages: 1978-1994' In: Andersen, P., Dwyer, J. and Gruen, D. (eds.) *Productivity and Growth: Proceedings of a Conference*, Reserve Bank of Australia, Sydney.

McFillen, J.M. and Maloney, W.F. (1988) 'New answers and new questions in construction worker motivation' *Construction Management and Economics,* **6** (1), 35-48.

Maloney, W. (1983) 'Productivity improvement: the influence of labor' *Journal of Construction Engineering Management,* **109** (3), 321-334.

Mason, G. and Osborne, M. (2007). *Productivity, Capital-Intensity and Labour Quality at Sector Level in New Zealand and the UK*, New Zealand Treasury Working Paper 07/01, Wellington.

Orr, A. (1989) *Productivity Trends in New Zealand: a Sectoral and Cyclical Analysis 1961-1987,* NZIER, Wellington.

Pearce, D. (2003) *The Social and Economic Value of Construction*, Davis Langdon Consultancy, London.

Philpott, B. (1995) *New Zealand's Aggregate and Sectoral Productivity Growth 1960-1995*, Research Project on Economic Planning, Paper 274, Victoria University of Wellington.

Pieper, P. E. (1990) 'The measurement of construction prices: retrospect and prospect.' In E. R. Berndt and J. E. Triplett (eds.) *Fifty Years of Economic Measurement*, National Bureau of Economic Research, University of Chicago Press, Chicago.

Reichstein, T., Salter, A. J. and Gann, D. M. (2005) 'Last among equals: a comparison of innovation in construction, services and manufacturing in the UK' *Construction Management and Economics*, **23**, 631–644

Rosenfielde, S. and Mills, D.Q. (1979) 'Is construction technologically stagnant?' In: Lange, J.E. and Mills, D.Q. (eds.) *The Construction Industry*, D.C. Heath and Company, Lexington MA.

Schmookler, J. (1952) 'The changing efficiency of the American economy, 1869-1938' *Review of Economics and Statistics*, **34** (3), 214-231.

Schriver, W.R. and Bowlby, R.L. (1985) ‘Changes in productivity and composition of output in building construction, 1972-1982’ *Review of Economics and Statistics*, **67** (2), 318-322.

Schultze, C.L. (1959) *Prices, Costs and Output for the Post War Decade: 1947-1957*, New Committee for Economic Development, New York.

Sidwell, A.C. (1987) *The Future for Building Education*, Occasional Paper No. 3, The Australian Institute of Building.

Slaughter, S. (1998) ‘Models of construction innovation’ *Journal of Construction Engineering and Management*, **124** (30), 226–31.

Statistics New Zealand (2011) *Industry Productivity Statistics, 1978-2009,* Statistics New Zealand, Wellington.

Stigler, G.J. (1947) *Trends in Output and Employment*, National Bureau of Economic Research, University of Princeton Press.

Stigler, G.J. (1961) ‘Economic problems in measuring changes in productivity’ In: *Output, Input and Productivity Measurement,* Conference on Research in Income and Wealth, UMI.

Stigler Report (1961) *Price Statistics of the Federal Government: Review, Appraisal and Recommendations*, Price Statistics Review Committee, NBER, New York.

Stokes, H.K. (1981) ‘An examination of the productivity decline in the construction industry’ *Review of Economics and Statistics,* **63** (4), 495-502.

Tatum, C.B. (1986) ‘Potential mechanisms for construction innovation’ *Journal of Construction Engineering and Management*, ASCE, **112** (2).

Tan, W., (2000) ‘Total factor productivity in Singapore construction’ *Engineering, Construction and Architectural Management*, **7** (2), 154-158.

Thomas, H., Maloney, W., Horner, R., Smith, G., Handa, V., and Sanders, S. (1990) ‘Modelling construction labor productivity’ *Journal of Construction Engineering Management*, **116** (4), 705-726.

Thomas, H. and Sakarcan, A. (1994) ‘Forecasting labor productivity using factor model’ *Journal of Construction Engineering Management*, **120** (1), 228-239.

Tucker, R.L. (1986) ‘Management of construction productivity’ *Journal of Management Engineering* **2** (3), 148-156.

Wang, Y.S. (1998) *An Analysis of the Technical Efficiency in Hong Kong’s Construction Industry*, unpublished PhD thesis, University of Hong Kong, Hong Kong.

Wang, Y.S. and Chau, K.W. (1997) 'An evaluation of the technical efficiency of construction industry in Hong Kong using the DEA approach', *Proceedings of ARCOM97 Conference*, Cambridge, 690-701.

Wang, Y.S. and Chau, K.W. (2001) 'An assessment of the technical efficiency of construction firms in Hong Kong' *International Journal of Construction Management*, **29**, 105-122.

Yu, M. K. W. and Ive, G. (2008) 'The compilation methods of building price indices in Britain: a critical review' *Construction Management and Economics*, **26** (7), 693-705.

Zhi, M., Hua, G. B., Wang, S. Q. and Ofori, G. (2003) 'Total factor productivity growth accounting in the construction industry of Singapore' *Construction Management and Economics,* **21**, 707-718.

Cremeans (1981)	Found younger, less experienced workers the main cause
Bowlby and Schriver (1986)	Identified seven compositional changes in building, and these account for much of the productivity slowdown
Tucker (1986)	The increased size and complexity of construction projects
Ive et al. (2004)	The output-structure of a country’s construction industry will influence average labour productivity
Blake et al. (2004)	UK construction has lower capital per worker than France, Germany and the US

Table 10.1 Representative papers: regional and sectoral effects on industry productivity

Borcherding and Oglesby (1974)	Concluded well organised construction jobs which permit workers to be productive lead directly to job satisfaction
Borcherding (1976)	Identified six factors having adverse effects on construction productivity
Kellogg et al. (1981)	Argued that the fragmented nature of the industry impedes productivity growth
Ganesan (1984)	Also argued fragmentation affects productivity
Hague (1985)	Found financial incentives and any other method for encouraging productivity has had arguments for and against
Koehn and Caplan (1987)	Productivity improvement efforts should be concentrated on planning, scheduling, supervision, and labour
Briscoe (1988)	The quality of construction management is an important factor which helps to explain low productivity
McFillen and Maloney (1988)	Found contractors did little to encourage good performance, so workers reported little incentive to be highly productive
Herbsman and Ellis (1990)	Developed of a statistical model of quantitative relationships between influence factors and productivity rates
Chau and Lai (1994)	Argue the fragmented nature of the industry is often seen as a hindrance to improving productivity
Dai, Goodrum, and Maloney (2007).	Foremen reported project management factors having more impact on their productivity, and craft workers reported factors related to construction materials having more impact

Table 10.2: Representative papers: project-based nature of the industry and the role of project management

Cassimatis (1969)	The major factors affecting the efficiency of organisations in construction are institutional
Tucker (1986)	Institutional issues were the tendency of construction firms to become larger and more specialised, legal restrictions on the management of construction projects and insufficient research in construction and project management methods
Sidwell (1987)	Described the Australian construction industry as thoroughly conservative and slow to change in any fundamental way
Cox and Townsend (1998).	Construction has not developed the supply chains and procurement methods as other industries have
Craig (2000)	Compared traditional and D&B (design and build) procurement for innovation
Dubois and Gadde (2002)	The separation of design and construction creates inefficiencies

Table 10.3: Representative papers: procurement and delivery systems and the effectiveness of construction industry policy

Rosefielde and Mills (1979)	Argue the rate of technological progress in the construction industry may be slow because buildings are heterogeneous
Koch and Moavenzadeh (1979)	Focused on the role of technology in highway construction and concluded new means of accomplishing technological change are needed
Arditi (1985)	Recommended areas that research should concentrate on
Tatum (1986)	Construction has many features that favour innovation
Gann (1997)	Discusses the role of government funded R&D
Gann and Salter (2000)	Construction has the potential to be more innovative
Fairclough (2002)	Construction lags in R&D and innovation
Hobday (2000)	Argues that the nature of construction projects and teams creates opportunities for innovation
Zhi, Hua, Wang and Ofori (2003)	Seven factors influencing TFP growth in the construction industry of Singapore over 1984–1997 were identified
Ivory (2005)	Argued clients will avoid risk associated with innovation

Table 10.4: Representative papers: contribution of research and development and innovation