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An analysis of construction productivity differences between Canada and the United States

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Comparisons of industry sectors in advanced economies since the 1960s show that the construction sector has lagged in productivity growth rates, especially in the United States. Although the US and Canadian economies are highly integrated, Canada's experience differs in key ways. Analysis of these differences offers insight into fundamental construction productivity drivers. Three levels of analyses of construction productivity in the US are provided in this study. The first analysis compared international levels of labour productivity growth. The second compared construction productivity between the US and Canada, and the third analysed cost estimating data from RS Means estimating manuals to measure the changes in labour and partial factor productivity in the US from 1995 to 2009. Statistical significance testing indicates that labour productivity remained nearly constant in the building sub-sector and that partial factor productivity has improved at an annual compound rate of 0.66%. This supports previous findings that US construction has stagnated but is still improving in Canada, with wage differentials and training systems as potential drivers of this difference. While growth rates of productivity seem to decline with higher absolute levels of productivity, there is no evidence that high absolute productivity levels preclude significant growth.

Keywords: Canada, economy, labour, productivity, United States.

Introduction

According to the European Construction Industry Federation (FIEC), the construction industry constitutes 9.7% of the gross domestic product (GDP) in the European Union (EU) with a total construction value of 1186 billion in 2010, providing 6.6% of Europe's total employment (European Construction Industry Federation, 2011). In Canada, the construction industry is estimated to have contributed 5.6% of the GDP in 2010 (Statistics Canada, 2011), and in the United States (US), the construction industry accounted for 5.3% of the GDP in 2011 (Bureau of Economic Analysis, 2012; US Census Bureau, 2012). According to the US Bureau of Labor Statistics (BLS), almost 11 million people, or about 8% of the total US workforce, were directly employed in the construction industry (Bureau of Labor Statistics, 2008). Therefore, the productivity of a major sector like construction in a national economy is of great importance for economic growth, which means that construction productivity must grow. Advancing the competitiveness and productivity of the construction industry is a challenge that warrants an international perspective. Many studies have been conducted that compare productivity between nations or regions within nations (Lal, 2003; Rao *et al.*, 2004; Ark *et al.*, 2008). However, fewer studies compare the competitiveness of construction industries between nations (Mohammadian and Seymour 1997; Harrison, 2007). To generate an international perspective on construction competitiveness and productivity, a synthesis of existing information is useful and is undertaken here.

The nature of the construction industry makes it difficult to understand productivity in the industry. It is complicated to measure productivity in construction

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at the national level, particularly in the US, because there are limited comparable input and output data (Finkel, 1997). Owing to a lack of suitable productivity indices of US construction activity (the US Bureau of Labor Statistics does not maintain a productivity index for the construction industry) there is not enough reliable and meaningful information. In Canada, standard disaggregated output indices have existed for decades, so the situation is more tenable. Despite these differences, it is essential to at least understand trends in construction productivity among the data that do exist in order to improve industry efficiency.

This paper reports three ways of understanding these trends by focusing on trends in construction productivity since the 1960s. First, a macro-level analysis of construction productivity and competitiveness of international construction industries synthesizes available information from 20 international construction markets including the US, Canada, Korea, Japan, and major countries in the EU. Next, changes in labour productivity between Canada and the US obtained from several sources are reported. The focus on the US and Canada is revealing because of, paradoxically, their close similarities and their few key differences.

The third part of the paper is a longitudinal study of labour and partial factor productivity. To obtain approximate trends for each type of productivity measurement, the percentage difference between 1995 and 2009 was calculated using a random sample. Statistical tests were used to analyse whether the changes are significant. This work is a continuation of the research by Goodrum *et al.* (2002) that examined the time frame between 1979 and 1998, measured a clear definition of construction productivity, and observed trends that have not been calculated in a similar fashion since 1998. This part of the study is limited to the use of only one data source, the RS Means construction estimation manuals. The data, especially data related to estimates of daily physical output for individual construction activities, are updated periodically but not annually, using anonymous industry sources distributed through the US and Canada. A 10-year difference in the dataset was sought to allow possible changes to occur in the means and methods of construction. Further, other studies suggest current technologies in the US become widely diffused within a 10-year period (Comin and Hobijn, 2010), thus having the potential to affect construction means and methods. The different levels of analyses are presented in order to provide a broader and more meaningful perspective to construction productivity in the US. The international construction productivity analyses, which use a macro approach for measuring construction productivity, are provided in order to give a broader perspective of how the US performed compared to other advanced economies. The data used by these analyses were at the aggregate level of the different construction industries. Unfortunately, similar industry measures for the US do not exist for a multitude of different reasons detailed elsewhere (Dacy, 1965; Gordon, 1968; Rosefielde and Quinn Mills, 1979; Pieper, 1990; Gullickson and Harper, 2002). As an alternative to aggregate-level data, RS Means data were used to provide another dimension of measuring construction productivity based on activities level using job estimating measures.

Issues with measurements of productivity in the construction industry

The concept of construction productivity can be difficult to define, measure, and communicate as a result of comparable inputs and outputs between varying projects, companies, and industry sectors. Another difficulty in analysing productivity statistically arises from the fact that it has different units of measurement for each construction activity. There is no standard definition of productivity in the US construction industry because each company defines productivity depending on its own unique project controls system. No one has succeeded in the US in forming standard definitions or survey tools that can be used to collect productivity data (Park *et al.*, 2005). However, a recently launched effort in the US seeks to standardize codes of account (National Institute of Standards and Technology, 2011), which is a step forward. At the national level, disaggregate output indices that are modelled on similar indices used in Canada have recently been introduced (Bureau of Labor Statistics, 2006).

Because measuring productivity of the US construction industry is challenging, it is difficult to compare it to productivity in construction sectors of other countries. Adjustment indices are used to adjust input and output numbers so that productivity calculations can be compared over time and between industry sectors and countries, but these indices differ between countries. For example, construction output is difficult to compare and measure even within a country because it is difficult to compare single-family houses to roads, schools to bridges, or office buildings to shopping centres. International productivity comparisons have similar challenges, such as the heterogeneity of outputs and inputs. Aggregating data to an industry level causes the loss of valuable information on the heterogeneous nature of construction outputs (Abdel-Wahab and Vogl, 2011). In addition, construction real outputs when adjusted using input cost indices do not always reflect innovation and design improvements in construction (Pieper, 1990).

Therefore, industry analysts differ on whether construction industry productivity is improving or declining, at least in the US. Some analyses for the industry as a whole indicate that productivity has been declining for over 30 years while other studies document improved productivity for construction projects and construction tasks (National Research Council, 2009). For example, in the US, aggregate-level productivity measures show long-term declines (Teicholz, 2001; Harrison, 2007), while activity-level productivity measures (e.g. labour hours per cubic yard of concrete footing) show long-term improvements (Allmon *et al.*, 2000). At the activity level, Goodrum *et al.* (2002) found that both labour and partial factor productivity improved between 1976 and 1998, which coincides with the same time periods reported in the previously mentioned studies.

Total factor productivity (TFP), also referred to as multi-factor productivity, is a common measurement of productivity that is used to monitor the state of the economy and is useful in measuring industry-level productivity (Zhi *et al.*, 2003). TFP is considered an economic measure because both the outputs and inputs are in dollar amounts. However, it is considered unsuitable for construction by many people because the complete inputs of any given project are difficult to measure (Thomas *et al.*, 1990). For example, equipment cost estimates depend on many factors (e.g. the depreciation method used). Also, confusion around construction productivity can be traced to differences in how it is defined. In many industries, productivity often means an increase in sales or output per worker leading to increased profit margins measured in current dollars. On the other hand, economists usually define productivity as the ratio of outputs in the form of either goods or services to inputs in the form of resources consumed (Harrison, 2007).

The migration of construction supply chain activities to offsite prefabrication facilities that are accounted in manufacturing sector statistics is another measurement issue that arises, particularly in the US. The distinction between offsite and onsite construction activities cancels the effect on construction productivity statistics of many important innovations (Eastman and Sacks, 2008). Studies of offsite production of building components (i.e. prefabrication) have found a distinct labour productivity advantage in comparison to related onsite activities and that the rate of productivity growth is greater compared to onsite sectors (Eastman and Sacks, 2008). It is problematic that productivity improvements related to prefabrication are counted towards the manufacturing industry and not the construction industry (Harrison, 2007). While construction productivity gains have resulted from the greater use of pre-work (defined as modularization, prefabrication and pre-assembly), the resulting productivity in terms of overall labour requirements for construction projects is not considered when investigating the construction industry. This significant issue should be kept in mind in the discussions that follow.

Comparison of international construction productivity analyses

For the first level of analysis in this study, absolute productivity and labour productivity growth rates were compared across 20 countries with advanced economies. Harrison (2007) reported on data for comparing labour productivity growth rates obtained from the Groningen Growth and Development Centre, 60-Industry Database. The 60-Industry Database updates and extends previous work at the Groningen Growth and Development Centre (GGDC) and the National Institute on Economic and Social Research (NIESR). The OECD STructural ANalysis (STAN) database and national accounts of individual OECD member states were used as data sources. In general, the method adopted was to use national accounts aggregates as control totals and the other data to divide these totals into sub-industries (Groningen Growth and Development Centre, 2006). (Additional data sources for the US and Canada are reported later.) STAN data were used because they are classified according to the International Standard Industrial Classification (ISIC), which allows comparisons of industries across countries for the period between 1979 and 2003 (Table 1).

Between 1979 and 2003, the growth rate of labour productivity varied significantly across countries (Figure 1). With an annual compound rate of decline of 0.84%, the US showed the worst performance while the Republic of Korea showed the best performance with an annual compound productivity growth of 2.56%. Japan and Germany also experienced negative growth in construction labour productivity while the United Kingdom, Austria, and Portugal were the top performers after Korea. Canada was reported to have experienced a very low productivity growth rate of 0.4% compounded annually. In many countries, the labour productivity growth rate in the construction industry was above 1.5% compounded annually over the period 1979–2003.

Except in case of the US, these analyses are generally consistent with Abdel-Wahab and Vogl (2011) who used the EU KLEMS database from the period between 1971 and 2005 to examine trends of productivity growth in the construction industry across Europe, the US, and Japan. KLEMS represents the first letters of inputs to the productivity process, capital (K), labour (L), energy (E), material (M), and business

Table 1 Construction productivity comparisons between countries

Country	Relative productivity in the construction sector from the Swedish Construction Federation (US is 100)	International labour productivity compound annual growth rates in construction industry, 1979–2003 Groningen Centre Data (Harrison, 2007)
Belgium	62	1.63
Finland	39	0.71
France	41	1.68
Greece	19	0.68
Ireland	48	1.64
Italy	38	0.95
Norway	56	1.40
Spain	44	1.54
Sweden	76	0.79
UK	20	1.92
USA	100	–0.84
Canada	120[a]	0.40
Rep. of Korea		2.56
Austria		2.43
Portugal		1.78
Australia		1.33
Denmark		1.24
Netherlands		1.21
Japan		–0.06
Germany		–0.06

Note: [a]From Rao *et al.* (2004).

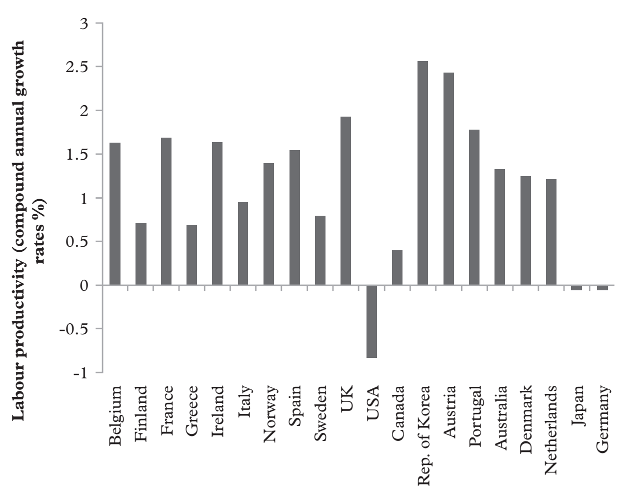

Figure 1 International labour productivity compound annual growth rates in construction industry, 1979–2003, Groningen Centre data (Harrison, 2007)

services (S). KLEMS uses data from national accounts and data obtained from National Statistical Institutes, Eurostat, and EU KLEMS consortium partners (EU KLEMS, 2011). O'Mahony and Timmer (2009) summarized the theoretical model and construction of the EU KLEMS database and found that there was a decline in the labour productivity growth rate in construction industries in major OECD countries, except in the UK. They found a positive growth in average annual labour productivity in major OECD countries from 1971 to 1990; however, there was generally a decline in the labour productivity growth rate from 1990 to 2005. In fact, they reported that Germany and Japan experienced negative annual compound growth rates in labour productivity of –1.77% and –1.91% respectively from 1990 to 2005. The US is shown to have achieved an annual compound labour productivity growth of 0.17% from 1990 to 2005. The UK was the only country reported to have achieved a steady annual compound growth rate of over 1% during this period. Ruddock and Ruddock (2011) using the same EU KLEMS database reported that the UK experienced a positive average annual growth rate of 0.68% in total factor productivity (TFP) over the period from 1981 to 2007. They reported negative TFP growth rates of –0.78% for Germany from 1992 to 2007 and –2.15% for the US from 1978 to 2007.

Table 1 also provides productivity information in the construction sector for several countries, relative to the US, which is benchmarked at 100. These data were obtained from the Swedish Construction Federation (BI), which represents the interests of the construction industry in Sweden; BI funded the study providing these data (Sveriges Byggindustrier, 2007). BI is noted in the construction research circles for its active involvement internationally. It is interesting to compare the relationship between the growth rate and absolute level of productivity for these reported numbers. Figure 2 shows this possible relationship between the growth rate and the absolute level of productivity. Despite the exponential curve projected on the data, there is no significant statistical relationship. On the

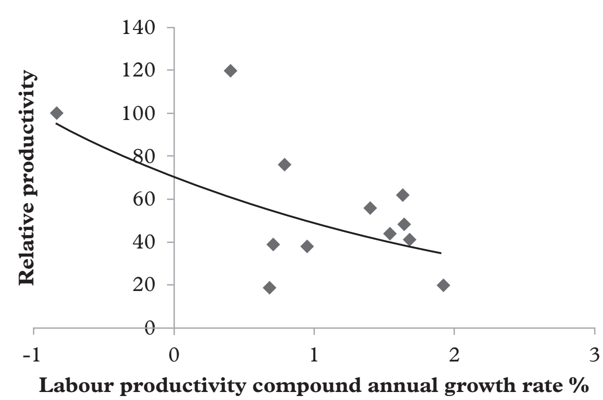

Figure 2 Productivity vs. productivity growth rate (Harrison, 2007 and the Swedish Construction Federation)

other hand, there is also no evidence that having a high productivity level impedes a country from improving at a high rate. Both Canada and the US have high productivity, and Canada's rate of productivity growth, while low, is still significant. This difference between the US and Canada needs to be explored further.

Comparison of US and Canadian construction productivity analyses

What is perhaps most fascinating from these three studies is the lack of consistency when it comes to measured productivity trends not only for the US but for multiple countries, including Canada. The Groningen Centre data suggest that US construction productivity plunged over a 24-year time period while most other construction international markets enjoyed moderate to substantial growth rates. On the other hand, data from the Swedish Construction Federation suggest that the US had one of the highest construction productivity performances among developed countries, including the EU and Canada. To add confusion, Harrison calculated US construction productivity at the national level based on the Bureau of Economic Analysis' (BEA) National Economic Accounts and Industry Economic Accounts (Harrison, 2007), although he acknowledges that the US government does not use these data to formulate its own productivity measures. Harrison estimates that between 1961 and 2005 construction labour productivity in the US annually declined at 1.44%. He notes that construction labour productivity growth was positive for Canada in the same period (Table 2), but also points out that within Canada, construction labour productivity growth rates vary substantially from province to province, by as much as 2% per year, and compared to Canada's average construction labour productivity, rates vary by as much as +18% and –33% depending on the province. He also points out that underestimates of output quality (via deflators) may shave almost 0.5% per year from the true construction productivity growth rate in Canada over the last two decades. Teicholz (2001) estimates a compound decline in the US of 0.48% annually for labour productivity growth between 1964 and 1999 based on BLS and US Department of Commerce data. His estimates vary slightly based on period, which is reflected by the fact that Teicholz (2001) utilized the same data sources as Harrison (2007); the BEA derives its output data from the US Department of Commerce. As an alternative to utilizing industry-level data, Goodrum *et al.* (2002) estimate a compound improvement in the US of labour productivity of between 0.80% and 1.80% annually between 1976 and 1998 based on task-level data from three sets of estimating manuals and 200 tasks. Once again utilizing the EU KLEMS database, Abdel-Wahab and Vogl (2011) show an annual rate of 0.17% from 1990 to 2005 for the US.

Table 2 Comparisons of US and Canadian construction labour productivity growth rates from various sources and over different periods (compound annual growth rates)

Source of estimate	Time frame	Canada	US
Harrison (2007)	1961–2006 for Canada; 1961–2005 for US	1.09% *Data source:* Statistics Canada Labour Force Survey andNational Accounts	–1.44% *Data source:* Bureau of Economic Analysis (BEA) National Economic Accounts and Industry Economic Accounts)
Harrison (2007)	1961–1981	1.81%	
Harrison (2007)	1981–2006	0.53%	
Harrison (2007)	1979–2003	0.40% *Data source:* Groningen Growth and Development Centre, 60-Industry Database	–0.84% *Data source:* Groningen Growth and Development Centre, 60-Industry Database
Teicholz (2001)	1964–1999		–0.48% *Data source:* US Bureau of Labour Statistics and US Department of Commerce
Goodrum *et al.* (2002)	1976–1998		0.80% to 1.80% *Data source:* RS Means, Richardson, and Dodge estimating manuals
Abdel-Wahab and Vogl (2011)	1990–2005		0.17% *Data source:* KLEMS

While there is inconsistency in meaning of these productivity measures, one consistent finding is that Canadian construction productivity outperforms US construction productivity. However, it should be noted that the two countries use different methods for measuring construction productivity, particularly in their inflation price indices, which complicates the comparison. Although Canada maintains a construction labour productivity index, because of concerns of adequately adjusting for change in the quality of construction output the US does not. This comparison shows that when measurements of only two countries vary so widely, it is clear that different sources of data, periods of analysis, levels of aggregation, and price indices used as deflators make international comparisons difficult. Therefore, scepticism of any measurement system is in order.

At the industry level, Chapman and Butry (2008) suggest continuing the BLS practice of using the North American Industry Classification System (NAICS) as a basis on which to assess US construction productivity in the future. The BLS does keep labour statistics, but, because of output measurement problems, does not track construction industry productivity. However, the US Census Bureau's Economic Census includes the value of construction work in terms of value added, every five years by NAICS code, so according to them, it is possible to generate industry-level metrics for each construction industry NAICS code if the quality adjustment challenge can be addressed. Harrison (2007), however, points out that Statistics Canada does not use the NAICS to estimate construction sector productivity. Gross output for construction in Canada's System of National Accounts (SNA) is based on types of construction rather than industrial class. Thus, comparing Canada's estimates at the national and sector levels to US estimates of productivity may be problematic, if the NAICS is used in the US.

Rao *et al.* (2004) analysed the general business sector labour productivity gap between the US and Canada, which shows that Canada lags behind the US by a factor of 0.82 to 1.00. However, construction stands out as an exception in their analysis. While the level of capital utilization production processes throughout most industries generally lags in Canada compared to the US, construction is one of the few industries in which Canadian capital intensity is close to that of the US.

Activity-level analysis of productivity trends in the US construction industry from 1995 to 2009

Goodrum *et al.* (2002) measured the labour and partial factor productivity trends in the US construction industry from 1976 to 1998 at the activity level using three longitudinal sources of estimating data. At the time, the Goodrum *et al.* (2002) study identified productivity improvement across many construction activities, but it is useful to explore whether these improvements have continued and are consistent today. This section examines activity-level productivity changes from 1995 to 2009. The methods used regarding the data sources, selection of activities, measuring labour and partial factor productivity, and data analyses are provided below.

Sources of data

A number of sources of published cost data in the US are available and can provide important information required in the estimating process, but some are prohibitively expensive. RS Means references are considered an important source of cost data. RS Means publishes *Building Construction Cost Data* books (referred to here as estimation manuals) that serve as pricing guides and provide data related to crew formations, hourly rates, and production rates of crews in different tasks related to buildings. Data for this article were collected from the 1995 and 2009 RS Means estimation manuals. One of the main advantages of using data from RS Means manuals is that they enable the development of an overall picture of the industry because they contain productivity data for numerous trades.

The manuals provide unit labour costs, unit equipment costs and physical output data. Means bases its labour costs on the average wage rates from 30 US cities while it bases the equipment costs on rental rates plus operating costs, which include fuel, lubricants, tyres and electricity, if applicable (Goodrum, 2001). The manuals are organized according to the 16 divisions of the Construction Specifications Institute's Master Format. Within these 16 main divisions, the manuals contain information about more than 21 000 activities (i.e. construction methods) that use 345 predefined crew configurations.

Although the estimation manuals provide one of the best sources of time-series data on productivity that is publicly available, there are weaknesses in the data that should be recognized. Many contractors will claim that estimation manuals should only be used as a data source for cost estimation if no other data source is available and that actual cost data derived from their own internal project controls system provide a more relevant cost and time estimate based on their own means and methods of construction. The perception among many contractors is that the manuals produce inflated price estimates because contractors who submit the data in the estimation manuals know they will not be required to construct the project based on their estimates, which tend to produce inflated estimates of construction costs (Pieper, 1989). This may be partly due to the difficulty of adjusting cost figures from the manuals to reflect actual geographic conditions such as labour and material availability, weather, and environmental considerations (Goodrum, 2001). Although the manuals do provide cost indices for different geographic locations, economic conditions can change faster than the manuals can be updated. The publishers of cost estimation manuals do a good job at updating unit cost data, but are rather slow at updating physical output. As demonstrated in Allmon *et al.* (2000), estimates of physical output are typically updated when a marked change has occurred in the method, materials, and equipment used in the crew makeup for the manuals' construction activities. However, although the RS Means estimation manuals have some weaknesses, their value as a data source for studying long-term construction trends is significant (Goodrum, 2001).

Selection of activities

Two criteria were used for selecting activities for analysis: (1) activities that were similar to those used in the Goodrum *et al.* (2002) study, even though an identical set was not possible due to evolution of methods; and (2) activities that represented a wide variety of types of construction activities. Based on these criteria, 200 activities were randomly selected from 12 of the 16 divisions in the 1995 estimation manual. The four divisions that were not sampled represent little industry volume. Twenty-eight of the 200 activities were dropped from the analysis because they did not appear in the 2009 estimation manual. The reasons for these missing activities were investigated and can be categorized as follows: materials are no longer used; dimensions are no longer used because they are no longer manufactured or are no longer included in building codes; a whole system has changed; new technology is being used for a particular construction method; and hazardous methods are no longer used.

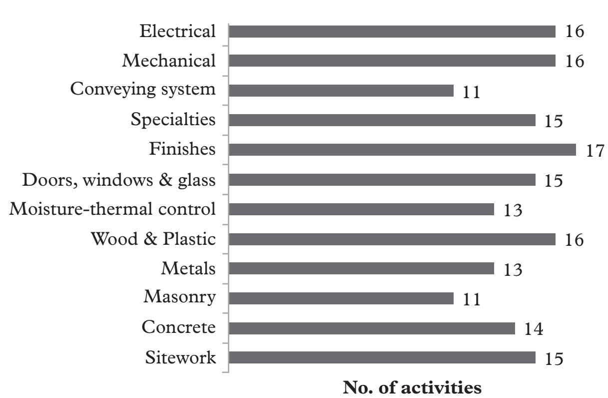

Figure 3 Distribution of construction activities by division (RS Means, 1995, 2009)

It would have been problematic if one of the categories had migrated to a prefabrication facility (e.g. duct work); however, this type of change did not occur in the sample. Figure 3 shows the number of activities selected from each division. Approximately equal numbers of activities were chosen for each category.

Cost adjustment related to inflation

Because this research compared partial productivity values for 1995 and 2009, costs were adjusted for inflation; all partial productivity numbers for 1995 were converted to 2009 dollars, based on the rate of inflation, which required the application of a specific price conversion. Two common indices used for this are the consumer price index (CPI) produced by the US Bureau of Labor Statistics and the Means Historical Cost Index. The CPI is calculated using a standard 'basket' of goods including consumer items and is a type of output price index, which is the preferred type of inflation index. The Means Historical Cost Index is derived from construction projects data to calculate annual conversion factors. The Means index is a type of input cost index, which has generally been shown to have the effect of underestimating real output (Dacy, 1965; Gordon, 1968; and Pieper, 1990). Still, because Means is more construction focused it was used for this study.

Data analysis

The data were used to first calculate two productivity measures for 1995 and 2009: labour productivity and partial factor productivity for each individual activity. Next, the percentages of change for both types of construction productivity were calculated. The average of the percentage change for the activities within each division was used to represent the change for a particular division. The average of changes in the divisions was used in calculating the final cumulative building sector productivity change from 1995 to 2009. The following definitions were used for labour productivity and partial factor productivity.

Labour productivity

Labour productivity defined in terms of unit rate was used in this research and is expressed by Equation 1 (Thomas *et al.*, 1990).

$$\text{Labour productivity} = \frac{\text{actual work} - \text{hours}}{\text{installed quantity}} \tag{1}$$

The Construction Industry Institute (CII) Benchmarking and Metrics Program also uses this definition for measuring and reporting labour productivity (Park *et al.*, 2005). An example is hours per cubic metre of concrete placed in a category of building element, such as footing.

The following formula is used to calculate the percentage change in construction labour productivity between 1995 and 2009 for each construction activity.

$$\begin{aligned}&\%\ \text{Change in labour productivity, } 1995 - 2009 \\ &= \frac{\text{labour productivity } 2009 - \text{labour productivity } 1995}{\text{labour productivity } 1995} * 100\end{aligned} \tag{2}$$

Partial factor productivity

Partial factor productivity is defined as the physical output per labour and equipment costs based on the estimation manuals and calculated with Equation 3:

$$\text{Partial factor productivity} = \frac{\text{physical output (units)}}{\text{labour}(\$) + \text{equipment}(\$)} \tag{3}$$

The percentage change in partial factor productivity between 1995 and 2009 was measured using the formula:

$$\begin{aligned}&\%\ \text{Change in partial factor productivity, } 1995 - 2009 \\ &= \frac{\text{partial factor productivity } 2009 - \text{partial factor productivity } 1995}{\text{partial factor productivity } 1995} * 100\end{aligned} \tag{4}$$

Results of analysis of RS Means data

Table 3 shows the changes in labour productivity for each of the 12 divisions studied. The annual compound growth rate in labour productivity overall for the 172 activities between 1995 and 2009 was negative. The labour productivity declined by 0.02% compounded annually. This number indicates that in the US building sector, construction labour productivity remained almost steady with no change between 1995 and 2009. Significant differences existed between divisions. Considerable improvement in labour productivity was experienced in site work and masonry activities while the concrete and conveying systems divisions showed only a slight improvement over the period of the study. The highest improvement was observed in masonry work, which experienced a 0.55% annual compound increase in labour productivity. Site work experienced a 0.53% annual compound improvement, which is most likely due to emerging ‘stakeless’ earthmoving technology based on equipment blade control servoed off global positioning system signals and driven by 3D cut and fill designs. In contrast, metals, finishes, and wood and plastic showed considerable decline. The highest decline was in the metals division, at 0.69% compounded annually.

Table 3 also shows the changes in partial factor productivity for each division. Based on these results, the overall change in partial factor productivity between 1995 and 2009 for the 172 activities was an annual compound rate of improvement of 0.66%. The majority of the improvement was related to both masonry and site work with annual compound rates of 1.73% and 1.40% respectively. The remaining divisions showed positive improvement that varied between 0.00 and 0.60% compounded annually over the same time period. Conveying systems was the only division which showed a small decline in the partial factor productivity.

One disadvantage of examining productivity trends based on individual construction activities is that it ignores the volume of construction work represented by the sampled activities. In order to address this effect, a number of economies, including Canada, attempt to measure construction productivity performance using a matched model approach, which weights specific construction activities’ volume based on different model project types. For example, Means provides square foot costs for each division for different types of buildings. They represent the typical contribution of a division to the overall cost of a building in one of the categories. Several sets of weights were used in a sensitivity analysis, but respective differences were only slight. Table 4 provides an example of these

Table 3 Compound annual rate of change in labour productivity and partial factor productivity by division from 1995 to 2009 (RS Means, 1995, 2009)

Division	Change in labour productivity (%) (compound annual growth rates)	Change in partial factor productivity (%) (compound annual growth rates)
Site work	0.53	1.40
Concrete	0.04	0.85
Masonry	0.55	1.73
Metals	−0.69	0.62
Wood & plastic	−0.24	0.46
Moisture-thermal control	−0.05	0.63
Doors, windows & glass	0.04	0.64
Finishes	−0.53	0.09
Specialties	0.00	0.62
Conveying system	0.07	−0.04
Mechanical	0.01	0.31
Electrical	0.00	0.38
Overall findings	−0.02	0.66

analyses for a typical low-rise, one- to three-storey building, but it is not intended to be representative of the entire construction population (RS Means, 2009). While the matched model approach is not being currently used to measure construction productivity in the US, the approach is being developed for use by the BLS producer price indices as a measure of construction inflation.

Significance testing for changes in labour and partial factor productivities

Table 5 shows the results of the t-test conducted to check the significance of the results. Given that the average percentage change in labour productivity is small and that the variation of the data is large, the results yielded from the t-test showed a non-significant change for labour productivity.

In contrast, the t-test shows that the average percentage change in the partial factor productivity is significant. In summary, by considering the t-test results, labour productivity showed no significant improvement since the P value is more than the significance level ($\alpha = 0.05$). Therefore, the test fails to reject the null hypothesis in which the average percentage change with regard to its variation is equal to zero. In contrast, the partial factor productivity results showed significant improvement since their P value is much less

Table 5 T-test results for labour and partial factor productivity from 1995 to 2009

T-test results	Labour productivity	Partial factor productivity
Mean	−0.22	9.24
Variance	269.55	535.66
Observations	172	172
df	171	171
t_{Stat}	−0.3475	5.2367
P (T<=t) one-tail	0.3643	2.37E-07
t_{critical} one-tail	1.6538	1.6538
P (T<=t) two-tail	0.7286	4.75E-07
t_{critical} two-tail	1.9739	1.9739

Note: The null hypothesis tested with average percentage change with regard to its variations is equal to zero.

Table 4 An example analysis of a typical low-rise apartment (1–3 storeys) (RS Means, 1995, 2009)

		Unweighted (%) change in productivity from 1995 to 2009 (compound annual growth rates)		Weighted (%) change in productivity from 1995 to 2009 (compound annual growth rates)	
Division	Average % square foot of total	Labour productivity	Partial factor productivity	Labour productivity	Partial factor productivity
Site work	10.6	0.52	1.40	0.06	0.15
Masonry	3.7	0.56	1.73	0.02	0.06
Finishes	10.8	−0.53	0.09	−0.06	0.01
Equipment	4.0	0.07	−0.04	0.00	0.00
Plumbing	9.0	0.01	0.31	0.00	0.03
Heating, ventilating, air conditioning	5.6	0.01	0.31	0.00	0.02
Electrical	6.7	0.00	0.38	0.00	0.03
Remaining	49.8	−0.01	0.66	−0.01	0.33
Overall % change				0.02	0.62

than the confidence value (α = 0.05). Therefore, for partial factor productivity the null hypothesis can be rejected with 95% confidence.

Discussion

Three levels of analyses were conducted in this research: the global level that compared the growth of labour productivity between different countries; a comparison of the construction industries of the US and Canada; and an analysis of estimating data from one source, RS Means manuals, to measure changes in labour and partial factor productivity in the US longitudinally from 1995 to 2009. These analyses indicate that construction labour productivity in the US during the last 50 years has either declined or remained static. However, legitimate concerns exist with the accuracy of estimates of US construction real output. Until these concerns are resolved, we really do not know which trend is seen at the industry level. Also it needs to be seen whether other countries have critically examined the accuracy of their estimates for industry output as has been done in the US. It needs to be seen how other countries report their construction productivity.

Observed changes in cost are one reason that the partial factor productivity analyses were positive and the labour productivity analyses were not. Different countries also have different industry composition. Over the time period, there was much more residential construction in the US compared to Canada and likely other countries; Allen (1985) suggested that the residential sector is less productive compared to other sectors. To resolve this issue, standard measures of construction productivity across international construction industries need to be put in place. This need for standardization is a primary reason why countries began measuring their overall output based on GDP versus unique GNP measures.

This contrasts with the other developed economies studied, including Canada. Also interesting is that although productivity in construction industries of the countries in the EU is increasing at a high rate, in an absolute sense it is still significantly lower than in the US. On the other hand, compared to the US, Canada has experienced positive growth and also has a high absolute productivity level. There could be several reasons for this discrepancy despite the fact that the countries share the same language, union organization, building design styles (if not precise codes), equipment spreads, and highly coupled broader economies. Two reasons could account for the discrepancy: wage differentials and training systems.

Wage differentials

Although US construction wages are relatively high in unionized centres and northern states, average construction wages in the US are much lower than in Canada and most EU countries (RS Means, 1995, 2009). One possible reason is the availability of immigrant workers in the US in construction who primarily work for relatively low wages. The Center for Construction Research and Training, formerly known as the Center to Protect Workers' Rights (CPWR), estimates that Hispanic workers make up more than 20% of the workforce nationally in the US, and in some states the majority (Center to Protect Workers' Rights, 2011). According to Goodrum and Dai (2005), Hispanics are the majority of the construction workforce in Texas (69.4%), New Mexico (55.9%), and California (51.4%). Low wages for these workers may be related to low skill levels, but could also be due to wage discrimination (Goodrum, 2004). However, the countries in this study that are experiencing positive growth in labour productivity have high labour costs, which is in line with economic theories that deal with wages and labour productivity. According to the efficiency theory, workers will be spurred to increase their productivity if high wages are paid. The efficiency-wage theory argues that higher wages can increase productivity among other desirable outputs, such as reduced absenteeism (Snowden and Vane, 2005). In efficiency theory, one hypothesis is that wages drive productivity rather than the reverse. Wakeford (2004) notes that this is because paying higher wages creates a higher opportunity cost of job loss. Thus, higher wages stimulate workers to put more effort into work to avoid redundancy. In other words, higher wages encourage workers to increase their productivity. Besides, higher wages put more pressure on labour costs so firms will substitute capital for labour. According to the rule of diminishing marginal product, when the quantity of labour decreases, the marginal product of labour increases, which is to say productivity increases. Several empirical studies support this theory. For example, Hall (1986) and Alexander (1993) used empirical evidence to show the cointegration relationship in the UK and concluded that higher wages spur improved labour productivity in the long run. Further, Narayan and Smyth (2009) used panel cointegration techniques to examine the effect of real wages on productivity in the G7 countries. They found that a 1% increase in real wages is correlated with a 0.6% increase in productivity for the panel as a whole. Similar results were obtained by Kumar *et al.* (2012) who applied cointegration and structural tests to Australian data over the 1965 to 2007 period and got the result that a 1% increase in manufacturing sector real wages related to a 0.5% to 0.8% increase in manufacturing labour productivity. Srour *et al.* (2006) performed statistical analyses to explore what the US construction industry values in its workers, as reflected in both hourly wages and average annual income. They reported that workers who know how to use computers and have extra years of experience were making more in terms of hourly wages and that workers who possess many skills have higher annual income but not higher hourly wages. This indicates that the industry does not reward workers with many skills by increasing their hourly wages; however, they have higher annual incomes by staying longer on job sites or getting more opportunities for new jobs. These findings suggest that there is a positive bi-directional relationship between wages and productivity (unit output per labour) that, given their construction wage differentials, may partially explain productivity discrepancies between the US and Canada.

Training systems

Training infrastructure in the US declined as the percentage of construction workers belonging to unions declined from roughly 70% in 1980 to 17% today. Historically, the union-based apprenticeship system supported training. Craft training systems also play an important role in improving labour productivity, and formal training programmes exist in the union and open shop sectors in the US (Wang *et al.*, 2010). However, these programmes are inconsistent and enjoy little government support. In Canada, formal apprenticeship training programmes are mandated and supported by the government sector in partnership with the private sector and unions, and similar training programmes exist in other developed countries of the world. This widely perceived lack of construction craft training infrastructure in the US could also be a possible reason for negative productivity growth in the US construction industry.

Conclusions

Three levels of analyses for looking at construction productivity in the US were provided in this study. The first analysis compared international levels of labour productivity growth. The second compared construction numbers between the US and Canada, and the third analysed data from one source of estimating data to measure the changes in labour and partial factor productivity in the US longitudinally from 1995 to 2009. A number of observations and conclusions can be drawn from this study that may be useful for influencing strategic planning for construction industries, although further study is merited because of some internal contradictions that were exposed. Most studies show construction labour productivity in the US to be declining or stagnant, but two studies contradict this trend. The activity-level analyses based on RS Means show that labour productivity in the US remained almost the same from 1995 to 2009. In contrast, partial factor productivity in construction in the US was estimated from Means data and revealed an annual compound rate of 0.66% from 1995 to 2009. A related, previous study showed positive improvements at least since 1976 (Goodrum *et al.*, 2002), leading to the conclusion that standard industry productivity measures are needed. The current, significant variances in how countries measure construction productivity mean that until these variances are controlled, it will remain uncertain whether differences are due to performance or different measurement systems.

There is no evidence that a high productivity level for a nation impedes the nation from continuing to improve at a high rate, despite the fact that while construction productivity in EU countries is increasing at a high rate, in an absolute sense the numbers are still significantly lower than in the US.

Finally, on an international scale, some experts and economists have observed that such productivity in construction, particularly labour productivity, tends to correlate with GDP per person and with wage rates. Perhaps higher prevailing wage rates force investment in capital and technology, thus at least improving labour productivity. Further study is required to buttress these observations and conclusions, and a meta-analysis approach, such as that advocated by Ben Goldacre in *Bad Science* (2009), might be appropriate.

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