COST INDICES AND TECHNOLOGY CHOICE: STRATEGIES FOR INDUSTRY DEVELOPMENT

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ABSTRACT

Building economists have produced construction cost indices to compare the cost of constructing buildings across many countries but these indices do not take into account or optimizes the choice of materials or the technology used in the construction process. The aim of this project is therefore to develop new construction cost indices which are linked to the various methods of building construction. The differences in local practices, availability of local resources (raw materials, land, labour, capital and technology), domestic building materials industries, and local regulations all combine to influence the construction cost of a building. These new indices are derived from a global survey of the costs of building material, construction costs for various building elements, labour costs, capital costs together with the choice of construction method and technology employed. The findings will inform on many current research and policy initiatives: to manage the exploitation of indigenous resources, to develop domestic building materials industries, to improve construction methods, modernise and upgrade the construction sector in developing countries.

INTRODUCTION

Construction technology is commonly understood as the choice of construction materials and the processes through which these are assembled to produce a building or a structure. The use of locally grown timber or stone quarried from a nearby location for residential housing is one example of material selection through the utilisation of native materials. Very often the skills of the local labour are closely matched with the type of material that is most commonly available. This simple and efficient selection of materials and construction technology has served to provide buildings for many centuries. Modern construction methods now offer the builder a number of options for a building system with a wider selection of materials, some of which may be procured from overseas. Fundamentally, the construction cost will comprise the cost of the raw materials, the labour to shape and assemble these materials, the purchase (or rental) of tools, machineries and other
construction equipment, overheads (management, head office, compliance with all regulations, fees, and insurances) and finally the builder’s profit. Builders may choose to adopt local construction methods and materials that are durable and inexpensive to maintain, to reduce the maintenance and life cycle cost of buildings. However, it is also possible that investments in new technologies may reduce the costs of construction in the long run when the technology becomes widely accepted locally. Modern construction methods employ various elements or sub-assemblies that may be fabricated elsewhere to reduce the physical work at the construction site. For example, prefabricated building has become the least expensive and widely used technique in the public housing sector of many developing countries while in other countries in-situ construction remains the cheapest and ubiquitous (Warszawski, 1999). Multi-storey buildings in Australia are predominantly constructed with concrete framed structures whereas the US has a greater proportion of steel framed buildings. Many developing economies, faced with increasing demand for building products and services, are faced with challenges to formulate policies to advance their local construction industries in the most appropriate directions with regards to construction materials and technologies. A careful choice of technology will have both economic and social consequences.

Stakeholders in multinational projects need to understand the total cost of projects at the feasibility stage and prior to bidding and construction. They require sufficient information that can help them choose different construction technologies when planning projects in different locations. Knowledge of differences in costs between locations accounted for by differences in technology can help stakeholders choose the most appropriate construction. On top of that, the choice and investment in appropriate technology can facilitate and advance the development of the local construction industry. The aim of this project is therefore to develop a series of construction cost indices which are linked to basic inputs that are available for the construction of buildings. The differences in local practices, availability of native resources (raw materials, land, labour, capital and technology), domestic building materials industries, and local regulations all combine to influence the construction cost of a building. These indices will be derived from a compilation of the costs of building material, construction costs for various building elements, labour costs, together with the choice of construction method and technology employed. The findings will inform on many current research and policy initiatives: to manage the exploitation of indigenous resources, to develop domestic building materials industries, to improve construction methods, modernise and upgrade the construction sector in different countries. The findings should provide a rational method for selecting an appropriate building technology to suit the conditions of the construction industry in different countries. This is important as developing countries continue to seek for ways of making construction products affordable as well as seek to encourage the development of domestic construction industry.

BACKGROUND AND LITERATURE REVIEW

International construction economists (Stapel 2002, Walsh and Sawhney 2004, Best et.al 2010, McCarthy 2011) are focused mainly on gathering data on construction costs in major cities around the globe and conducting research to explain observed differences in these indices based on the type of building; whether the building is to be used as a hotel, premium office tower, or an industrial or manufacturing facility. The demand for these indices are driven mainly by investors from developed countries looking to invest in major growth areas, or by manufacturers seeking to relocate their operations to less expensive locations. Sultan and Kajewski (2006) indicated that in some developing countries, the construction industry is very dependent on the import of construction components and materials combined with issues of high unemployment leading to high construction costs from imported materials, inflation.
and an unstable economy. Thus policies put forward by various countries to improve the economic performance of their respective construction industries need to be informed by a precise economic model that illustrates the link between the cost of inputs to the construction industry to the price of its outputs and its follow-on benefits to the national economy.

The insistence by many developing countries seeking to import expensive construction technologies or use advanced products from overseas in their local construction sectors to improve productivity or quality of their products may be misguided. Ganesan (2000) suggested that construction methods that provide greater employment be adopted in Sri Lanka to cater for the under-employment of the labour force.

METHODOLOGY

This project explores the use of basic construction material and labour cost indices to develop a framework for evaluating the choice of construction technology. The framework is used to map the technology choices to various combinations of input cost indices in a number of developed and emerging economies. The approach is to examine a number of countries with the availability of indigenous raw materials, high and low labour costs, and to show the price developments of production factors used in their respective construction industries. Data for gross domestic product (GDP) per capita based on purchasing power parity (PPP) was obtained from the World Bank’s world development indicators database for 2011 to correspond with the year the cost survey was carried out (World Bank, 2013).

Compilation of Basic Prices

Construction cost data from sixteen countries was obtained from an international construction cost survey conducted by Turner and Townsend (2012). The cost components analysed were limited to skilled labour cost (calculated as an average of skilled workers in three groups of trades), five basic material cost items (concrete, reinforcing bars, standard bricks, steel sections and softwood timber for framing) and four key elements in the building trades (concrete in slabs, reinforcement in beams, formwork to soffit of slabs, and structural steel sections). These basic prices were converted to ratios or indices by dividing the cost of each material with the hourly rate for skilled labour or the cost of supplying one cubic metre of concrete. Hourly wage rates for Vietnam and South Korea were adjusted by reference to Phan (2012) and Lee and Kim (2013).

ANALYSIS OF COST INDICES

Of the 16 countries examined, Singapore, US, UAE, Ireland, Canada, Australia, Germany, UK, Japan, and South Korea were classified by the World Bank as high income (HI) with Russia, Malaysia and South Africa in the upper middle income (UMI) category, and China, India, Vietnam in the lower middle income (LMI) category. In an international comparison of construction industries, the single most important factor is usually the difference in labour cost across different economies. Figure 1 shows the hourly wage rate for skilled workers in these countries in US dollars plotted together with descending GDP per capital (PPP adjusted) for these 16 countries. As expected, the hourly wages for skilled workers are significantly higher for the high income countries (US$66 per hour in the US) but lower for the middle income countries (ranging from US$1.03 in India to US$17 per hour in Russia). As the construction sector in Singapore and the UAE are heavily reliant on the employment of migrant workers, the wage levels in these two countries are depressed by the lower wages paid to these transient workers compared to the local nationals. A similar depression of wage is evident in Malaysia where a large proportion of the construction labour is from either Indonesia or
Bangladesh. The hourly wage for skilled workers in both Singapore and the UAE reflects the wage levels in the middle income economies from where these workers originate.

An examination of the cost of one cubic metre of 30MPa concrete indicates that this ranges from a low of US$55 in Vietnam to a maximum of US$191 in Australia. A plot of the concrete costs against the level of economic development in Figure 1 indicate that concrete is not necessarily cheaper in a middle income economy when compared in US$.

![Figure 1: Hourly wage for skilled workers and supply rate of concrete versus GDP per capital](image)

**Indexed to Labour**

The effect of different currencies can be eliminated if basic materials such as concrete, brick, timber, reinforcements and structural steel are divided by the hour wage of the skilled workers (see Figures 2 and 3). A cubic metre of concrete is now equivalent to 2.8 hours of wages in the high income countries if we disregard Singapore and UAE. Concrete is valued at between 7 to 8 hours of wages for Singapore and UAE, but increases rapidly as GDP per capita reduces. Supply of Indian concrete is the most expensive at 104 times the hourly wage. Similar trends can be seen for timber; with Japan and the UAE exhibiting significantly high index costs. The difference in the index for bricks is not as significant with an average of 15 for high income countries and a range from 20 to 130 for middle income countries.

The supply of reinforcing bars and structural steel is equivalent to 21 hours and 40 hours of wages, respectively, for high income countries. The lower cost of labour in Singapore and UAE distorts the relative cost of steel in these two countries leading to ratios more aligned to the middle income countries. Steel is relatively expensive in the upper middle and lower middle income countries. The extremely low wage in India leads to very high relative cost of both reinforcing bars
and structural steel there with ratios exceeding 800 for a tonne of reinforcing bars and 1000 for a tonne of structural steel as shown in Figure 3.

The higher relative cost of materials in lower middle income countries will drive designers to adopt labour intensive construction processes with a corresponding minimisation of materials used. High income economies, on the other hand, will attempt to adopt labour saving practices but may utilise more materials as these materials are relatively cheap in comparison. Large differences can be observed for materials such as concrete, timber, reinforcing bars and structural steel, but less obvious with bricks.

Figure 2: Concrete, Bricks and Timber cost indexed to Labour

Figure 3: Reinforcing bars and Structural Steel costs indexed to labour
Indexed to Concrete

Similarly, the cost of basic construction materials can be divided by the cost of one cubic metre of concrete in Figures 4 and 5. Bricks are only slightly more expensive relative to concrete in the high income countries than in the middle income countries. This observation may lend itself to the wider use of brick in buildings in the middle income countries where the cost 1000 bricks is only one or two times more than one cubic metre of concrete.

The cost for one tonne of reinforcing steel is between 5 to 15 times the cost of one cubic metre concrete for all the countries examined. No clear trend was observed relative to the level of income for these countries. But the examination of the cost of structural steel, countries such as the US, Japan, Russia and India have very low cost relative to concrete. This observation may account for the higher prevalence of steel structures in these countries compared to reinforced concrete frames.

Figure 4: Brick and Timber Costs Indexed to Concrete

Figure 5: Reinforcement and Structural steel indexed to concrete
The cost of a cubic metre of concrete in a reinforced concrete slab is the sum of the material and labour costs plus an allowance for wastage. One cubic metre of concrete in a slab is equivalent to approximately 3.4 hours of wages in the high income economies (excluding Singapore and the UAE) whilst the ratio increases to 16 for the upper middle income and 57 for the lower middle income countries. This observation reinforces the earlier finding that concrete as a material is cheap relative to labour in high income countries but significantly more expensive in lower wage economies.

The utilisation of timber formwork is examined next. One square metre of timber formwork to the soffit of a slab is equivalent to 0.5 cubic metres of concrete in the high income nations, but decreased to 0.18 cubic metres for the lower middle income nations. This reduction in the relative cost of timber formwork seems to suggest that timber formwork remains the most cost effective method of moulding concrete in lower middle income nations.

**COMPARISONS WITH CASE STUDIES**

In this section, these cost indices are employed in an attempt to rationalise the findings from various case studies on the choice system in various countries. Three case studies were identified from literature to represent the various framing options for multi-storey construction: cast-in-place reinforced concrete, precast concrete, prestressed concrete and structural steel frame with composite concrete-steel deck systems. The purpose of these case studies was to demonstrate the use of these indices to rationalise the choice of structural system in each location based on the cost of inputs. Yong (2010) determined that when the projects were priced with local Melbourne rates, the materials consist of 50% of the total structural costs with labour and plant at 45% and 5%, respectively. The material, labour and plant split for the UK and the US remained at approximately 43%-46%-11% and 45%-54%-1%, respectively. Pricing the same project in Malaysia resulted in a lower proportion for labour at 22% with a corresponding material component at 72%. A detailed examination of these labour components indicates that labour intensive activities such as the installation and dismantling of formwork comprise a large proportion of the labour costs. It is not surprising that numerous innovative systems of precast concrete elements or lost formwork systems have been developed to reduce the utilisation of timber forms in reinforced concrete works in HI countries. Given that labour constitutes only 22% of the total structure works there is little incentive to employ more productive methods of construction.

A comparison of cast-in-place reinforced concrete with a precast concrete system in Australia is shown in Table 1. The cost for the cast-in-situ system was the more economical compared to the precast system which was 9% more expensive. The precast material cost had increased to AUD 207 due to higher manufacturing and transportation costs for the precast elements, but there was a consequential reduction in onsite labour costs for the assembly of these elements. The need for a larger capacity crane for the assembly of the precast elements increased the equipment cost.

There is an analogous increase in total cost when a precast system is utilised in place of the conventional reinforced concrete system in UMI Malaysia. This is to be expected as the cost of precast elements are higher than cast-in-place elements due to additional connectors and increased cost of transportation and handling. A comparable decrease in site labour is observed. The remarkable difference is in the sizeable increase in material cost for precast elements in Malaysia where the precast was shown to be three times the cost of cast-in-place materials whereas the precast elements in Australia were only 34% more expensive. This resulted in a total system cost for precast that was 163% higher than the conventional system, negating any obvious advantages in speedier construction, increased productivity or improved quality.
Table 1: Unit cost (per square metre) of concrete systems in Australia and Malaysia (Yong 2010)

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<thead>
<tr>
<th></th>
<th>Total</th>
<th>Material</th>
<th>Labour</th>
<th>Plant</th>
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<tbody>
<tr>
<td><strong>Australia (in AUD)</strong></td>
<td></td>
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<tr>
<td>Cast-in-place Reinforced Concrete</td>
<td>309</td>
<td>154 (50%)</td>
<td>138 (45%)</td>
<td>17 (5%)</td>
</tr>
<tr>
<td>Precast planks, beams and columns</td>
<td>336</td>
<td>207 (62%)</td>
<td>85 (25%)</td>
<td>44 (13%)</td>
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<tr>
<td><strong>Malaysia (in MYR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cast-in-place Reinforced Concrete</td>
<td>146</td>
<td>105 (72%)</td>
<td>32 (22%)</td>
<td>9 (6%)</td>
</tr>
<tr>
<td>Precast planks, beams and columns</td>
<td>384</td>
<td>336 (88%)</td>
<td>21 (6%)</td>
<td>26 (7%)</td>
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The cost indices for concrete-skilled worker and reinforcement-skilled worker indicate clearly that concrete and steel reinforcements are relatively cheap compared to the cost of labour in Australia. It is apparent that with a concrete-skilled worker index of 12.6, and steel reinforcement-skilled worker index of 176, it is more economical to adopt conventional cast-in-place concrete practices instead of precast systems in Malaysia. This study has also shown that analogous ratios of 3.1 and 20.8, respectively in Australia, will lead to a precast system cost that is only marginally higher than cast-in-place systems, and the additional benefits of quicker construction, better control over quality, and reduced exposure to weather risk can be achieved.

Mills (2009) analysed a range of construction designs that were applicable to commercial buildings in Australia. Costs were worked out to include all work necessary to complete the item fixed in place in its final position. The objective was to compare the cost relativities between five Australian cities; Adelaide, Brisbane, Melbourne, Perth Sydney; but the data can be easily averaged to provide a comparison of the different building systems instead. Six different systems were computed by Mills although only four are discussed here as shown in Table 2 below.

Table 2: Comparison of per square metre cost for framing systems in Australia (Mills 2009)

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<tr>
<th>Framing System</th>
<th>Cost (sq.m)</th>
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<tr>
<td>RC frame with timber formwork</td>
<td>AUD 499</td>
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<tr>
<td>RC frame with metal deck formwork</td>
<td>AUD 477</td>
</tr>
<tr>
<td>Steel frame concrete slab with metal deck formwork</td>
<td>AUD 769</td>
</tr>
<tr>
<td>Precast concrete frame</td>
<td>AUD 348</td>
</tr>
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</table>

The steel frame solution was significantly more expensive than all other options in this study. Only about 10% of multi-storey buildings in Australia use this system due to the higher cost of steel elements and the additional requirement for fire protection. The structural steel-concrete index of 16 for Australia is significantly higher than the 6.7, 7.8 and 8.5 reported for Japan, Russia and the US, respectively. The higher relative cost of structural steel may account for fewer steel buildings in Australia compared to these countries. Additionally, builders in Australia have a long culture of using concrete in multi-rise buildings, and have invested time and technology to achieve a high level of cost performance. Precast appears to be the most cost efficient design based on lower relative cost
of concrete compared to skilled labour as discussed in the earlier section. With the cost of formwork-reinforcement index at 0.10 in Australia it makes economic sense to utilise metal decks to substitute for timber forms. Middle income countries with a formwork index of 0.01 to 0.03 would find it prohibitively expensive to adopt a similar product.

On a similar track, Proverbs et al (1999) examined the mean productivity rate in man-hours per square metre for formwork for beams for UK, French and German builders. Their findings indicate that the apparent differences were due to significantly more productive prefabricated formwork systems used in France and the proprietary formwork system preferred by German builders. The mean productivity rate for traditional timber formwork in the UK was 2.45 man-hours per m² whereas the best productivity rate for the Germans using proprietary forms was 1.25 man-hours per m² followed by the French using prefabricated forms at 1.34 man-hours per m². Where German construction workers were the most very highly paid by in Europe, builders were inclined to invest more into mechanizing production processes; thereby counteracting the impact of such high wage rates. The economics of each nation are likely to have some influence on preferred systems.

The above three case studies have shown how these indices can be utilised to justify the decision to adopt more prefabrication in high income, high wage country like Australia while more labour intensive construction processes are preferred in upper middle income, low wage Malaysia. Many other examples of these options can be found if comparisons are made between systems used in high income and middle income countries. Taking all basic construction materials together in this comparison indicate that at locations where labour is relatively cheap, it will certainly be worthwhile to adopt more labour intensive construction processes to reduce material utilisation. The higher wage costs in a high income economy will evidently motivate builders to reduce their dependence on labour by adopting labour saving options such as standardisation, prefabrication or pre-casting even though these options may result in a greater quantity of materials.

The indices can also inform on choice of materials to be used in the construction. At locations where one material is cheap relative to another (eg. in Australia where one tonne of structural steel is 16 times more costly than a cubic metre of concrete), one will observe a naturally higher utilisation of more concrete relative to structural steel for buildings. This is also borne out by the anecdotal evidence of a greater number of structural steel buildings in the US and Japan as compared to Australia or the UK where there is a stronger tradition of concrete construction.

At locations where timber formwork is expensive due to the high wages, metal decking is more widely used. In countries where formwork-reinforcement index was 0.05 or lower, timber, prefabricated or proprietary formwork systems remain viable.

**IMPLICATIONS FOR INDUSTRY DEVELOPMENT**

Annual construction spending in Asia in 2012 was led by China (US$1.245 trillion), Japan (US$487 billion), and India (US$477 billion) followed by South Korea ($222 billion), Indonesia and Taiwan. In the longer term, both China and India are set to see continued high levels of growth in construction spending (AECOM, 2012). Whilst the construction market in India was large at US$477 billion in 2012, it was only one third of the size of the construction market in China, despite similar population levels. AECOM (2012) reports that India is seeking to increase private funding for much of the new infrastructure needed to support economic growth.

In a study to compare China and India, Bosworth and Collins (2008) reported that the growth in the industrial sector (which includes manufacturing, construction utilities and mining) differs dramatically between these two emerging economies. In China, this sector accounts for about half of GDP, whereas in India it has remained below 30%. Productivity in China was doubled by increased capital per worker and total factor productivity whereas the productivity gain in India was only about one-third that for China. The contribution of increased capital per worker has been much smaller,
and gains in total factor productivity averaged a modest 1% per year. Productivity gains from education and training remain low for both countries at between 0.3 and 0.4% per annum. The CIDC (2013) reported that in 2010, 82% or 29 million of the construction workers in India were unskilled.

From a macro-economic viewpoint, increased productivity in India can be achieved by increasing investment in capital per worker, perhaps attracting a higher amount of foreign direct investments into the country, and increased training for the large number of unskilled workers. With Indian labour productivity in industry and services somewhat four to five times that for agriculture, respectively, productivity growth can be achieved by a relocation of workers from agriculture into these sectors. This shift from the agricultural sector to industry and services will naturally lead to more unskilled workers engaging in construction activities compounding further the demand for training of workers.

The use of these indices indicates that where a large pool of workers is readily available, the most appropriate construction technology appears to be those that remain labour intensive. Investments in technology and equipment must be focused on productivity and quality improvement strategies as opposed to labour saving devices.

CONCLUSIONS

A set of cost indices have been derived from a data for construction material and building elements in 16 countries ranging from high income, upper middle income and lower middle income economies. The small set of derived ratios based on skilled worker wages, and basic construction materials such as concrete, steel reinforcements and structural steel is able to adequately rationalise the choice between cast-in-place, metal decking systems, precast methods of construction and structural steel framing systems.

While the focus of this paper is initially concerned with reinforced concrete methods of construction, the derived ratios may be extended to inform on a wide range of construction choices, either locally developed or imported from overseas, available to developing economies. An indexed cost-technology model will provide the construction industry with a practical and informative tool to evaluate the most appropriate options for construction industry development and economic growth, especially for rapidly developing economies facing constraints of labour, capital or resources. This research project is part of a broader study to deploy these indices to analyse a wider range of construction technologies globally.

REFERENCES


